REPORT ITU-R SM.2057*

Studies related to the impact of devices using ultra-wideband technology on radiocommunication services

(2005)

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* Radiocommunication Study Group 1 made editorial amendments to this Report in the year 2017 in accordance with Resolution ITU-R 1.

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1 Introduction

This Report considers interferences from devices using ultra-wideband (UWB) technology on radiocommunication services. As a main objective, it evaluates UWB e.i.r.p. density required for the protection of radiocommunication services.

The protection criteria for radiocommunication services were taken from liaison statements from the relevant Working Parties of the ITU-R, input contributions to Radiocommunication Task Group (TG) 1/8, and some from relevant ITU-R Recommendations and Reports.

The technical studies consider the effect of a single device using UWB technology and/or the aggregate effect from multiple devices. For the aggregate case, reference UWB deployment scenarios were defined.

This Report also includes laboratory and field measurements on the impact of devices using UWB technology on radiocommunication services.

As a result of the studies, the maximum e.i.r.p. density for generic devices using UWB technology is provided; assuming a minimum separation distance from the device in the case of a single interferer or a relevant deployment scenario in the case of aggregate interference. Such limits are primarily based on analytical studies.

Noting the regulatory status of the victim radiocommunication services and to ensure their full protection, conservative reference analyses have been applied.

The propagation models used in the studies are presented in a specific section. Mitigation techniques for devices using UWB technology are also provided.

2 Characteristics of radiocommunication services

2.1 Characteristics and protection criteria of radiocommunication services

Interference analyses between devices using UWB technology and radiocommunication services require knowledge of the protection criteria and the technical characteristics of potentially affected radiocommunication systems. The relevant ITU-R Recommendations and Reports are listed in Annex 8 to this Report. The Recommendations and Reports in Annex 8 may not be up to date as some of them may have been modified or their status have been changed. Annex 8 also contains technical characteristics and protection criteria of potential victim systems from input contributions and from liaison statements of various Radiocommunication Working Parties. These characteristics and criteria are intended to aid interference calculations at the time of preparing this Report. The responsible Radiocommunication Working Parties may have developed or adopted different values since then.

2.2 Categories of victim receivers

Different interference scenarios may be identified depending on the victim receiver that is considered.

It is however expected that great similarities can be found on the relevant methodologies and UWB deployment scenarios to be used for different general categories of victim receiver.

It is therefore proposed to distinguish three general categories of victim receivers:

Category	Designation	Victim receivers	Dominant interference scenarios
Category A	Mobile and portable stations	Mobile handset (GSM, DCS1800, IMT2000, MSS, RNSS), Portable broadcasting receiver (ATSC-DTV, T-DAB, DVB-T, Analogue TV, Digital FM, ISDB-T, ISDB-T_{SB}), RLAN, Indoor FWA	Single-entry interference
Category B	Fixed outdoor stations	Fixed service station (P-P, P-M-P) Base station from the mobile service Radio astronomy station Earth station (FSS, MSS…) Broadcasting fixed outdoor receiver Radar station	Aggregate interference from surrounding UWB Single-entry interference
Category C	Satellite/aeronautical on-board receivers	Satellite receiver (EESS, MSS, FSS…) Aircraft stations	Aggregate interference from large scale area

3 UWB characteristics

3.1 Characteristics of devices using UWB technology

The basic "Characteristics of devices using UWB technology" to be used in interference studies are included in Recommendation ITU-R SM.1755:

– Annex A: UWB terms, definitions and abbreviations.

– Annex B: General characteristics of UWB technology.

– Annex C: Technical and operational characteristics of devices using UWB technology.

More advanced UWB signalling are described in the following sections.

3.1.1 Multi-carrier/multi-band signalling

Divide the available –10 dB bandwidth into subbands and choose the transmit subbands according to an interference threshold. This can also be combined with notch filtering and time hopping code design in each subband. UWB can coexist with other spectrum users by turning off sub-bands to avoid interference.

3.1.2 Time hopping

Another technique is to design the time hopping pattern such that the power spectrum density (PSD) of the UWB transmitted signal has less power in certain bands. This technique can only be applied to UWB impulse radio systems.

FIGURE 1

Example of a sub-band turned off to avoid interference

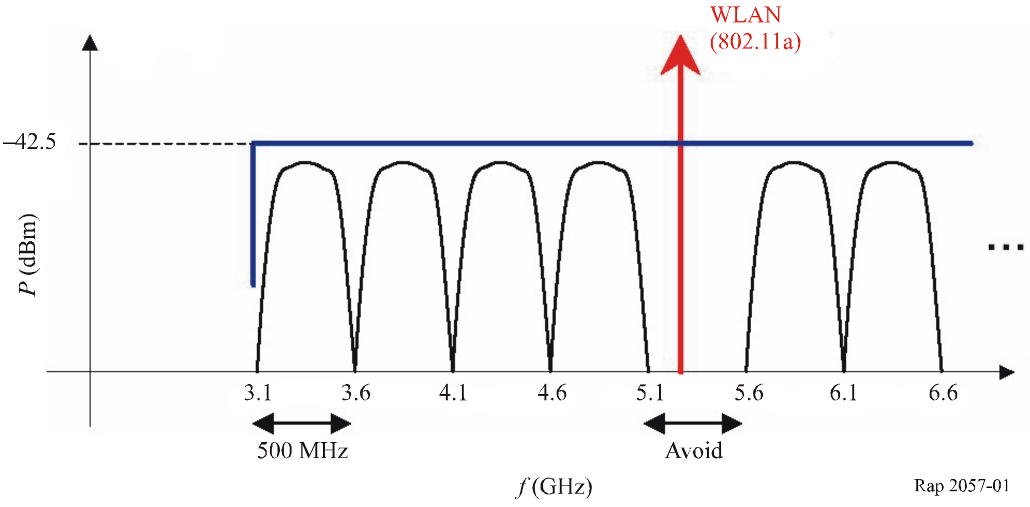
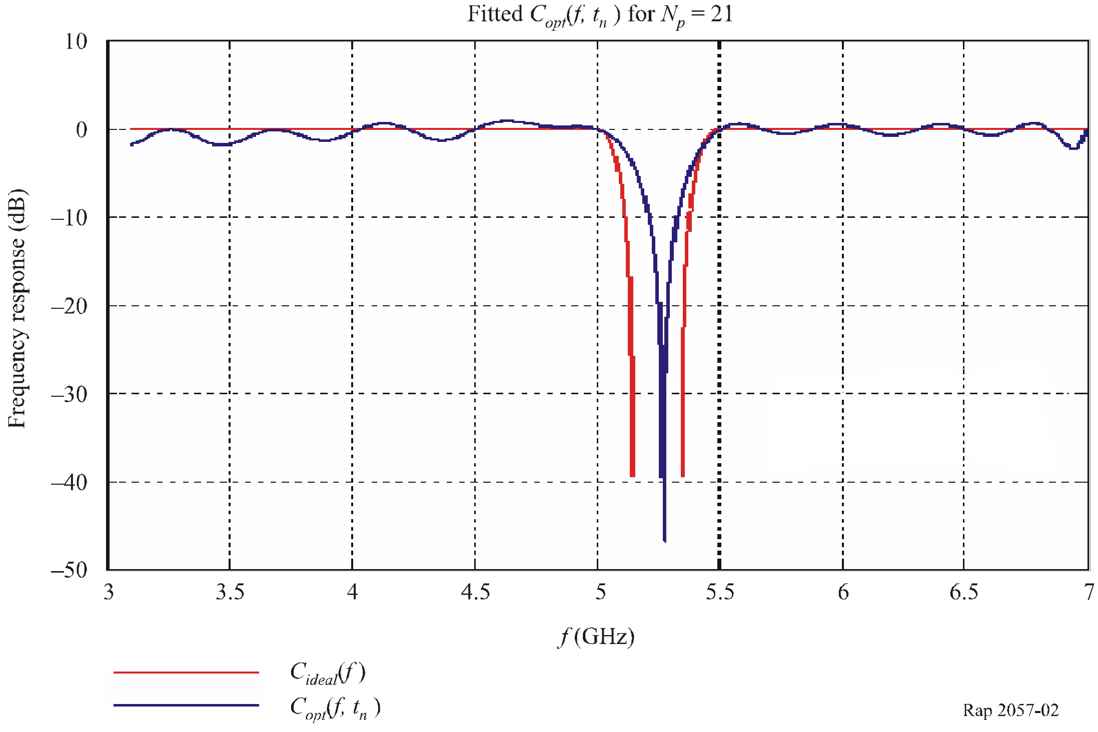


FIGURE 2

Example of time hopping code design to suppress a band



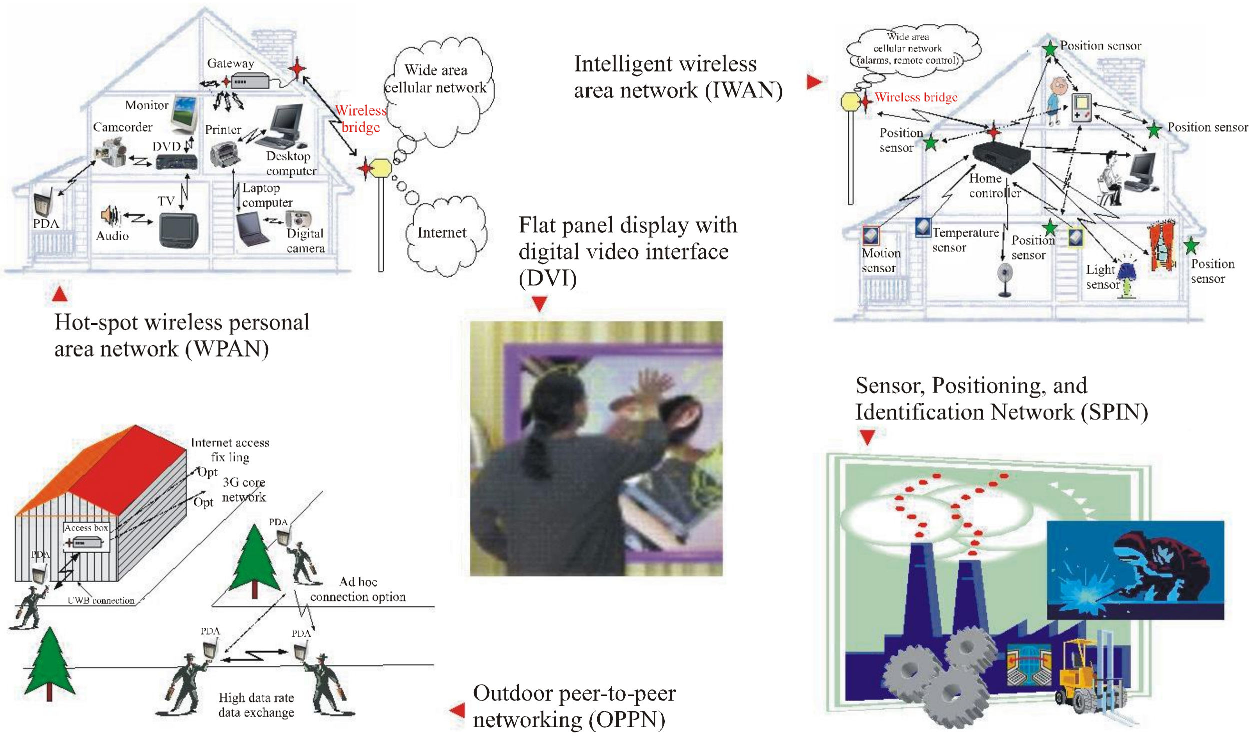
3.2 UWB applications

3.2.1 Applications of pervasive ultra-wideband radio systems (PULSERS)

Certain inadequacies of existing short-range wireless technologies, such as limited spectral resources, missing functional features (e.g. precise indoor location tracking), relatively high power consumption or cost, typically prevent an immediate realization of the vision "optimally connected anywhere, anytime" as envisaged by the European Commission's Information Society Technologies (IST) initiative[1, 2, 3]. UWB radio technology (UWB-RT) has the potential to help alleviate this limited state of the current *Pervasive Wireless World*, as it provides an alternate – if not somewhat disruptive – radio technology. PULSERS exploit the specific capabilities of UWB-RT, enabling a wide range of potential applications, for example as shown in Fig. 3[4].

FIGURE 3

Examples of usage scenarios enabled by PULSERS



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3.2.1.1 Key application areas of PULSERS

It is expected that PULSERS will enable application concepts for indoor (primarily) and certain outdoor (handheld) deployment scenarios, some examples are shown in Fig. 3. This will be accomplished by two mainstream technology platforms; in the future, these platforms could be extended to include certain interoperability features:

– Systems offering high (>100 Mbit/s) or very high (>500 Mbit/s) data rates (HDR or VHDR);

– Systems supporting low data rates (e.g. few kbit/s to 100 kbit/s) with localization and tracking (LDR-LT) capabilities (e.g. ranging accuracy below 1 m over a range of tens of metres).

For example, the usage scenarios shown in Fig. 3 can approximately be classified as HDR and LDR-LT platforms as shown in Table 1.

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1 Information Society Technologies home page; URL: http://www.cordis.lu/ist.

2 IST – Mobile and Wireless Systems Beyond 3G; URL: http://www.cordis.lu/ist/so/mobile-wireless/home.html.

3 IST – Networked Audiovisual Systems and Home Platforms; URL: http://www.cordis.lu/ist/so/audiovisual/home.html.

4 PULSERS public Web page; URL: http://www.pulsers.net.

TABLE 1

Approximate classification of the usage scenarios of Fig. 3

HDR/VHDR (High data rate/very high data rate)	LDR-LT (Low data rate with location tracking)
Hot-spot wireless personal area network (WPAN)	Intelligent wireless area network (IWAN)
Flat panel display with digital visual interface (DVI)	Sensor, positioning and identification network (SPIN)
Outdoor peer-to-peer networking (OPPN)	

Based on the significant potential identified for the use and application of UWB-RT, PULSERS support, for example, primarily two strategic objectives of the thematic area *Communication, Computing and Software Technologies* as defined in the IST thematic priorities under the current Framework 6 Program (FP6), namely:

Mobile and Wireless Systems Beyond 3G – PULSERS will contribute towards realization of the IST vision calling for users to be "*optimally connected anywhere, anytime*". In particular, novel physical layer (PHY) and medium access control (MAC) schemes supporting (indoor) short-range links will be developed by the industry to support a diversity of user scenarios as shown by the examples in Fig. 3. UWB-RT offers significant potential for embedding a broad set of networking schemes for the consumer and commercial spaces within a heterogeneous 4G network architecture, e.g. to enable wireless sensing, control and/or identification networks, where precise indoor location tracking is required.

Networked audiovisual systems and home platforms – PULSERS based on HDR platforms using UWB-RT will help the realization of this priority's challenging key objectives. Thus, HDR type PULSERS will enable high performance wireless DVIs to enable wireless high definition television (HDTV) data streaming applications (e.g. DVI in Fig. 3).

3.3 UWB characteristics and their impact on UWB capabilities

3.3.1 Introduction

In order to have an overall picture of the potential impact of UWB devices on incumbent services in the 1-10 GHz range, it appears that, in complement to impact analysis on incumbent services, it is necessary to also consider the potential impact of UWB characteristics on their operation capabilities. On this basis, UWB link budgets are hereby analysed to determine the significance of several UWB characteristics and potential link budget reductions.

3.3.2 UWB link budgets

On a general basis, UWB link budget can be expressed as follows and aims as calculating the link margin that will dictate the UWB capabilities to operate in different propagation conditions:

Link margin assessment is a complex process, as there are a large panel of parameters to be considered when trying to estimate the realistic link margin for a specific radiocommunication application such as UWB.

In Table 2, it is proposed to consider five components to assess the link margin for UWB devices, i.e., *D*: distance, *H*: average noise, *E*: required E_b/N_0 and *I*: implementation loss.

TABLE 2

Frequency	MHz	F
Data rate	Mbit/s	D_r
Distance d	m	D
Tx e.i.r.p. density	dBm/MHz	P_{tx}
Bandwidth	MHz	B
Average tx power	dBm	$P_{tx} + 10 \log (B) = A$
Path loss 1 m	dB	$20 \log (4 \pi F/c) = B$
Path at distance *d*	dB	$20 \log (d) = C$
Rx antenna gain	dBi	G_{rx}
Rx power	dBm	$A - B - C + G_{rx} = D$
Noise per bit	dBm	$-174 + 10 \log (D_r) = G$
Noise figure	dB	NF
Average noise	dBm	$G + NF = H$
Required E_b/N_0	dB	E
Implementation loss	dB	I
Link margin	dB	$D - H - E - I = M$

It can be seen that many factors control this link budget and hence the link margin, each of it having a different impact: as examples of factors interactions it can be seen that:

– a decrease of the data rate increases the link margin and vice-versa;

– a decrease of the distance increases the link margin and vice-versa;

– a decrease of the transmitted power density decreases the link margin;

– a decrease of the bandwidth decreases the link margin;

– an increase of the receiving antenna gain increases the link margin;

– an increase of the E_b/N_0 decreases the link margin.

All these elements are inter-related and there is thus multiple combinations of these factors to provide, at a given power level, required data rates and possible associated achievable distances. As an example, at constant link margin, a decrease by 3 dB of the e.i.r.p. density can be compensated by either an increase by 3 dB of the receive antenna gain *f* by increasing the bandwidth by a factor of 2.

Table 3 provides example of UWB applications and their related link budgets.

Based on system UWB 1 as in Table 3, Table 4 describes different cases of link budget showing how different parameters can compensate each other to finally give the same level of link margin.

TABLE 3

	UWB 1		
System type	Multiband OFDM		
Frequency (MHz)	3 882	3 882	3 882
Data rate (Mbit/s)	110	200	480
Distance (m)	10	4	2
Tx e.i.r.p. density (dBm/MHz)	–41.3	–41.3	–41.3
Bandwidth (MHz)	1 384	1 384	1 384
Average tx power (dBm)	–9.9	–9.9	–9.9
Path loss 1 m (dB)	44.2	44.2	44.2
Path loss at distance (dB)	20.0	12.0	6.0
Rx antenna gain (dBi)	0	0	0
Rx power (dBm)	–74.1	–66.1	–60.1
Average noise per bit (dBm)	–93.6	–91.0	–87.2
Noise figure	6.6	6.6	6.6
Average noise	–87.0	–84.4	–80.6
E_b/N_0	3.6	4.3	4.6
Implementation loss	2.9	2.9	3.4
Link margin	**6.4**	**11.1**	**12.5**

TABLE 4

Frequency (MHz)	3 882	3 882	3 882	3 882			
Data rate (Mbit/s)	53	110	110	110	200	200	480
Distance (m)	10	7	4	3	3	2	1
Tx e.i.r.p. density (dBm/MHz)	–47.4	–46.0	–49.2	–54.7	–45.4	–47.4	–51.3
Bandwidth (MHz)	1 384.0	2 000	1 384	1 384	2000.0	1 384	1 384.0
Average tx power (dBm)	–16.0	–13.0	–17.8	–23.3	–12.4	–16.0	–19.9
Path loss 1 m (dB)	44.2	44.2	44.2	44.2	44.2	44.2	44.2
Path loss at distance (dB)	20.0	16.9	12.0	9.5	9.5	6.0	0.0
Rx antenna gain (dBi)	3.0	0.0	0.0	3.0	0.0	0.0	4.0
Rx power (dBm)	–77.2	–74.1	–74.1	–74.1	–66.2	–66.2	–60.1
Average noise per bit (dBm)	–96.8	–93.6	–93.6	–93.6	–91.0	–91.0	–87.2
Noise figure	6.6	6.6	6.6	6.6	6.6	6.6	6.6
Average noise	–90.2	–87.0	–87.0	–87.0	–84.4	–84.4	–80.6
E_b/N_0	3.6	3.6	3.6	3.6	4.3	4.3	4.6
Implementation loss	2.9	2.9	2.9	2.9	2.9	2.9	3.4
Link margin	**6.4**	**6.4**	**6.4**	**6.4**	**11.0**	**11.0**	**12.5**

3.3.3 Justification for a link margin

UWB link margins are necessary to account for propagation environments expected to occur on the UWB path and a factor Sum(I) which is the sum of all Interferers and Impairments which are specific to the radiocommunication application, in this case the UWB devices.

The impact of the Sum(I^2) on the link margin assessment is not yet included but will be introduced in a later stage. This component is including all link margin estimation when considering application parameters distribution (distance, data rates), UWB devices performances degradation due to their operating modes (intra system and inter systems interferers) and to the implementation impairments (antennas, filters).

Propagation conditions can be either in line-of-sight (LoS) or in non-line-of-sight (NLoS) conditions. To that respect, based upon a statistical model which was created to match a number of measurement results, different channel models have been standardized for LoS 0-4 m (CM1), NLoS 0-4 m (CM2), NLoS 4-10 m (CM3) and severe NLoS (CM4) conditions.

In addition, a log-normal shadowing term with a standard deviation of 3 dB to capture the random effects of device location and people moving within a room.

For a 90% outage rate for the target 100 channel models used and a packet error rate (PER) < 8%, Table 5 provides the achievable distance for UWB 1 system above, comparing those under AWGN case (direct path without any propagation impairments) and the above-mentioned channel models.

TABLE 5

	Channel model impact on UWB radio link distance				
	AWGN[(1)] (m)	**CM1 (m)**	**CM2 (m)**	**CM3 (m)**	**CM4 (m)**
110 Mbit/s	21.4	12.0	11.4	12.3	11.3
200 Mbit/s	14.6	7.4	7.1	7.5	6.6
480 Mbit/s	9.3	3.2	3.0	Not available	Not available

(1) AWGN corresponds to a situation where only the single direct path is considered.

Based on Table 5, it is possible to roughly assess the "channel margin" included in the link budget. Indeed, the only difference between the AWGN case and the other cases relate to the achievable distance and one can calculate the margin as follows (see results in Table 6):

$$M_{ch} = 20 \log_{10}\left(\frac{d_{AWGN}}{d_{CMi}}\right) \qquad (1)$$

where:

M_{ch}: channel margin

d_{AWGN}: distance related to the AWGN case

d_{CMi}: distance related to the corresponding channel.

TABLE 6

	Channel margin included in the link budget (dB)				
	AWGN	CM1	CM2	CM3	CM4
110 Mbit/s	0	5.1	5.6	5.0	5.5
200 Mbit/s	0	6.2	7.0	6.3	9.5
480 Mbit/s	0	8.6	9.5	Not available	Not available

These margins corresponds to the distance as in Table 5 that are exceeding the distance given in the UWB typical link budget in Table 3 (as 10, 4 and 2 m for respectively 110, 200 and 480 Mbit/s). Compared to the available margin as given in Table 3, it is hence possible to calculate the potential extra-margin for the UWB systems criteria as in Table 7.

TABLE 7

	Extra margin available (dB) with a –41.3 dBm/MHz at the nominal distance				
	AWGN	CM1	CM2	CM3	CM4
110 Mbit/s (10 m)	0	1.3	0.8	1.4	50.9
200 Mbit/s (4 m)	0	4.9	4.1	Not available	Not available
480 Mbit/s (2 m)	0	3.9	3.0	Not available	Not available

Finally, it should be noted that CM1 and CM2 channel models corresponds respectively to LoS and NLoS cases at distances from 0 to 4 m. Table 8 hence provides the extra margin value for the different data rates at different distances corresponding to the range of the given channel model as well as to the maximum distance requirement.

TABLE 8

	Extra margin available (dB) with a –41.3 dBm/MHz at different distances				
	CM1 at 4 m	CM2 at 2 m	CM2 at 4 m	CM3 at 10 m	CM4 at 10 m
110 Mbit/s	9.3	14.8	8.8	1.4	0.9
200 Mbit/s	4.9	10.1	4.1	Not available	Not available
480 Mbit/s	Not available	3	Not available	Not available	Not available

Table 8 confirms that, pending on the achievable distance and taking into different channel models to account for propagation environments, it is possible to adapt UWB link budget parameters, and in particular the maximum e.i.r.p., to maintain initial UWB capabilities without capacity reduction.

Finally, it should be noted that the amount of link margin that is needed to enable a highly reliable link will vary depending on application requirements and expected location of the UWB transmitter and receiver. The above IEEE 802.15.3a models are theoretical and based upon a limited number of measurements which were available at the time the models were developed. These models were primarily developed to compare different physical layer proposals to be considered by the IEEE 802.15.3a task group.

It was not the intention that these models reflect all possible deployment scenarios for UWB devices, since these will vary widely and highly depend on the applications and usage scenarios. In addition, the amount of link margin needed for different applications will depend on the mobility of the device and the level of reliability desired. For example, consumers who are using UWB technology which is integrated into cellular phones have the ability to move the phone closer to the device with which it is communicating and so the link margin needed and level of reliability may be somewhat flexible.

On the other hand, UWB technology integrated into set-top boxes to communication with TV sets may not have the flexibility to be moved closer to improve the link easily, and the link may need to operate through a cabinet door creating a NLoS link. In addition, these devices will require a high level of reliability to prevent consumers from returning the equipment if it does not happen to work in their home. If power limits compromise the link reliability for video applications, consumers will experience pixilation on their displays. If the consumer has purchased a high definition plasma display with a UWB link, they will not simply return the radio. They will return the plasma display. Consumer electronics manufacturers cannot afford to accept a material increase in their return rates on expensive equipment (where UWB will penetrate first).

If the link margin is reduced, causing unacceptable link failure in say 5% of user cases, those users will return the devices that had UWB built into them. Consumer electronics vendors have a return rate that is significantly below this level. A 5% return rate would represent roughly a doubling of returned equipment. They would reasonably withdraw the technology from implementation on those platforms. In turn, the market for STBs, PVRs and other dependent devices would also evaporate. The end result will yield additional link margin needed to ensure video applications can be supported in a large percentage of the locations in the home.

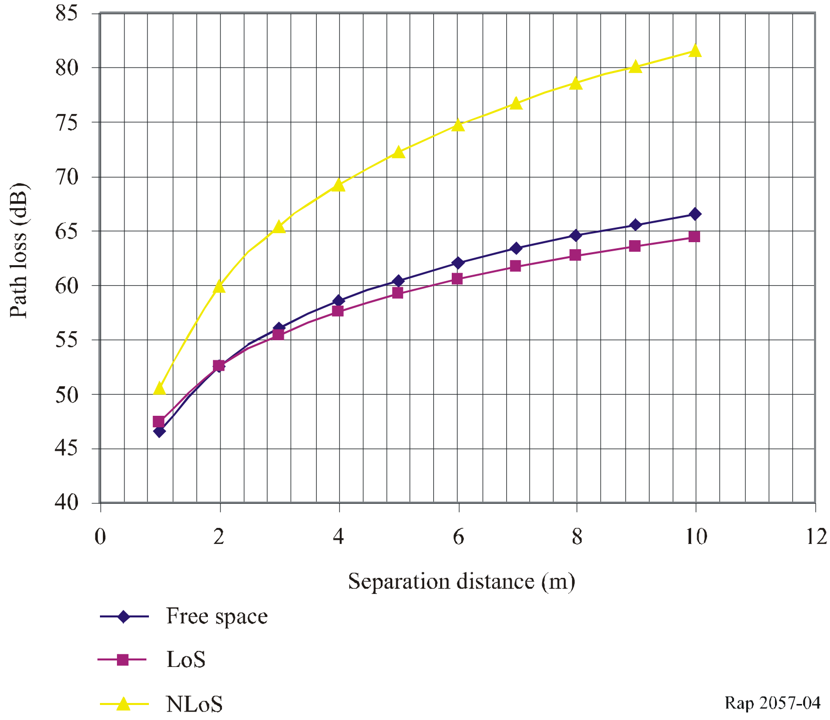
This value could be quantified given a statistical channel model, as described below, for different levels of reliability (95%, 99%, etc.) and should be considered when determining the impact of the link margin on the applications.

In order to get a better feeling about alternative path-loss models, there has been much more recent channel modelling efforts to better characterize the channel environment in the home due to the recent increase in interest in deploying wireless home networks and other wireless devices in the home. One of the more extensive recent campaigns was done by AT&T [Ghassemzadeh, *et al.*, 2004], which included measurements in over 300 000 channels in 23 different homes. Figure 4 compares the average path-loss model which best fit the measurement data for ranges from 1 to 10 m. Also included in the figure is the free-space path loss.

The measurements also showed a lognormal shadow-fading component in addition to the average path loss with a standard deviation of 2.8 dB for LoS and 4.4 dB for NLoS. As a result of the significant variations of the measurements, the authors proposed a statistical model for the path loss which modelled the loss at 1 m, the path-loss exponent, and a shadow-fading term each as a random variable. The average path-loss results are shown in Fig. 4.

FIGURE 4

Path loss vs. separation distance



Average path loss vs. separation distance for NLoS and LoS based upon AT&T measurements.

The implications of Fig. 4 and associated real measurements, which showed significant variation from different locations in the home, are the following:

– LoS average path loss can experience up to 3 dB gain compared to free space.

– NLoS average path loss can experience from 3 to 10 dB more loss compared to free space even for short separation distances of 1-4 m.

– If products want to address the majority of locations in the homes in this study (hence, increasing the level of reliability of meeting the stated ranges), some margin needs to be added to account for the random log-normal shadowing of at least 4.4 dB for the NLoS locations (corresponding to just one standard deviation from the mean).

As a result, expected margins for reliable device operation should be at least 7.7 to 14.4 dB relative to free-space propagation based upon this model.

The impact of the channel model uncertainties should be taken into account when considering potential impacts on UWB capabilities.

3.3.4 Impact on UWB capabilities

Based on the budget links and hence the link margins, UWB are able to support different type of applications as summarized in Tables 10 and 11 that at the end result in UWB activity factors that reflects the percentage of time the application would be using the UWB channel.

Tables 10 and 11 provide such activity factors for the UWB 1 as described in Table 3 as well as for different values of link budget reduction, maintaining a constant link margin, but using different parameters such as e.i.r.p. density, bandwidth or receive antenna gain, or a combination of these parameters.

As examples, Table 9 provides, for UWB 1 system, the achievable data rate for various distances comparing the initial budget link as in Table 3, taking into account IEEE channel models (see margins in Table 6) and possible link budget reductions by 4, 9 and 14 dB, that could be achieved, for example, with an equivalent e.i.r.p. power reduction.

TABLE 9

	1 m (Mbit/s)	**2 m (Mbit/s)**	**3 m (Mbit/s)**	**4 m (Mbit/s)**
4 dB reduction	480	380	300	200
9 dB reduction	480	255	190	110
14 dB reduction	320	140	60	35

TABLE 10

Office case					**UWB 1 system nominal link budget**		**4 dB link budget reduction**		**9 dB link budget reduction**		**14 dB link budget reduction**	
Type of applica-tion	**File size/streaming throughput with 30% MAC inefficiency**	**"On Air" session duration**	**Frequency of the session duration**	**Average link range (m)**	**Data rate**	**Activity rate by application**	**Data rate**	**Activity rate by application**	**Data rate**	**Activity rate by application**	**Data rate**	**Activity rate by application**
Remote backups	2.6 GBytes	43.3 s	1/week	**2**	480	0.00045138	380	0.000570175	255	0.000849673	140	0.001547619
PC – Scanner	169 Mbytes	2.8 s	1	**2**	480	9.78×10^{-5}	380	0.000123538	255	0.000184096	140	0.000335317
PC – Printer	91 Mbytes	2 s	2	**2**	480	0.00010532	380	0.000133041	255	0.000198257	140	0.000361111
PC-PDA	130 Mbytes	2.2 s	2	**1**	480	0.00015046	480	0.000150463	480	0.000150463	320	0.000225694
Video projector	13 Mbit/s	1 h	3	**3**	200	0.01625	300	0.010833333	190	0.017105263	60	0.054166667
Wireless monitor	10.4 Mbit/s	8 h	1	**1**	480	0.02166666	480	0.021666667	480	0.021666667	320	0.0325
Resulting activity factor per device (based on the methodology proposed by the UWB community)						**0.0029**		**0.0027**		**0.0031**		**0.0063**

TABLE 11

Home case					**UWB 1 system nominal link budget**		**4 dB link budget reduction**		**9 dB link budget reduction**		**14 dB link budget reduction**	
Type of applica-tion	**File size/streaming throughput with 30% MAC inefficiency**	**"On Air" session duration**	**Frequency of the session duration**	**Average link range (m)**	**Data rate**	**Activity rate by application**	**Data rate**	**Activity rate by application**	**Data rate**	**Activity rate by application**	**Data rate**	**Activity rate by application**
Wireless monitor	10.4 Mbit/s	3 h	1	**1**	480	0.0054167	480	0.0054167	480	0.0054167	320	0.0081250
Remote backups	2.6 GBytes	43 s	1/week	**2**	480	0.0001433	380	0.0001810	255	0.0002697	140	0.0004913
PC-scanner	7.41 Mbit/s	<1 s	1	**2**	480	3.5735×10^{-7}	380	0.0000005	255	0.0000007	140	0.0000012
PC – Printer	12.35 Mbit/s	<1s	2	**2**	480	1.19117×10^{-6}	380	0.0000015	255	0.0000022	140	0.0000041
PDA/handheld game	130 Mbytes	2 s	1	**1**	480	5.01543×10^{-5}	480	0.0000502	480	0.0000502	320	0.0000752
MP3 download	130 Mbytes	2 s	1/week	**1**	480	7.1649×10^{-6}	480	0.0000072	480	0.0000072	320	0.0000107
Digital camera download	41.6 Mbytes	0.7 s	1/week	**1**	480	2.29277×10^{-6}	480	0.0000023	480	0.0000023	320	0.0000034
Camcorder download	15.6 GBytes	33 s	2/month	**1**	480	0.000401235	480	0.0004012	480	0.0004012	320	0.0006019
CE – Television	34 Mbit/s	62% (peak)	1	**2**	480	0.043916667	380	0.0554737	255	0.0826667	140	0.1505714
Home theatre speakers	1.95 Mbit/s	62% (peak)	1	**5**	200	0.00251875	200	0.0025188	110	0.0045795	35	0.0143929
Game controller	10.5 Mbit/s	2 h	1	**3**	200	5.20833×10^{-6}	300	0.0000035	190	0.0000055	60	0.0000174
Set top boxes	34 Mbit/s	62% (peak)	1	**3**	200	0.041333333	300	0.0275556	190	0.0435088	60	0.1377778

TABLE 11 (*end*)

Home case					UWB 1 system nominal link budget		4 dB link budget reduction		9 dB link budget reduction		14 dB link budget reduction	
Type of applica-tion	**File size/streaming throughput with 30% MAC inefficiency**	**"On Air" session duration**	**Frequency of the session duration**	**Average link range (m)**	**Data rate**	**Activity rate by application**	**Data rate**	**Activity rate by application**	**Data rate**	**Activity rate by application**	**Data rate**	**Activity rate by application**
Cellular 3G handsets	41.6 Mbytes	0.7 s	1/week	**1**	480	2.29277×10^{-6}	480	0.0000023	480	0.0000023	320	0.0000034
PC web cameras	1.95 Mbit/s	2 h	3/week	**1**	480	0.000290179	480	0.0002902	480	0.0002902	320	0.0004353
Flash card readers	41.6 Mbytes	0.7 s	1/week	**1**	480	2.29277×10^{-6}	480	0.0000023	480	0.0000023	320	0.0000034
Input devices	10.5 kbit/s	3 h	1	**1**	480	5.46875×10^{-6}	480	0.0000055	480	0.0000055	320	0.0000082
Cellular 2.5G handsets	41.6 Mbytes	0.7 s	1/week	**1**	480	2.29277×10^{-6}	480	0.0000023	480	0.0000023	320	0.0000034
Digital home audio electronics	1.95 Mbit/s	2 h	2/week	**1**	480	0.000193452	480	0.0001935	480	0.0001935	320	0.0002902
Cell phone headset	457 kbit/s	3 min	10/day	**1**	480	$3.96701E \times 10^{-5}$	480	0.0000397	480	0.0000397	320	0.0000595
Resulting activity factor per device (based on the methodology proposed by the UWB community)						**0.025**		**0.0299**		**0.0446**		**0.0853**

It can be seen in both the Office and the Home cases that a potential link budget reduction, even though decreasing the instantaneous data rate, results in a limited increase of the global UWB activity factors that are still quite low and show that it would hence have a limited impact on the average use of the radio channel and demonstrate that it would not have a significant impact on the provided applications.

These calculation were based on UWB 1 system as described in Table 3 but other UWB systems presents different link budget showing different link margins, even higher such as for UWB 2 systems (6.7 dB at 10 m for 110 Mbit/s, 11.9 dB at 4 m for 200 Mbit/s, 17 dB at 2 m for 480 Mbit/s). Calculations for other types of UWB might result in different activity factors and impacts but it is not expected a significant difference compared to the case studied above.

Considering UWB link budget impact and justifications for different propagation impairment, the following factors need to be taken into account

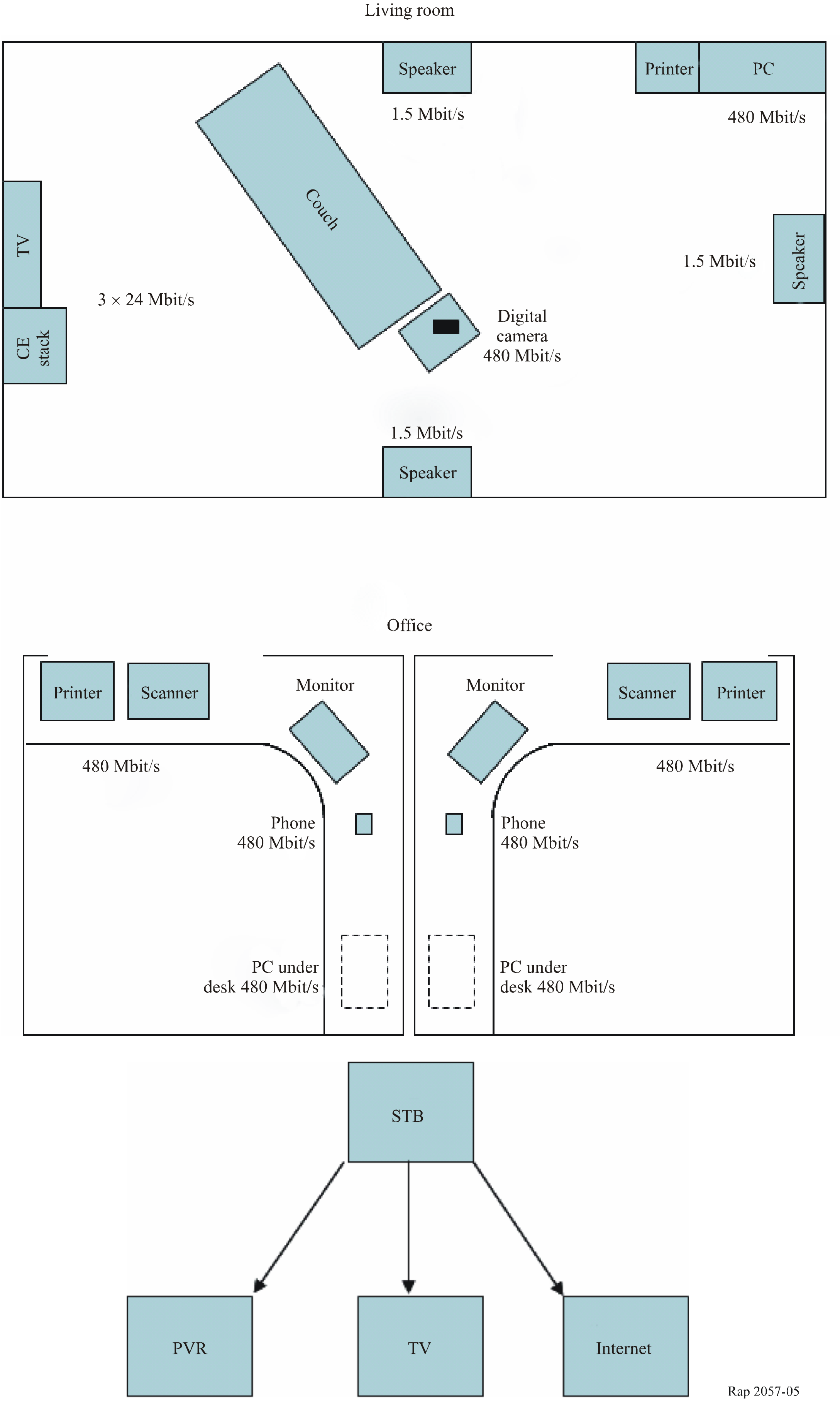
First, consider the home environment:

– There may be one television, a PVR, a set top box, multiple speakers, a PC and numerous peripherals (cameras, printers) sharing a single piconet. This time sharing of the channel results in a lower average available throughput for each application, and if one of the applications must use a low rate, that application will dominate the channel and limit access by other applications. For example, it is possible to have three video streams feeding the TV, PVR and picture in picture which would result in the video application occupying the majority of the channel time and could limit access from other applications if the video application is relegated to a low throughput based upon a link budget reduction.

– There are numerous NLoS unknowns. Many consumers put their entertainment equipment into a cabinet or enclosure. The composition of the enclosure is highly variable. Even if the consumer does not shut the door, there are LoS blockages, antenna alignment issues and other factors which will affect the path-loss equation. People will move around in the environment and block the LoS. Furniture will block the LoS. PCs are frequently placed inside of and beneath desks.

FIGURE 5

Example environments



– Video streams pixelate unacceptably at 1% PER contrary to the selection criteria used in the IEEE. On coded streams, these errors are very noticeable. As a result, a more reliable link may be needed for some applications. The above link budgets are based upon an average 8% PER.
– Interference will be generated into the system from, for example, adjacent apartments/piconets, WiFi systems, UNII band devices or WiMax systems which may be operating in the area at much higher power levels. Link margin accounting for this interference budget should be considered in the link budget analysis.

Second, consider the office environment as depicted below.

– NLoS propagation is likely since PCs are frequently placed beneath desks and people act to block LoS.
– Interfering piconets are in very close proximity, separated by a fabric wall.
– Interference will be generated into the system from, for example, WiFi and WiMax systems that will be operating in the area at much higher power levels.

3.3.5 UWB operational criteria

In any effort to evaluate the degree of sensitivity that exists relative to the link budget of a given application, it is necessary to take into account all of factors that affect the commercial viability of a technology. A few of these are described below.

– *Platform and market dependencies* – If regulatory decisions are made which adversely affect a critical platform application to the point that it is not commercially viable, the platform will no longer support UWB. This, in turn, breaks all of the dependent applications as well. An example of this would be video. If the reliability of the video link were compromised, it would not simply be televisions that would be affected. Televisions, camcorders, digital cameras, game consoles, PVRs and STBs would all be removed as well. The value of the technology is not buried in a single killer application, but rather the value is in bringing together three major markets (personal computing, consumer electronics, and mobile telephony). If one or more of these markets are eliminated due to a link budget reduction, the value to the market will not be eliminated, but it will be seriously degraded. This effect should be considered when determining the viability of different link budget reductions.
– *Competition* – There are a number of technologies which are co-existent in the home and office environment. As envisioned, and as enabled at a –41.3 dB power level, UWB has a unique value proposition. If the regulatory environment changes this equation, it is necessary to consider the competitive implications. For instance, if it were possible to reduce the throughput without damaging the applications materially, UWB would potentially be in greater conflict with WiFi, reducing the value of UWB. A similar effect would occur if mitigation techniques were used that raised the cost of a UWB device materially. In various parts of the market, Bluetooth, WiFi, WiMax, Wired USB and Wired 1394 potentially represent competitive variables that would need to be evaluated.

3.3.6 Conclusion

UWB link budgets are controlled by a multiple of parameters that hence give, to a certain extent, flexibility to adapt this link budget to the application.

An initial assessment of link margin study has been provided considering a limited set of parameters impacting the link budget calculation, acknowledging that to get a complete view of the impact on UWB link budget additional parameters should be considered, such as all Interferers and Impairments which are specific to the UWB radiocommunication application, defined as Sum(I).

To face a link budget reduction that could occur with, for example, a lower e.i.r.p. density, it is possible to take into account different solutions:

– decrease the instantaneous data rate without impacting the average data rate and UWB capabilities;

– decrease the achievable distance;

– increase the –10 dB bandwidth;

– increase the receiving antenna;

– decrease the required E_b/N_0 by applying different modulation scheme or make use of different coding.

In addition, such link budget reduction should also be considered in the light of impact on meeting application reliability requirements and impact on value proposition for other applications need to be considered, if certain applications are effected.

3.4 Slope emission masks

During the deliberations of Radiocommunication TG 1/8, a "slope mask" was considered for several meetings and the term is included within the text of many contributions. It is therefore included here because it is used as a reference in some interference studies. It is noted that no administration has indicated the slope mask is currently being considered for adoption.

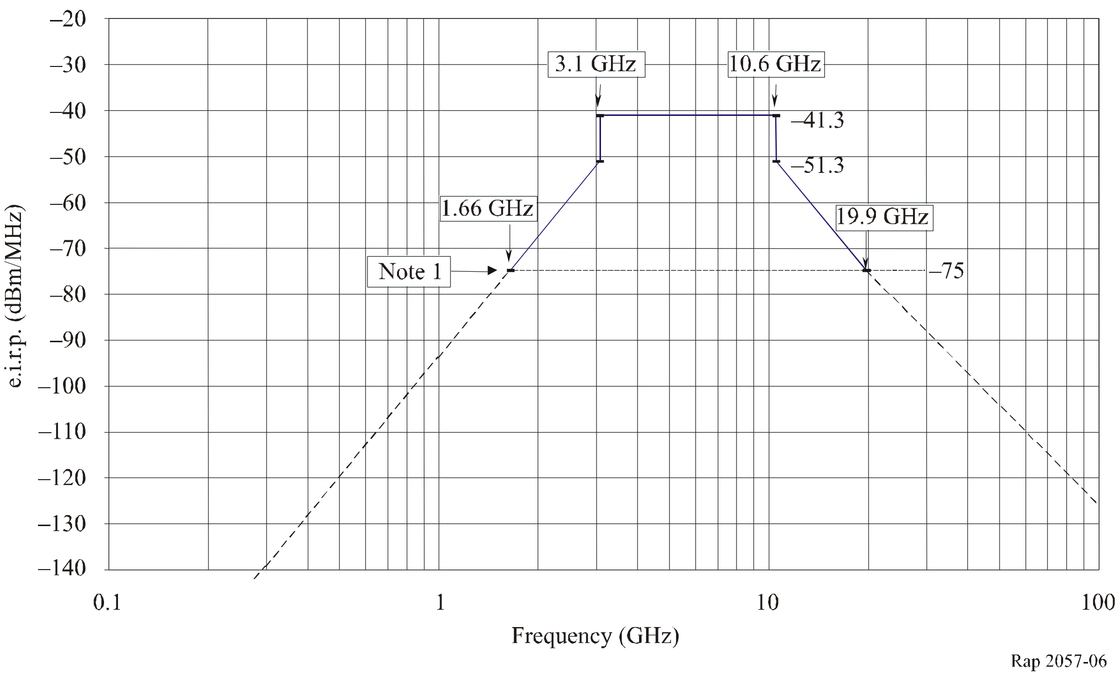
It is difficult to implement a UWB staircase mask. The advantage of a slope emission mask is a slope offers more interference protection to critical sensitive services operating below 3.1 GHz and above 10.6 GHz.

Two different slope emission masks for radiated power density are given for indoor and outdoor use respectively. The mask for outdoor use is 10 dB lower than the indoor mask.

Graphical representations of the indoor and outdoor slope masks are given in Fig. 6 and Fig. 7.

FIGURE 6

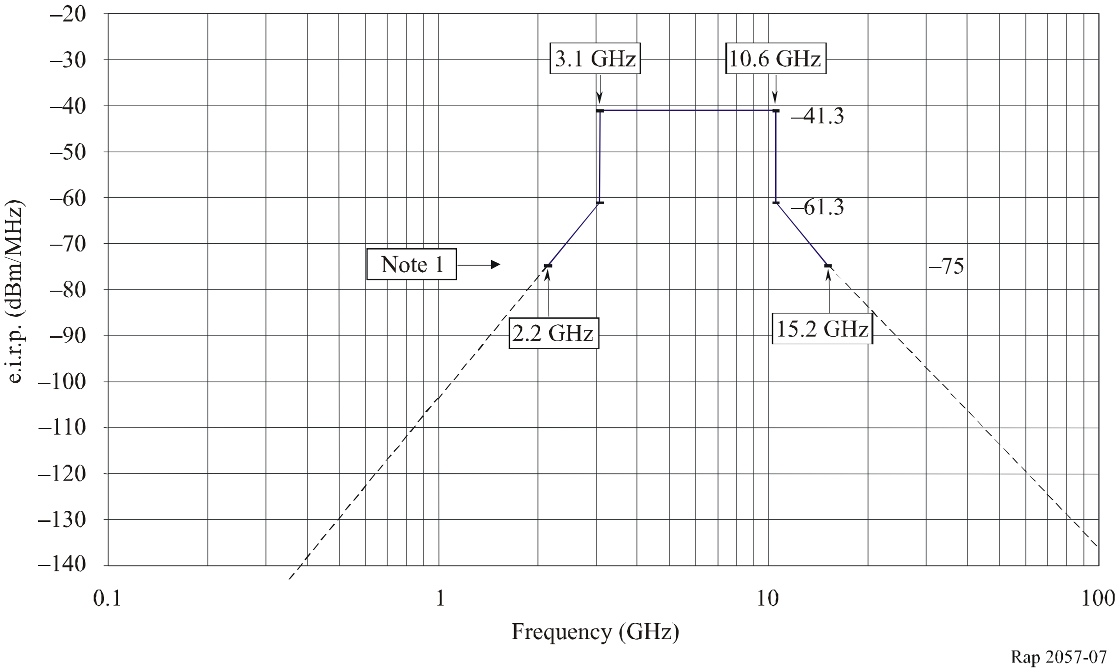
Indoor slope mask



Note 1 – Current measurement technology prevents measurements below –75 dBm in a 1 MHz bandwidth.

FIGURE 7

Outdoor slope mask



Note 1 – Current measurement technology prevents measurements below –75 dBm in a 1 MHz bandwidth.

4 Impact of UWB on radiocommunication services

4.1 Methodologies

4.2 Propagation prediction models for UWB interference studies

4.2.1 Background

The characterization of UWB signal propagation channels is fundamental for the determination of received UWB signals and to all radiocommunication compatibility effort. Thus, one of the key issues in any interference assessment is the determination of the propagation loss between a transmitting station and a victim receiver. In the context of UWB systems, the large bandwidth of the signal must be taken into account. Indeed, narrowband studies and measurements may not adequately reflect the special bandwidth-dependent effects associated with propagation of UWB signals. Specifically, as the bandwidth of the channel probing signal increases, a composite propagation path at narrow bandwidth may be resolved into distinguishable propagation paths at large bandwidth with distinct propagation delays. This corresponds to characterizing the channel transfer function over a broader frequency range. An appropriate UWB propagation channel models should capture both the path loss and multipath characteristics of typical environments where UWB devices are expected to operate. The existence of multipath propagation with different time delays and amplitudes gives rise to complex spatial and time varying transmission channels that place limitation on the performance of wireless systems. Nevertheless, the very fine time resolution of UWB signals allows resolving multipath components down to differential delays on the order of tenths of a nanosecond thus significantly reducing or eliminating fading effects in relatively dense multipath environment.

4.2.2 Radio modelling

The radio channel model has to physically represent the sum of all the effects of loss and distortion that the signals undergo during their propagation from a transmitter to a receiver. In the case of studies of UWB coexistence with systems of other services, it is interesting to know how the UWB signals propagate through air and how this might affect the link budget of other systems. The main effects that a radio wave encounters during its propagation can be divided into:

Long-term: *path-loss* characteristics: describe how the mean signal behaves as a function of distance at a given frequency. The loss is gradual with a received power level decreasing almost in an exponential decay on a logarithm scale.

Medium-term: *shadow fading* characteristics: show the time-varying factors, such as shadowing from building or big objects and is represented as a random fluctuation with a log-normal distribution, with a standard deviation σ dependent on propagation conditions.

Short-term: *multipath or fast fading* characteristics: describe the sudden variations of the received signal strength due to multipath and reflections coming off buildings and objects.

These three effects are summed together and are not easily discernible in normal conditions.

A classical way to represent the propagation phenomena independently from the transmitter and receiver characteristics is to give an appropriate definition of the channel impulse response $h(t)$ between a source signal $x(t)$ and a received signal $y(t)$. The channel is represented by multiple paths having real positive gain, E_i, and propagation delays, τ_i, where *the* is the path index. The channel impulse response is given by:

$$h(t) = \sum_{i=1}^{N} E_i(t) \cdot \delta(t - \tau_i(t)) \tag{2}$$

where δ(·) is the Dirac delta function.

The channel impulse response is therefore described as the sum of a number N of scattered $E_i(t)$ arriving at the receiver (with N typically considered between 6 and 20). Each scatter is itself the summation of numerous partial waves. Thus, each single scattered E_i is the result of the sum of N_{waves} (theoretically infinite, but in typical simulation models limited to 100) each characterized by amplitude a_i, phase φ_{the}, angle of incidence α_{the} (relative to the vector movement of the user).

$$E_{iFF}(t) = \sum_{k=0}^{Nwaves} a_{ik}(t) \cdot e^{j\left(\varphi_{ik} + \frac{2\cdot\pi}{\lambda} \cdot v \cdot t \cdot \cos\alpha_{ik}\right)} \tag{3}$$

The summation of these N_{waves} partial waves at each instant is a good representation of the short-term characteristics. In addition to these fast fading effects, it is important to consider the long and medium term variation in the signal strength at a given distance, represented by the attenuation At_i (including path loss and shadowing) of each single scatter.

The simple analysis often used in coexistence studies limit the propagation characteristics to the long-term average (path loss) of the signal loss at given distances. In mathematical terms, the mean received power, around which there still be shadowing and multipath, varies with distance with an exponential law. The total loss $PL(d)$ at a distance d is generally given by:

$$PL(d) = PL_0 + 10n \log_{10}\left(\frac{d}{d_0}\right) \tag{4}$$

where PL_0, the intercept point, is the path loss at distance d_0 and almost defined as in free-space propagation.

$$PL_0 = 20 \log\left(\frac{4\pi f_c d_0}{c}\right) \text{ and } f_c = \sqrt{f_{min} f_{max}}$$

where f_c is the geometric centre frequency of UWB waveform with f_{min} and f_{max} the –10 dB edges of the waveform spectrum. The parameter n is the important path-loss exponent.

4.2.3 Propagation models to assess potential interference from devices using UWB technology into conventional and relatively narrowband receivers

The ITU-R P-Series Recommendations cover a broad frequency range which also includes the foreseeable frequency bands for UWB devices. Therefore, it can be assumed that for assessing the interference from UWB devices via linear media into conventional, i.e. relatively narrowband receivers the following ITU-R P-Series Recommendations are suitable, within their range of applicability:

– Recommendation ITU-R P.452 describes the procedure for the evaluation of microwave interference between stations on the surface of the Earth in the frequency range of about 0.7 GHz to 30 GHz.

– Recommendation ITU-R P.525 provides for free-space attenuation.

– Recommendation ITU-R P.528 provides propagation curves for aeronautical mobile and radionavigation services using the VHF, UHF, and SHF bands.

– Recommendation ITU-R P.530 provides propagation data and prediction methods for the design of terrestrial line-of-sight systems.

– Recommendation ITU-R P.618 provides propagation data and prediction methods for Earth-space links.

– Recommendation ITU-R P.1238 provides propagation information relating to short paths specifically for indoor situations, in the frequency range from about 900 MHz to 100 GHz.

– Recommendation ITU-R P.1411 provides propagation methods for short paths in outdoor situations, in the frequency range from about 300 MHz to 100 GHz. A subsection dealing with characteristics of direction of arrival of signals has been transferred to Recommendation ITU-R P.1407 where additional and more fundamental propagation information is given.

– Recommendation ITU-R P.1546 provides the method for point-to-area predictions of field strength for terrestrial services in the frequency range 30 MHz to 3 GHz.

It should be pointed out that Recommendation ITU-R P.1546 provides the method for propagation path-loss calculations at distances between 1 km and 1 000 km. However, the application of this Recommendation has not been extended beyond 3 GHz which may not cover the frequency range intended for UWB emissions. Recommendation ITU-R P.1411 is intended for distances up to 1 km. Furthermore, concerning the applicability of Recommendation ITU-R P.1411 to the FS/UWB study the following remarks have to be considered:

– The title of Recommendation ITU-R P.1411 defines its applicability "…for the planning of short-range outdoor radiocommunication systems and radio local area networks…". This means that this Recommendation is tailored for assessing the planning of similarly deployed systems (i.e. short-range and RLAN) and is not intended to be used to address propagation aspect of interfering path to other services, as FS.

– Recommendation ITU-R P.1411 and other similar ITU-R P-Series Recommendations propose, in general, few scarce experimental data, very valid for having a raw idea of the physics in models very close to the tested one; the data are valid because might represent an "average worst-case of attenuation" that is useful to operators for defining the "average minimum coverage" for that short range service to be deployed (i.e. number of base stations). For an inter service sharing studies, an "average better-case" of the attenuation is needed in order to define the "average maximum interference" expected. Recommendation ITU-R P.1411 could be only applied for adding the (negligible) contribution of those UWB that are NLoS.
– Recommendation ITU-R P.1411 is focused on "less than 1 km" propagation effects on similar "short-range" systems deployed on the same ground. In UWB/FS the aggregate interference on a FS potential victim, might have a significant increment up to ~ 10 km and in completely different conditions.

4.2.4 Propagation models to assess compatibility between different devices using UWB technology

An important aspect that is relevant to UWB devices but not currently covered by the Recommendations in § 4.1.3 is consideration of specific propagation models for UWB emissions. The propagation models are required to assess compatibility between different UWB devices.

Since the recent developments of UWB systems, many studies in the field of UWB propagation have been done and extensive measurement campaigns between 1 and 10 GHz have been performed in different parts of the world including the United States of America and Europe, for different indoor and outdoor environments. Depending on the studies, different situations were considered that could be classified between LoS and NLoS. It should be noted that an LoS path between the transmitter and the receiver seldom exists in indoor environments, because of natural or man-made blocking and one must rely on the signal arriving via multipath. In this context, different definitions of indoor NLoS have been applied depending on the studies, i.e. NLoS or soft-NLoS and hard-NLoS or NLoS[5]. In fact, the differentiation is made between NLos, e.g. standard obstacle or at least one plasterboard and hard-NLoS, e.g. large number of obstacles or at least one concrete wall. An overview and comparison of these different UWB propagation studies[5] and consideration of the comments and precisions given by the authors in the case of certain experiments, allow proposing adequate basic UWB transmission loss in the following traditional form: (For the moment it is not foreseen to assess compatibility between UWB devices, if in the future such studies are needed such as the device density of UWB applications, the following model may be used). The received power $PL(d)$, at distance d from a UWB transmitter, could be modelled by traditional path-loss model typically used for narrowband signals and given by:

$$PL(d) = PL_0(d_0) + 10n \ \log_{10}\left(\frac{d}{d_0}\right) + X_\sigma \qquad \text{dB} \qquad (5)$$

where:

$PL_0(d_0)$: path loss at the reference distance d_0

n: path-loss exponent

X_σ: lognormal shadow fading, i.e. a zero-mean Gaussian random variable (dB) with standard deviation σ.

5 ITU-R Documents 1-8/60, 3K/5, 3M/4, 10 October 2003, ITU-R Document 3K/34, 10 December 2003.

Path loss is traditionally understood to be frequency dependent. With narrowband systems, the change in received power over the signal bandwidth is usually ignored as it has little effect. However, UWB signals can occupy octave or even decade bandwidths so the frequency dependency could have a considerable effect in the case of UWB propagation. However, the frequency dependency in UWB propagation is actually due to antenna rather than path loss[6]. Therefore, the traditional path-loss model typically used in narrowband signals as given in equation (5) can be used in modelling the path loss experienced by UWB signals.

It should be pointed out that depending on the studies, two kinds of path-loss models have been proposed, i.e. single slope models corresponding to the above formulation and dual slope models also named "breakpoint" models where two equations are given, one for the ranges below and one for the range above a certain breakpoint distance d_{BP}. These two kinds of models show a more or less similar dependence on the path-loss exponential factor considering the fact that by the breakpoint models proposals, the propagation before breakpoint is mostly assimilated to LoS situations and the propagation after breakpoint corresponds generally to NLoS situations or sometimes to hard-NLoS for large distance breakpoint d_{BP}, e.g. $d_{BP} > 10$ m. Therefore, by differentiating between LoS, NLoS and hard-NLoS situations, it is possible to compare the different studies and to give a unified formulation of the path-loss equation in the form of the above given single slope UWB path-loss model.

The derived parameters for the UWB path-loss equation are given in Table 12 for the different environments and specific situations. They are based on measurements and are suitable for distances of 15 m or less.

TABLE 12

Parameters for transmission loss calculation

Environment	**Path category**	***n***	**σ (dB)**
Indoor residential	LoS Soft-NLoS Hard-NLoS	~ 1.7 3.5 – 5 ~ 7	1.5 2.7 – 4 4
Indoor industrial	LoS Soft-NLoS Hard-NLoS	~ 1.5 2.5 – 4 4 – 7.5	≥ 0.3 1.2 – 4 ≥ 4
Outdoor	LoS NLoS	~ 2 3 – 4	– –

It should be noted that the UWB technology and measurement techniques used in the different studies are in some extent different from one experiment to another, thus leading to a certain variability of the results. In particular, different receiver structures lead to different values of path loss exponent *n* and standard deviation σ. Nevertheless, the good agreement of the different studies concerning the path-loss exponent *n* for LoS situations allows an almost precise definition of this important parameter. Furthermore, it is possible to determine the path-loss exponent for NLoS situations within a reasonable value range in particular for indoor NLoS cases considering on the one side the high environment dependence of the determining parameters like geometry of the rooms, construction materials, characteristics of the obstacles, etc. and on the other side the fact that the definitions of NLoS, Soft- or hard-NLoS or NLoS[5] are slightly different from one experiment to another.

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[6] ITU-R Document 3K/30, 13 November 2003.

4.2.5 A theoretical UWB multipath propagation model

A theoretical model for UWB signals in multipath initially has a basic $1/d^2$ behaviour of spherical wave expansion, and then a further $1/d^{(\gamma-2)}$ behaviour beyond a breakpoint distance d_t due to shedding of energy to multipath dispersion, yielding a total behaviour of $1/d^\gamma$. The resulting dual slope propagation model is:

$$PL(d) = -10\log([c/4\pi d f_m]^2[1-\exp(-(d_t/d)^{\gamma-2})]) \quad (6)$$

with f_m equal to the geometrical mean of the UWB signal frequency, and c is the velocity of propagation. Suitable values of index $\gamma > 2$ with $d_t = 1$. The formula, with $d_t = h_1 h_2 4\pi f_m/c$ and $\gamma = 4$, is also useful in a two-ray path model when the shape of the UWB wavelet is not specified.

4.3 Aggregate interference analysis

4.3.1 UWB deployment scenarios for aggregate interference analysis

Specific UWB deployment scenarios may be developed for the purpose of impact studies.

Concerning UWB communication applications, the following set of reference deployment scenarios should be used for the calculation of aggregate interference.

These scenarios will be applicable depending on the type of victim receiver that is considered.

Deployment Scenarios 1 or 3 will hence be typically applicable to "Category B" receivers whereas Deployment Scenario 2 will most likely only be applicable to "Category C" receivers.

Where aggregate interference analysis would be appropriate to "Category A" receivers, deployment Scenario 3 could also be applicable.

Deployment scenario 1	(1a) Rural	(1b) Suburban	(1c) Dense urban
UWB density (/km^2)	100	1 000	10 000
Activity factor (busy hours) (%)	5	5	5
Resulting density of active UWB transmitters (/km^2)	5	50	500
Outdoor (%)	50	20	10

Deployment scenario 2	Average large scale
UWB penetration rate over the population (%)	80
Activity factor (busy hours) (%)	5
Resulting percentage of active (%) UWB transmitters over the population	4
Outdoor (%)	20

NOTE 1 – It may be necessary to assume a maximum number of UWB devices for global beam scenarios in the impact studies. As an alternative approach, it is therefore proposed to calculate a density of UWB transmitters based on a maximum number of UWB devices deployed over a large scale area.

Assuming a total of 2×10^9 UWB devices over a 200 million km^2, the density of UWB transmitters would be 10 UWB/km^2.

Deployment scenario 2*bis*	
Resulting density of active UWB transmitters (/km^2)	0.5

Deployment scenario 3	(3a)	(3b)
	Home/Office	Home/Office
UWB density (per floor) (/10 m^2)	1	2
Activity factor (busy hours) (%)	20	4, 20, 50
Density of active UWB transmitters (/10 m^2)	0.2	

NOTE 1 – This scenario reflects deployment of UWB devices in indoor environment; it may be used for reference in the evaluation of interference to indoor as well as to outdoor receivers.

NOTE 2 – Parameters for Scenario (3a) and Scenario (3b) were derived from two different studies.

4.3.2 Aggregate interference analysis in outdoor terrestrial urban environments

This section analyses aggregate interference from randomly distributed UWB transmitters using five propagation models (free-space, log-normal shadowing, random propagation factor, two-ray, and modified two-ray) in an outdoor environment and suitability and limitations of these models.

4.3.2.1 Analysis using free-space, log-normal shadowing and random propagation factor models

A uniformly random distribution of UWB devices can be used to evaluate the aggregate interference effects of UWB devices. The initial assumption is a 2-dimensional uniformly random distribution of 100 identical UWB transmitters within a 100 m × 100 m square zone (a density of 10 000/km^2). The victim is located at the centre of this zone, as illustrated in Fig. 8. The value of the e.i.r.p. power density, –41.3 dBm/MHz, is used as the output power of each device. The interfering power spectral density level (dBm/MHz) of a UWB transmitter calculated at the input of the antenna of the victim receiver is evaluated as:

$$PSD = \text{e.i.r.p.} - L \tag{7}$$

where L is the path loss (dB). With the free-space model, L is given by:

$$L = -27.55 + 20 \log d + 20 \log f$$

where:

- d: distance from the transmitter to the victim (m)
- f: evaluation frequency (MHz).

It is assumed that f = 5 GHz for the free-space model and for the other four propagation models utilized in this work. It should be noted that while the UWB emissions occupy a large portion of the spectrum, their effects have to be evaluated at the potential victim's frequency, which is normally different from the centre frequency of the UWB emission. Considering realistic propagation environments, the log-normal shadowing model [Rappaport, 1996] and random propagation factor (RPF) model[7] are also studied in this Report. The log-normal shadowing model is suitable in the scenarios where the path-loss exponent is basically invariable, and the attenuation level fluctuates around some value. The RPF model is applicable to the cases where the path-loss exponent and attenuation level vary within their respective ranges. With both models, L, can be expressed by:

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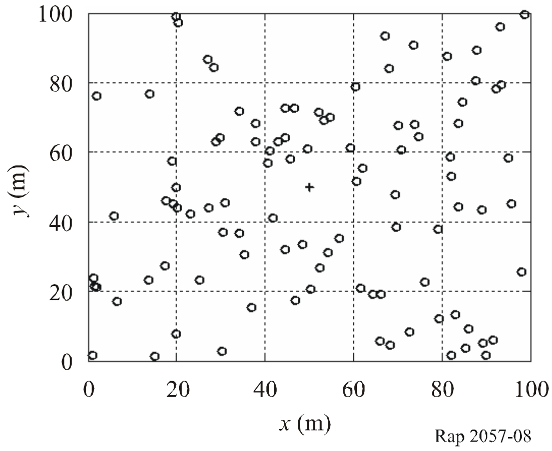
[7] ITU-R, dynamic frequency selection (DFS) in wireless access systems including radio local area networks for the purpose of protecting the radiodetermination service in the 5 GHz band, Recommendation ITU-R M.1652.

$$L = 10n \log d - 27.55 + 20 \log f + X_\sigma$$

FIGURE 8

Typical 2-dimensional uniformly random distribution of 100 identical UWB transmitters within a 100 m × 100 m zone



o: emitter location
+: victim location

In the log-normal shadowing model, the path-loss exponent n is a constant, and the attenuation X_σ is a zero-mean Gaussian distributed random variable (dB) with standard deviation σ (dB). In the RPF model, n and X_σ are two uniformly distributed random variables in their respective intervals. To characterize a typical outdoor propagation environment, $n = 2.7$ and $\sigma = 6$ are selected in the log-normal shadowing model. n and X_σ are assumed to be uniformly distributed within the ranges of 2.0 to 3.5 and 0 to 20, respectively, in the RPF model[5].

Figure 8 shows a typical uniformly random distribution of UWB transmitters. The distances from each emitter to the victim are sorted in ascending order and the interfering PSD from each emitter in order of increasing distance are summed up. By analysing a number of different uniformly random distributions of emitters, one can calculate the median number of the distance-sorted emitters required to reach the PSD level, 1 dB below that from all 100 transmitters. Figure 9 illustrates that, when the number of distributions is over 50, 110 and 140, the median number of the transmitters, which contributes to a received PSD level equals 1 dB below that from all 100 transmitters will remain 24, 10 and 17 for the free-space, log-normal shadowing and RPF models, respectively. These contributing transmitters are the ones located close to the victim receiver.

FIGURE 9

Median number of the distance-sorted transmitters required to reach the level 1 dB below the cumulative PSD from all 100 emitters in a 100 m × 100 m zone against number of distributions for three propagation models

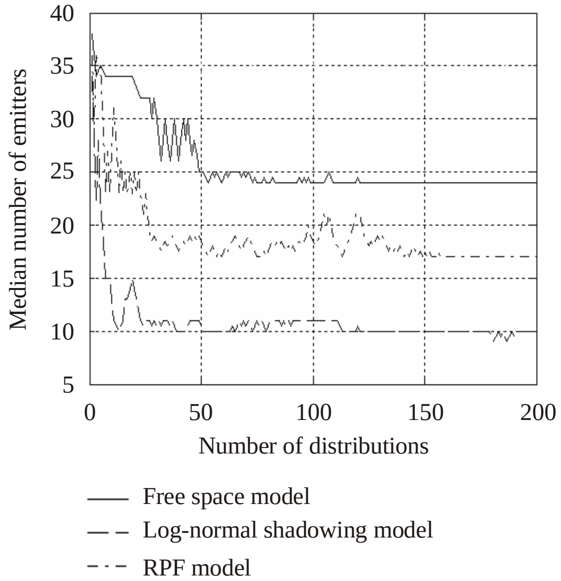


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Figure 10 shows that the median cumulative PSD level from all 100 transmitters over different numbers of random distributions will stay about –94.5, –98.5 and –108 dBm/MHz with the variation less than 0.1, 0.2 and 1 dBm/MHz for the free-space, log-normal shadowing and RPF models, respectively, if the number of distributions is larger than 40. Figure 11 represents the median cumulative PSD for 50 and 200 random distributions versus the number of distance-sorted transmitters. From Fig. 11, one can see that the median PSD tends to approach some value asymptotically when one continues to add distance-sorted transmitters.

FIGURE 10

Median cumulative PSD from 100 transmitters in a 100 m × 100 m zone versus number of distributions for three propagation models

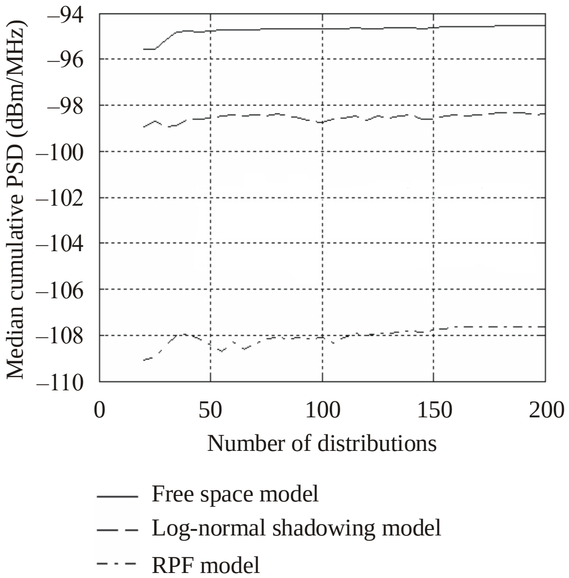

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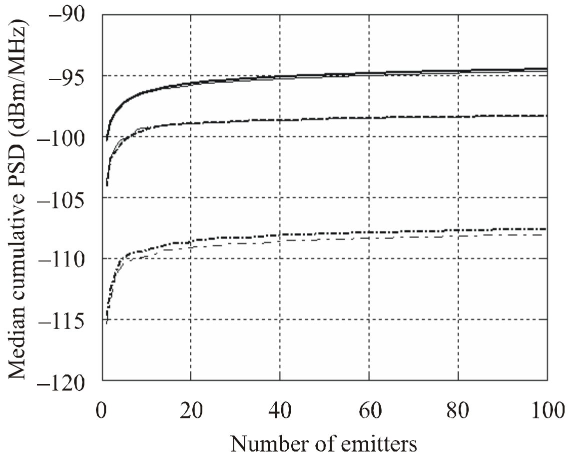
FIGURE 11

Median cumulative PSD against number of distance-sorted transmitters in a 100 m × 100 m zone for free-space (solid lines), log-normal shadowing (dashed lines) and RPF (dash-dot lines) models for 50 (thin lines) and 200 (thick lines) random distributions



Rap 2057-11

For zones of different sizes, the number of transmitters is kept constant, viz., 100, so that some specific device densities are obtained. Moreover, the same set of random distributions of transmitters as in a 100 m × 100 m square zone is used for the comparison with the above results.

Figures 12-14 give the results for 100 identical UWB transmitters randomly distributed in a 1 000 m × 1 000 m square zone (a density of 100/km^2), corresponding to Figs. 9-11 respectively. The median number of the distance-sorted transmitters required to reach the level 1 dB below the cumulative PSD from all 100 transmitters in a 100 m × 100 m zone is the same as that in a 1 000 m × 1 000 m zone for the free-space and log-normal shadowing models respectively, but is less than that in a 1 000 m × 1 000 m zone for the RPF model, which is indicated by the comparison between Figs. 9 and 12. Comparing Figs. 10 and 11 with Figs. 13 and 14 respectively, one can see that the median cumulative PSD in a 100 m × 100 m zone is higher than that in a 1 000 m × 1 000 m, however the shapes of the curves are still maintained for each of the three propagation models.

FIGURE 12

Median number of the distance-sorted transmitters required to reach the level 1 dB below the cumulative PSD from all 100 transmitters in a 1 000 m × 1 000 m zone against number of distributions for three propagation models

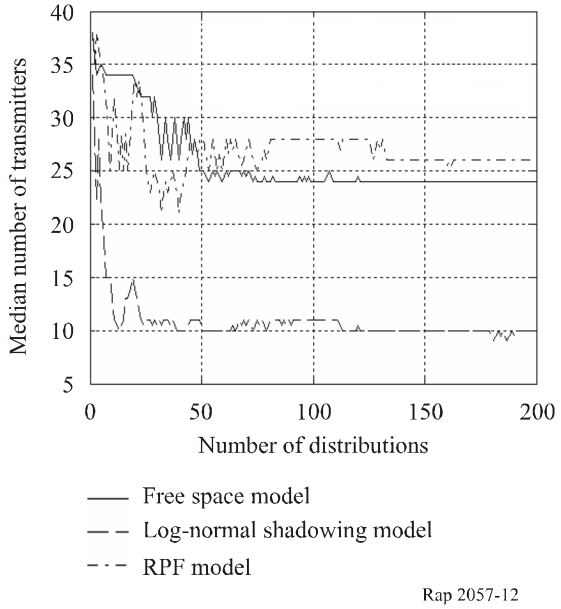


FIGURE 13

Median cumulative PSD from 100 transmitters in a 1 000 m × 1 000 m zone versus number of distributions for three propagation models

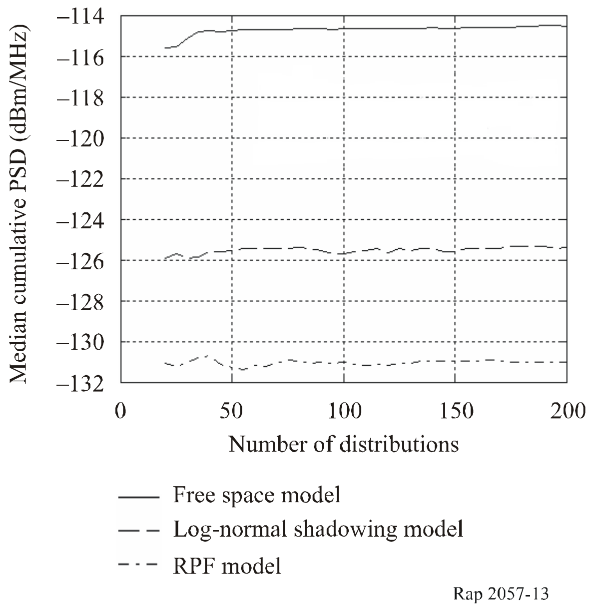
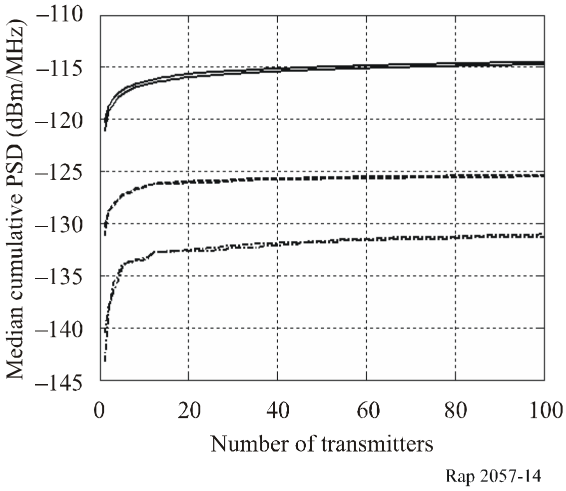


FIGURE 14

Median cumulative PSD against number of distance-sorted transmitters in a 1 000 m × 1 000 m zone for free space (solid lines), log-normal shadowing (dashed lines) and RPF (dash-dot lines) models for 50 (thin lines) and 200 (thick lines) random distributions



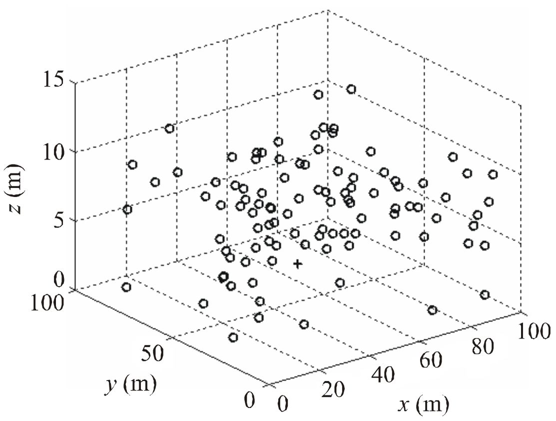
4.3.2.2 Analysis using two-ray and modified two-ray models

The above free-space, log-normal shadowing and RPF models do not take into account transmitter and receiver heights (thus regarded in this Report as 2-dimensional models[8]), the reflection from the ground, and other factors. In order to take some of these factors into consideration, the two-ray and modified two-ray models are used for the short-range case. To allow the comparison with the 2-dimensional models, 100 identical UWB transmitters that are uniformly and randomly distributed within a 100 m × 100 m square zone are maintained. Furthermore, to take into account the heights of the UWB transmitters and the victim, the heights of UWB transmitters have a uniformly random distribution within the range of (1.4 m, 11.4 m). The victim is located at position (50 m, 50 m, 2.7 m), as shown in Fig. 15.

[8] Propagation models that take antenna height into considerations are regarded in this Report as 3-dimensional models.

FIGURE 15

Typical 3-dimensional uniformly random distribution of 100 identical UWB transmitters within a 100 m × 100 m zone



o: transmitter location
+: victim location

With the two-ray model [Jakes, 1974] the path loss can be given by:

$$L = -27.55 + 20 \log f - 20 \log A \tag{8}$$

where f (MHz) is the evaluation frequency,

$$A = \left| \frac{e^{-jkr_t}}{r_t} + R \frac{e^{jkr_r}}{r_r} \right| \tag{9}$$

where r_t is the direct distance from transmitter to victim, r_r is the distance via reflection on the ground and is given by:

$$r_r = \sqrt{d^2 + (h_t + h_r)^2} \tag{10}$$

where:

d: distance from the transmitter to the victim (m)

h_t and h_r: transmitter and victim heights, respectively

k: wave number

R: reflection coefficient, depends on the incident angle α and is given by:

$$R = \frac{\sin\alpha - a\sqrt{\varepsilon - \cos^2\alpha}}{\sin\alpha + a\sqrt{\varepsilon - \cos^2\alpha}} \tag{11}$$

where a = 1/ε or 1 for vertical or horizontal polarization, respectively. For the average ground, the relative dielectric constant is given by ε = 15 – j60δλ, and the conductivity δ of the surface is assumed to be 0.005 mho/m. For long distances, α is small and R is approximately equal to –1. For short distances, α increases and |R| decreases. Then the approximation of R = –1 overestimates the peaks of the signal as well as the depths of fades. Since |R| is larger for horizontal polarization than for vertical polarization, the horizontal polarization is used for the estimation of the upper bound of interference from multiple UWB emitters. The relative dielectric constant ε is a function of the frequency, however, the reflection coefficient |R| just varies slightly with different frequencies.

In order to accommodate low-level obstacles (e.g. vehicles on the roads) and high-level obstacles (e.g., roadside trees), the modified two-ray model [Oda *et al.*, 2000] is also utilized. The path loss L can be expressed by:

$$L = -27.55 + 20 \log f - 20 \log A - 20 \log P(d) \qquad (12)$$

where f is the evaluation frequency (MHz), A is still calculated by equations (8) and (9) where h_t and h_r are replaced by $h_t - h$ and $h_r - h$ respectively, h is the effective road height. The value h = 1.4 m, a typical value determined by the traffic conditions, is chosen for modelling low-level obstacles. The visibility $P(d)$ for modelling high-level obstacles is given by:

$$P(d) = e^{-sd}$$

where d is the distance from the transmitter to the victim (m), s is the collision probability per unit distance and is equal to 0.002 in this work.

By carrying out the same analysis as in § 4.3.2.1, one can find the median number of the distance-sorted transmitters required to reach the PSD level 1 dB below that from all 100 transmitters for different uniformly random distributions of transmitters. Figure 16 shows that the median number of distance-sorted transmitters will basically remain 40 and 35 for the two-ray and modified two-ray models, respectively, when the number of distributions is above 80 and 70. These contributing emitters are the ones located close to the victim receiver.

FIGURE 16

Median number of the distance-sorted transmitters required to reach the level 1 dB below the cumulative PSD from all 100 transmitters in a 100 m × 100 m zone against number of distributions for two 3-dimensional models

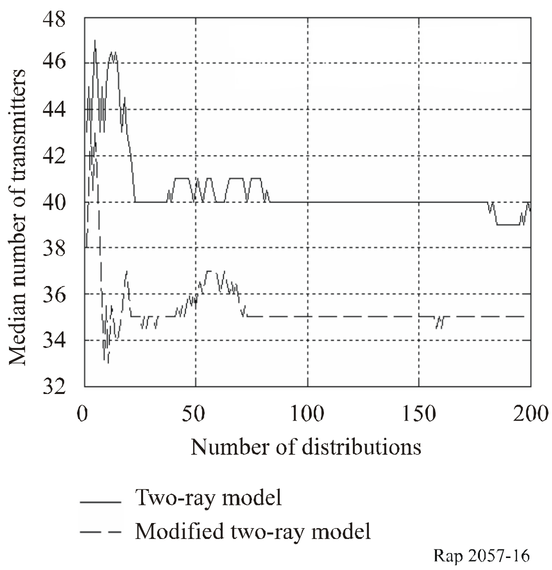


Figure 17 indicates that the median cumulative PSD from 100 transmitters over different numbers of random distributions will stay around –94 and –94.1 dBm/MHz with the variation less than 0.2 and 0.1 dBm/MHz for the two-ray and modified two-ray model, respectively, when the number of distributions is larger than 30. In comparison with Fig. 10, the median PSD in Fig. 17 has a weak trend of increasing with the number of random distributions. Figure 18 represents the median cumulative PSD over 80 and 200 random distributions against the number of distance-sorted transmitters. Although the median PSD in Fig. 18 looks similar to that shown in Fig.11, the asymptotical behaviour of the median PSD for the two 3-D propagation models is not as good as that for three 2-D propagation models. When the number of distance-sorted transmitters is above 40, the median PSD in Fig. 18 still increases slowly but the median PSD in Fig. 11 does not increase significantly with the number of distance-sorted transmitters.

FIGURE 17

Median cumulative PSD from 100 transmitters in a 100 m × 100 m zone versus number of distributions for two 3-dimensional propagation models

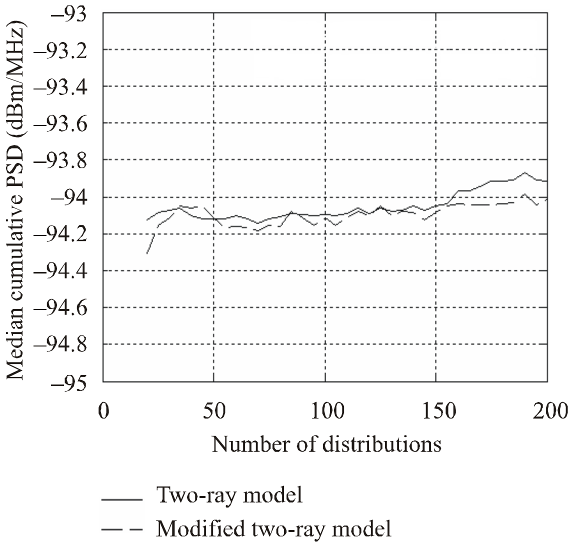


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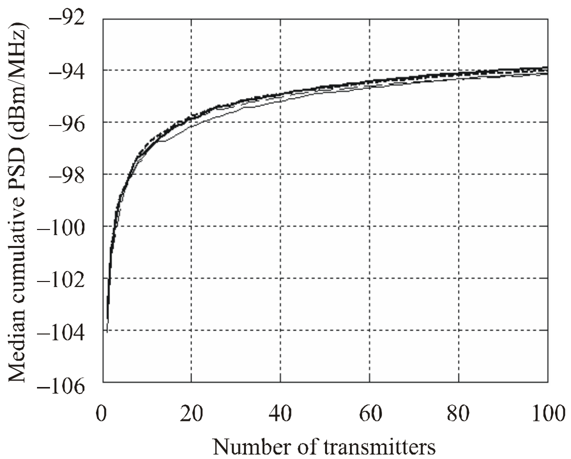
FIGURE 18

Median cumulative PSD against number of distance-sorted transmitters in a 100 m × 100 m zone for two-ray (solid lines) and modified two-ray (dashed lines) models for 80 (thin lines) and 200 (thick lines) random distributions



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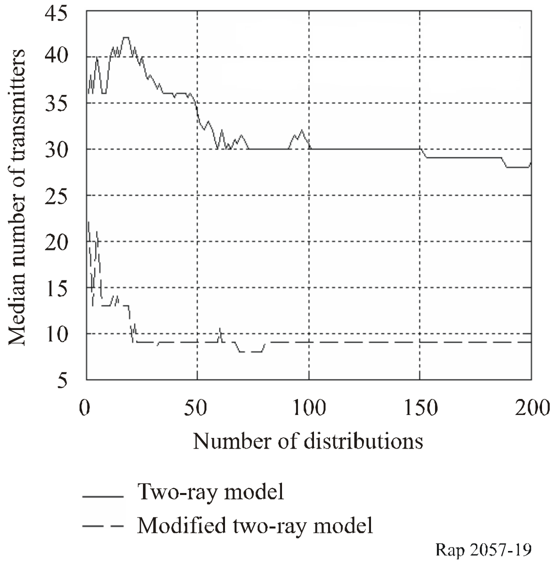
Figures 19-21 illustrate the results for 100 identical UWB transmitters randomly distributed in a 1 000 m × 1 000 m square zone (a density of 100/km^2), corresponding to Figs. 16-18 respectively. The comparison between Figs. 16 and 19 indicates that the median number of the distance-sorted transmitters required to reach the level 1 dB below the cumulative PSD from all 100 emitters in a 100 m × 100 m zone is larger than that in a 1 000 m × 1 000 m zone for the two 3-D models, respectively.

FIGURE 19

Median number of the distance-sorted transmitters required to reach the level 1 dB below the cumulative PSD from all 100 transmitters in a 1 000 m × 1 000 m zone against number of distributions for two 3-dimensional propagation models



Comparing Figs. 17 and 18 with Figs. 20 and 21 respectively makes the following points:

a) The median cumulative PSD in a 100 m × 100 m zone is higher than that in a 1 000 m × 1 000 m.

b) The statistical properties of the results for a 1 000 m × 1 000 m zone do not improve significantly upon those for a 100 m × 100 m zone with the modified two-ray model. The statistical properties of the results for a 1 000 m × 1 000 m zone are worse than those for a 100 m × 100 m zone with the two-ray model, i.e. the median PSD in Fig. 20 has a stronger trend of increasing with the number of random distributions than the median PSD in Fig. 17 has, and when the number of distance-sorted emitters is above 40, the median PSD in Fig. 21 increases faster with the number of distance-sorted emitters than the median PSD in Fig. 18 does.

c) For a 1 000 m × 1 000 m zone, the median cumulative PSD level from all emitters calculated with the two-ray and modified two-ray models is close to and is about 2.5 dBm/MHz higher than that calculated with the free-space model, respectively.

FIGURE 20

Median cumulative PSD from 100 transmitters in a 1 000 m × 1 000 m zone versus number of distributions for two 3-dimensional propagation models

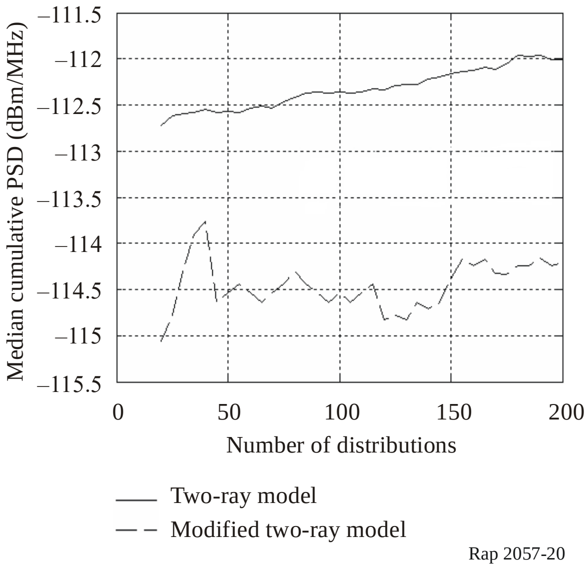
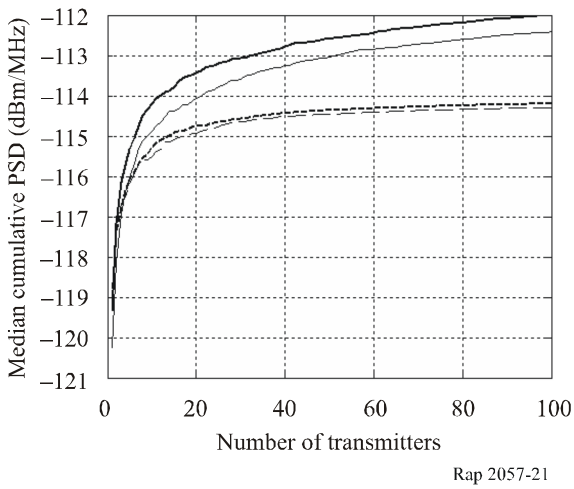


FIGURE 21

Median cumulative PSD against number of distance-sorted transmitters in a 1 000 m × 1 000 m zone for two-ray (solid lines) and modified two-ray (dashed lines) models for 80 (thin lines) and 200 (thick lines) random distributions



4.3.2.3 Aggregate interference conclusions

The free-space, two-ray, and modified two-ray models may not characterize realistically the outdoor propagation environment due to lack of random parameters and due to inability to represent multipath scenarios. The free-space, two-ray, and modified two-ray propagation models were initially developed for long-distance communications and continuous wave emissions. UWB systems are short-range devices and their emission is pulsive. Consequently, these three propagation models may not be suitable for UWB outdoor impact studies. Unlike the previously discussed three models, the log-normal shadowing and random propagation factor models consider environment statistics. Further studies and propagation measurements are needed for the derivation of appropriate propagation model(s) for UWB emissions.

From the statistical analysis of the cumulative PSD from 100 identical UWB transmitters randomly distributed in a 100 m × 100 m and a 1 000 m × 1 000 m square zones using five different propagation models at 5 GHz, it can be concluded:

– The median cumulative PSD from all transmitters obtained with the log-normal shadowing and RPF models is approximately 4 and 13.5 dBm/MHz lower than that obtained with the free-space model for a 100 m × 100 m zone, and is around 10 and 17 dBm/MHz lower than that obtained with the free-space model for a 1 000 m × 1 000 m zone, respectively. For both zones, all three 2-D propagation models lead to stable results: The cumulative PSD from all transmitters averaged over different numbers of random distributions does not vary with the number of distributions when the number of distributions is sufficiently large. The average cumulative PSD over some number of distributions increases with the number of transmitters up to a certain value beyond which the PSD level does not increase appreciably with the number of distance-sorted transmitters.

– For a 100 m × 100 m zone, the median cumulative PSD levels from all transmitters evaluated using the two 3-D propagation models are just slightly different from that evaluated using the free-space model. For a 1 000 m × 1 000 m zone, the median cumulative PSD level from all transmitters calculated with the two-ray and modified two-ray models is close to and is about 2.5 dB(m/MHz) higher than that calculated with the free-space model, respectively. For both zones, these two 3-D propagation models lead to the results that are not as stable as those obtained with the three 2-D propagation models: The average cumulative PSD from all transmitters over different numbers of random distributions shows a weak trend of increasing with the number of random distributions for the two-ray model. The average cumulative PSD over some number of distributions increases with the number of transmitters up to a certain value beyond which the PSD level increases slowly with the number of distance-sorted transmitters.

– Like the free-space model, the two-ray and modified two-ray models do not contain any random parameter, and therefore may not reflect realistic propagation scenarios, even if the two-ray and modified two-ray models have taken the ground reflection and the effects due to vehicles on the roads and roadside trees into account. These two 3-D propagation models may not be quite suitable for a statistical analysis of aggregate emission from multiple sources within a specific area and more complex 3-D propagation models with random parameters need to be developed.

– It should be noted that the above considerations are valid when the victim service is of ground mobile or nomadic nature. However, when the victim receiver is in a fixed location (often on a high location with respect to the area of deployment of UWB devices), is airborne, or is a satellite, there is the need of considering the contribution of the number of UWB devices that appear in a LoS path to the victim antenna location. In such cases, the contribution of these UWB devices, which might be predominant, should be separately evaluated by means of the free space model, and further augmented by the contribution of the remaining NLoS UWB devices whose aggregate effects would have been evaluated with another suitable propagation model presented in this section.

4.3.3 Aggregate interference measurement results

4.3.3.1 Laboratory study of impact of UWB signal aggregation on GSM/GPRS systems

4.3.3.1.1 UWB transmitter set-up

The UWB transmitter used in this study is the TFP1001 UWB impulse source from Multispectral Solutions (MSSI). A Mini-Circuits VHP-16 high-pass filter was placed at the output of each TFP1001 to attenuate the UWB signal below 1.6 GHz so as to minimize the possibility of non-linear effects arising from OoB interference. Each transmitter was controlled by two triggering signals generated by a Tektronix DG2030 data pattern generator. Two DG2030 units in total were used, each of which has eight outputs and can control up to 4 UWB transmitters. The triggering signals for each UWB transmitter were individually generated and then randomly offset in time to minimize excessive coherent summing of UWB pulses.

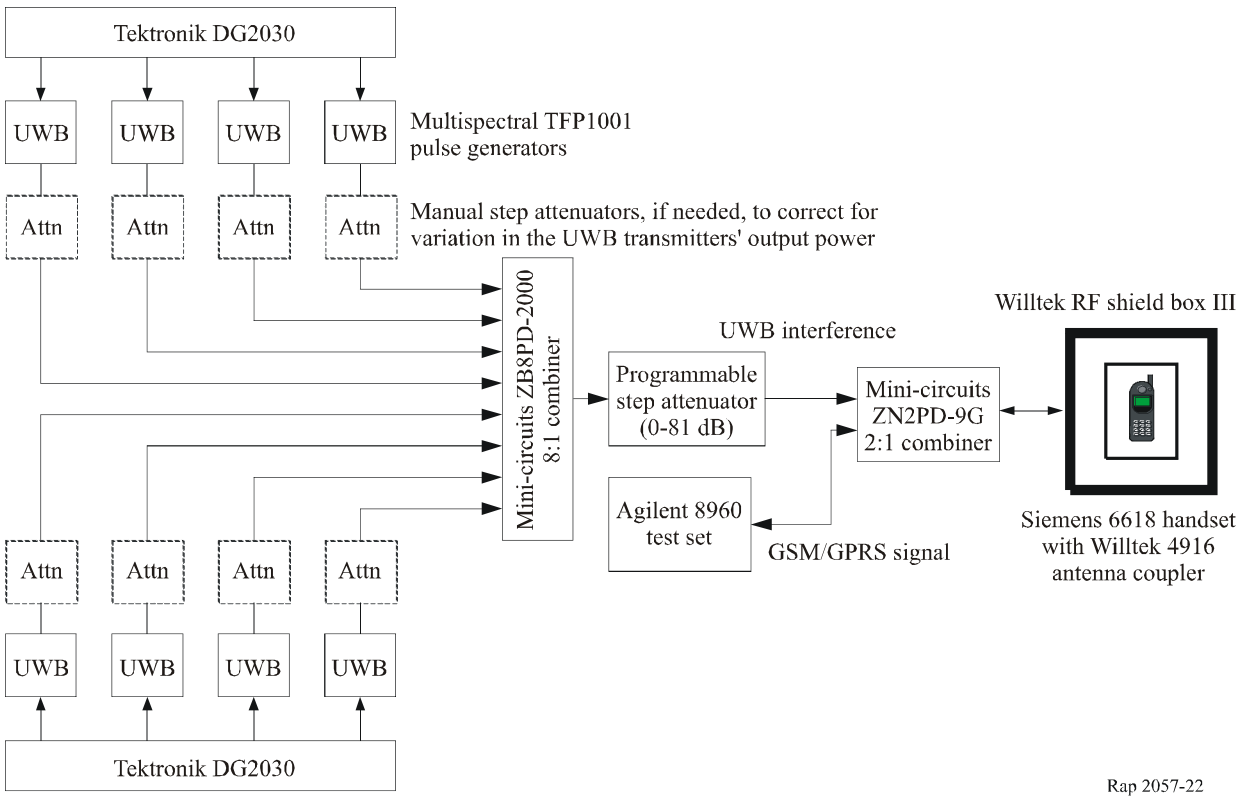
The output from all eight UWB transmitters was added together using an 8:1 Mini-Circuits ZB8PD-2000 RF combiner. A manual step attenuator was placed between the UWB transmitter and the 8:1 combiner where necessary to correct for any significant variation in output power among the 8 transmitters.

4.3.3.1.2 Test set-up

The set-up used for the GSM and GPRS laboratory experiments is shown in Fig. 22. The victim handset used in this experiment was an ordinary, commercially available GSM/GPRS mobile phone. The base station signal was generated by an Agilent 8960 Series 10 wireless communications test set running the E1968A GSM/GPRS Mobile Test Application (version A.03.32). The step attenuator connected to the output of the 8:1 combiner enabled to vary the power of the combined UWB signal in 1 dB steps. The step attenuator, both DG 2030s, and the Agilent test set were controlled remotely via GPIB from the IBM laptop, which ran an automation script developed using Matlab for this study.

FIGURE 22

GSM/GPRS aggregation test set-up



This set-up allowed us to determine how the residual BER (for GSM) or BLER (for GPRS) of the radio downlink varies with the C/I_{UWB} ratio for 30 different combinations of PRF, pulse position modulation (PPM) steps and signal polarity for the GSM/GPRS tests, as shown in Table 13 for the IMT-DS tests. Only 1 UWB signal type were used (PRF = 50 MHz, PPM = 1, mono-phase) for the ambient noise test.

C is the handset's received signal power level and I_{UWB} is the amount of UWB signal power within the 3 dB bandwidth (81.25 kHz) of the handset's receiver. Note that it was relied on the RXLEV value reported by the handset to determine the total path loss between the test set and the handset receiver. According to 3GPP TS 45.008 V6.8.0 (section 8.1.2), RXLEV is accurate only to ±4 dB at best. Fortunately, this large margin of error does not affect the ability to calculate C/I_{UWB} because C and I_{UWB} can be measured accurately at the input of the combiner with a spectrum analyser.

TABLE 13

MSSI UWB transmitter settings (GSM/GPRS tests)

Type	PRF (MHz)	PPM	Polarity
1	0.1	1	Mono-phase
2	0.1	1	Bi-phase
3	0.1	4	Mono-phase
4	0.1	4	Bi-phase
5	0.1	8	Mono-phase
6	0.1	8	Bi-phase
7	0.5	1	Bi-phase
8	0.5	4	Mono-phase
9	0.5	4	Bi-phase
10	0.5	8	Mono-phase
11	0.5	8	Bi-phase
12	1	1	Bi-phase
13	1	4	Mono-phase
14	1	4	Bi-phase
15	1	8	Mono-phase
16	1	8	Bi-phase
17	5	1	Bi-phase
18	5	4	Mono-phase
19	5	4	Bi-phase
20	5	8	Mono-phase
21	5	8	Bi-phase
22	10	1	Bi-phase
23	10	4	Mono-phase
24	10	4	Bi-phase
25	10	8	Mono-phase
26	10	8	Bi-phase
27	50	1	Bi-phase
28	50	2	Mono-phase
29	50	2	Bi-phase
30	100	1	Bi-phase

4.3.3.1.3 Test procedure

The residual BER (RBER) of the GSM downlink and the block error rate (BLER) of the GPRS downlink was measured in the presence of 1, 2, 4 and 8 active UWB transmitters. For every one of the 30 UWB signal types, the UWB power level was brought down to a very low level and increased it gradually in 1 dB steps until the RBER exceeded around 7% (for GSM) or when the GPRS downlink failed (for GPRS). The handset's received signal level was –90 dBm. For the GPRS case, the CS-2 coding scheme was used, one of the most widely used coding schemes in commercial GPRS networks.

The key test parameters for the GSM and GPRS measurements are summarized in Tables 14 and 15 respectively.

TABLE 14

GSM test parameters

BCH and TCH channel	883
Downlink frequency	1 879.4 MHz
Uplink frequency	1 784.4 MHz
Received signal level at handset	–90 dBm
BER type	Residual Type II (with Loopback Type A)
Number of bits for BER test	50 000
Payload pattern type	PRBS-15
Degradation criterion	RBER < 2%
Test reference	3GPP TS 05.05 V8.16.0, Table 1 3GPP TS 45.005 V6.6.0, Table 1 See under DCS 1 800, TCH/FS class II (RBER), static propagation conditions

TABLE 15

GPRS test parameters

BCH and TCH channel	883
Downlink frequency	1 879.4 MHz
Uplink frequency	1 784.4 MHz
Received signal level at handset	–90 dBm
PDTCH coding scheme	CS-2
PDTCH time-slot configuration	2 downlink time-slots, 1 uplink time-slot
BLER type	ETSI B Acknowledged (Loopback) mode
Number of blocks for BLER test	2 000
Payload pattern type	PRBS-15
Degradation criterion	BLER < 10%
Test reference	3GPP TS 51.010-1 V5.9.0, section 14.16.1.2

4.3.3.1.4 Results and discussion

Figure 23 shows the 30 BER curves for 1, 2, 4 and 8 active UWB transmitters for the GSM measurements, while Fig. 24 shows the corresponding BLER curves for the GPRS measurements. Note that the BER/BLER is plotted against the in-band UWB signal power of a *single* UWB device, not the combined UWB signal power.

It can be seen clearly in Fig. 23 that the bundles of curves are spaced roughly 3 dB apart, suggesting that the C/I_{UWB} ratio for the GSM case increases by 3 dB for every doubling of the number of active UWB transmitters. This observation is confirmed in Table 16, which shows how the C/I_{UWB} ratio varies with the number of UWB transmitters, where I_{UWB} is the logarithmic average in-band UWB signal power *of a single UWB transmitter* that results in a BER of 2%. These results provide experimental evidence that linear power addition applies well to the aggregation of UWB signals.

The unusual position of the rightmost curve of the rightmost set of curves (i.e. the single UWB transmitter test case) in Fig. 23, which indicates increased robustness of the victim handset to UWB interference, requires further clarification. This outlier corresponds to the 0.1 MHz, PPM = 1 (i.e. no time dithering), mono-phase UWB signal type. In another submission to Radiocommunication TG 1/8, it was posited that this UWB signal type, which appears like continuous wave (CW) interference to a GSM/GPRS receiver, may be less harmful than the other signal types, which resemble white noise. However, it can be seen in Fig. 23 that, as the number of active UWB transmitters increases, the BER curve for this signal type shifts closer and closer to the other curves in the set. With eight active UWB transmitters, the BER curve for this signal type is indistinguishable from the rest. This observation suggests that any specific characteristics that a single UWB signal type may have is lost when multiple transmitters are present.

FIGURE 23

GSM BER vs. in-band UWB signal power for multiple UWB devices

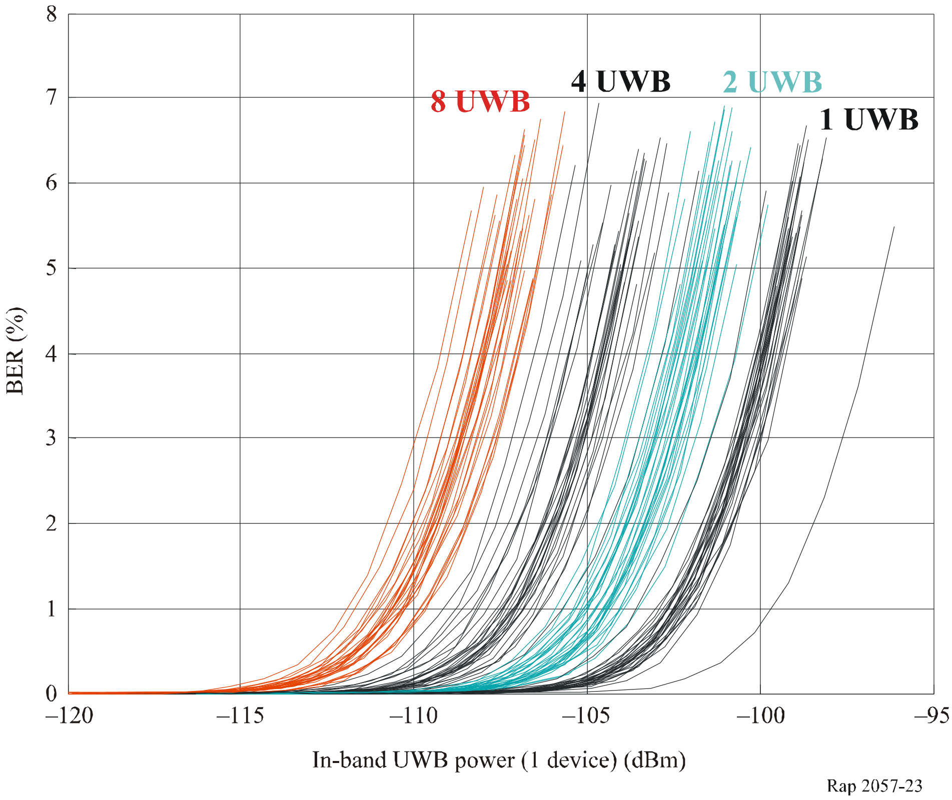


TABLE 16

GSM C/I_{UWB} results (C = –90 dBm)

Number of UWB transmitters	I_{UWB} (dB)	C/I_{UWB} (dB)	Δ C/I_{UWB} (dB)
1	–101	11	–
2	–103	13	2
4	–106	16	3
8	–109	19	3

The 3 dB spacing between the sets of curves for the GPRS case (see Fig. 24) is less clear because of the steepness of the BLER curves and the abruptness with which they terminate. Nevertheless, this linear relationship becomes evident when considering the logarithmic average of the I_{UWB} values, which was defined as the UWB power level *of a single UWB transmitter* beyond which either the GPRS link will break or the BLER will exceed 10%. Table 17 clearly shows that the log average C/I_{UWB} increases linearly with the number of active UWB transmitters.

FIGURE 24

GPRS BLER vs. in-band UWB signal power for multiple UWB devices

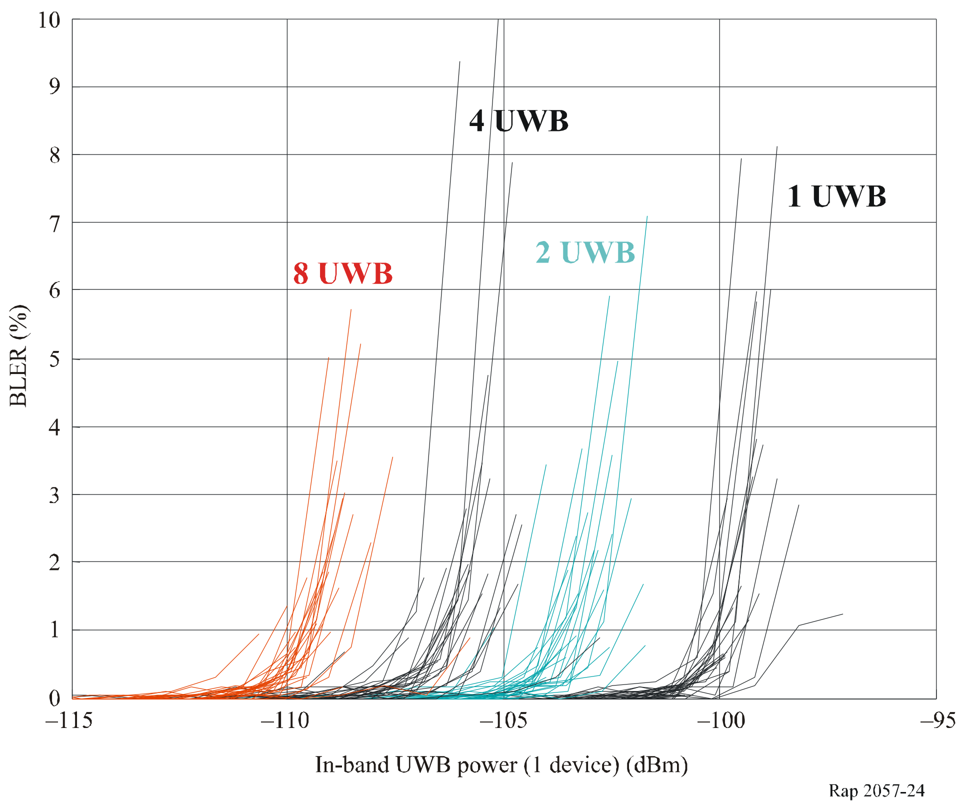


TABLE 17

GPRS C/I_{UWB} results (C = –90 dBm)

Number of UWB transmitters	Log average I_{UWB} (dB)	C/I_{UWB} (dB)	$\Delta C/I_{UWB}$ (dB)
1	–100	10	–
2	–103	13	3
4	–106	16	3
8	–109	19	3

4.3.3.2 Laboratory study of impact of UWB signal aggregation on IMT-DS systems

4.3.3.2.1 Test set-up

The test set-up is identical to the set-up for the GSM/GPRS laboratory test (see Fig. 25), except for the following changes. The handset (thereafter referred to as UE) was replaced with a commercial off-the-shelf Motorola A835. The application running on the Agilent 8960 was changed to the E1963A IMT-DS Mobile Test Application (version A.05.16). The 8:1 combiner was changed to a Mini-Circuits ZB8PD-4 combiner to better suit the higher downlink frequency of the IMT-DS signal. I_{UWB} for this test now refers to the UWB spectral power within a 3.84 MHz bandwidth centred on the selected downlink carrier frequency. Finally, the total number of UWB signal types was expanded slightly to 32, see Tables 18-20.

FIGURE 25

IMT-DS aggregation set-up

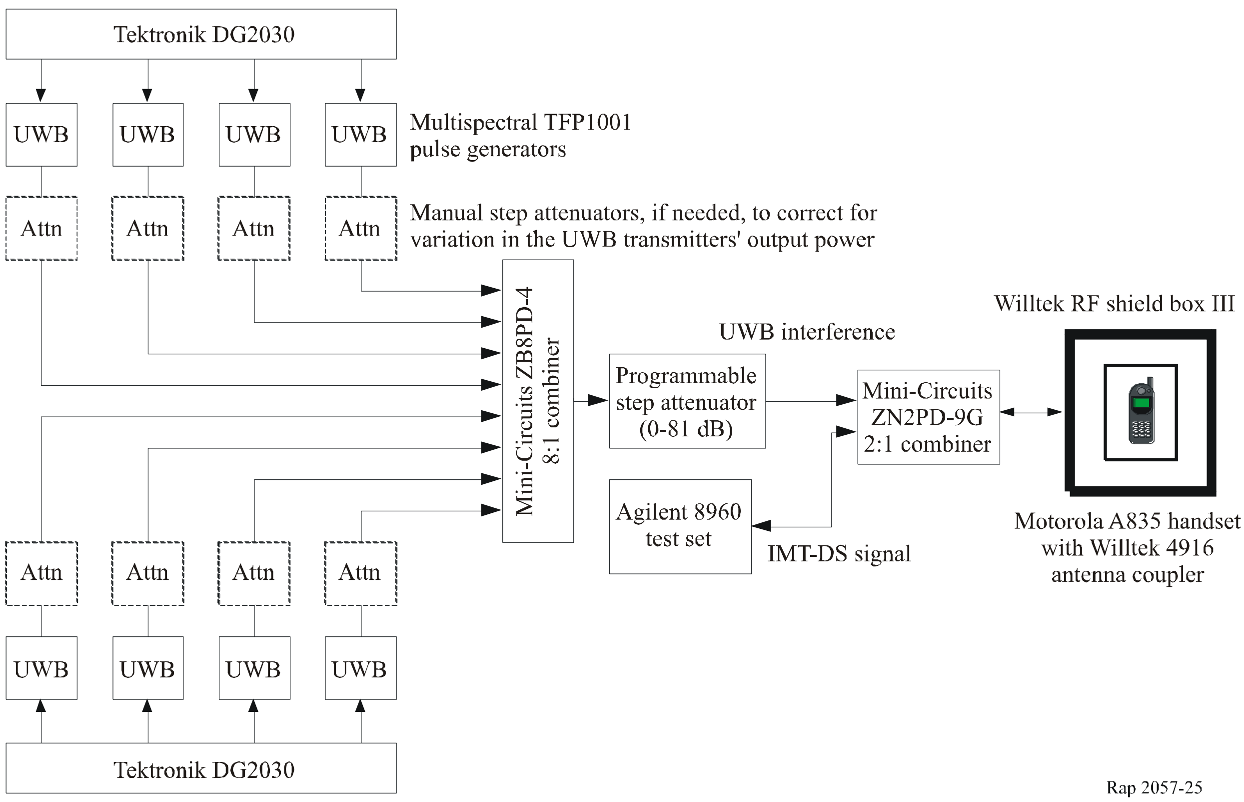


TABLE 18

MSSI UWB transmitter settings (IMT-DS tests)

Type	PRF (MHz)	PPM	Polarity
1	0.1	1	Mono-phase
2	0.1	1	Bi-phase
3	0.1	4	Mono-phase
4	0.1	4	Bi-phase
5	0.1	8	Mono-phase
6	0.1	8	Bi-phase
7	0.5	1	Mono-phase
8	0.5	1	Bi-phase
9	0.5	4	Mono-phase
10	0.5	4	Bi-phase
11	0.5	8	Mono-phase
12	0.5	8	Bi-phase
13	1	1	Mono-phase
14	1	1	Bi-phase
15	1	4	Mono-phase
16	1	4	Bi-phase
17	1	8	Mono-phase
18	1	8	Bi-phase
19	5	1	Bi-phase
20	5	4	Mono-phase
21	5	4	Bi-phase
22	5	8	Mono-phase
23	5	8	Bi-phase
24	10	1	Bi-phase
25	10	4	Mono-phase
26	10	4	Bi-phase
27	10	8	Mono-phase
28	10	8	Bi-phase
29	50	1	Bi-phase
30	50	2	Mono-phase
31	50	2	Bi-phase
32	100	1	Bi-phase

Note that it was relied on the CPICH RSCP value reported by the UE to determine the total path loss between the test set and the UE receiver. Knowing from 3GPP TS 34.121 V5.3.1 (Table E.3.2.1) that, for the physical channels used in these tests, $\hat{I}or$ = CPICH RSCP + 3.32 dB. As with the GSM/GPRS lab experiment, this large margin of error does not affect our ability to calculate $\hat{I}or/I_{UWB}$ accurately based on measurements of $\hat{I}or$ and I_{UWB}.

4.3.3.2.2 Test procedure

The loopback BER of the IMT-DS downlink was measured in the presence of UWB interference. For every one of the 32 UWB signal types, the UWB power level was brought down to a very low level and increased it gradually in 1 dB steps until communication failure. This experiment was carried out with the 12.2k reference measurement channel (RMC) at a received signal level $\hat{I}or$ of –96 dBm.

The key test parameters are given in Table 19.

TABLE 19

IMT-DS test parameters

Downlink frequency	2 167.4 MHz (Channel 10 837)
Uplink frequency	1 977.4 MHz (Channel 9 887)
Îor at UE	–96 dBm
Channel type	12.2k RMC
Downlink physical channels	Established according to 3GPP TS 34.121 V5.3.1, Table E.3.2.1
BER type	Loopback BER (Loopback Mode 1)
Number of bits for BER test	50 000
Payload pattern type	PRBS-15
Degradation criterion	BER < 0.1%
Test reference	3GPP TS 34.121 V5.3.1 section 6.2

4.3.3.2.3 Results and discussion

Beyond a certain threshold UWB signal power level, the BER would increase rapidly until the Agilent test set issued a “Signal Lost of Uplink DCH” error, indicating that the UE was unable to receive the downlink signal and loop it back. Table 20 shows, arranged in ascending PRF, the $\hat{I}or/I_{UWB}$ values obtained from this experiment, where I_{UWB} is the logarithmic average of the amount of in-band UWB signal power *for a single UWB transmitter* beyond which the BER of the downlink would exceed 0.1%. As explained, the UWB signals with PRF = 0.1 MHz were less harmful than expected. For the other UWB signal types, it can be seen clearly see a 3 dB increase in $\hat{I}or/I_{UWB}$ for every doubling of the number of active UWB transmitters.

TABLE 20

IMT-DS test results

PRF (MHz)	Number of UWB Devices	Log average I_{UWB} (Single UWB) (dBm)	$\hat{I}_{or}/I_{UWB}$ (Single UWB) (dB)	Δ $\hat{I}_{or}/I_{UWB}$ (dB)
0.1	1	UWB transmitter power is too weak to have any impact		
	2	UWB transmitter power is too weak to have any impact		
	4	–91	–5	–
	8	–95	–1	4
0.5	1	–87	–9	–
	2	–90	–6	3
	4	–93	–3	3
	8	–96	0	3
1	1	–88	–8	–
	2	–90	–6	2
	4	–93	–3	3
	8	–96	0	3
5	1	–88	–8	–
	2	–90	–6	2
	4	–93	–3	3
	8	–96	0	3
10–100	1	–88	–8	–
	2	–91	–5	3
	4	–94	–2	3
	8	–97	1	3

4.3.3.3 Impact of multiple UWB transmitters on ambient environment

4.3.3.3.1 Introduction

This section aims to study how these aggregated UWB emissions from multiple devices affect the ambient radio noise environment in eight selected frequency bands in one Administration. These frequency bands, shown in Table 21, are currently unassigned and unused, but are located adjacent to radio spectrum occupied by commonly used wireless services. They are intended to approximate the ambient environment within the frequency bands occupied by these wireless services.

TABLE 21

Frequency bands and wireless services

Band No.	Service	Centre frequency (GHz)	Frequency span (MHz)
1	GPS	1.565	10
2	GSM (uplink)	1.735	10
3	GSM (downlink)	1.830	5[(1)]
4	WCDMA (uplink)	1.973	10
5	WCDMA (downlink)	2.163	10
6	Bluetooth/2.4 GHz RLAN	2.305	10
7	C-band FSS downlink	4.205	10
8	5 GHz RLAN	5.105	10

(1) Only 5 MHz of "quiet" spectrum is available at this frequency.

4.4.3.3.2 Test set-up

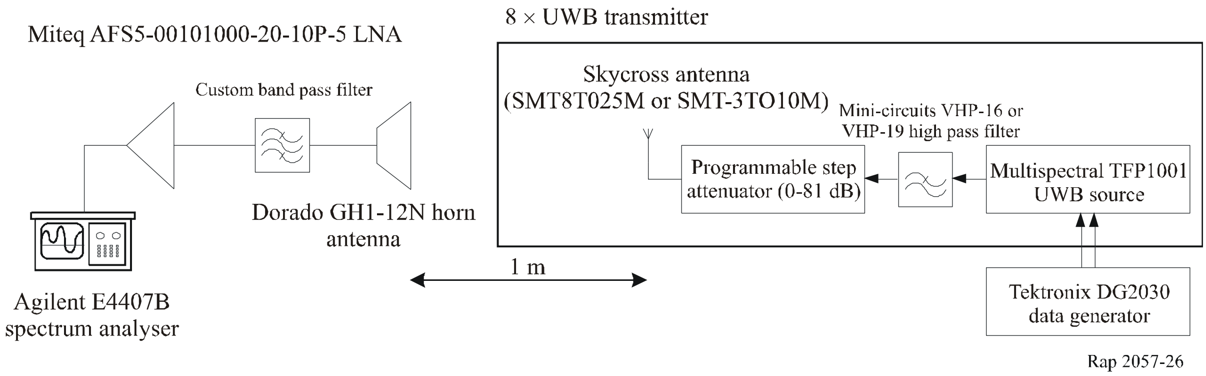
The measurement system used to measure the power spectral density (on a per MHz basis) of the ambient environment is shown in Fig. 26. Note that it was used a specially fabricated band-pass filter for each of the eight frequency bands considered in this experiment. The gain of the measurement system up to the connector of the horn antenna had previously been measured using a power meter and a signal generator.

The antennas of eight TFP1001 UWB impulse transmitters from Multispectral Solutions (MSSI) were placed 1 m away from the horn antenna of the measurement system. Each UWB transmitter was controlled by two triggering signals generated by a Tektronix DG2030 data pattern generator to produce a noise-like, bi-phase UWB signal with a pulse repetition frequency of 50 MHz and a pulse position modulation setting of 2. For bands 1-6, it was attached to each UWB transmitter a Skycross SMT-8TO25M broadband antenna connected to a Mini-Circuits VHP-16 high pass filter. For bands 7 and 8, a Skycross SMT-3TO10M UWB antenna and a Mini-Circuits VHP-19 high-pass filter were used. The e.i.r.p. spectral density of both transmitter set-ups had previously been measured over a wide range of frequencies (1-11 GHz) in an anechoic chamber.

A manual step attenuator was placed at the output of each UWB transmitter, before the antenna, to adjust the e.i.r.p. of the transmitter to conform to the emission limits of the US rules for hand held UWB devices. This adjustment was carried out separately for each of the eight frequency bands under consideration. It was not needed to apply any attenuation to the UWB signal for bands 7 and 8 because the power spectral density of the UWB transmitters at those frequencies was already below the emission limits of the United States of America rules.

FIGURE 26

Ambient environment measurement set-up



4.3.3.3.3 Test procedure

For each of the eight frequency bands:

Step 1: Set the resolution bandwidth (RBW), video bandwidth (VBW) and span of the spectrum analyser to 1 MHz, 3 MHz and 10 MHz (5 MHz for band 3) respectively.

Step 2: Set the centre frequency of the spectrum analyser to the centre frequency of the band under study.

Step 3: Set the detector type of the spectrum analyser to "RMS average detector".

Step 4: Ensure that the correct band pass filter is used for the current frequency band.

Step 5: Turn on a UWB transmitter.

Step 6: Adjust the step attenuator connected to all active UWB transmitters to achieve the desired e.i.r.p. spectral density.

Step 7: "Max hold" the trace for a few seconds.

Step 8: Repeat Steps (5) to (7) with 2, 4 and 8 simultaneously active UWB transmitters.

NOTE 1 – A different high pass filter-antenna pair was used for bands 1-6 and bands 7-8.

4.3.3.3.4 Results and discussion

Figures 27 to 34 show radiated PSD of the signal generated by 1, 2, 4 and 8 UWB devices overlaid on the ambient noise environment in the eight frequency bands identified earlier. These measurements were carried out in an office, situated in Singapore's central business district.

The "0", "1", "2", "4" and "8" traces in the figures correspond to the ambient PSD with 0, 1, 2, 4, 8 simultaneously transmitting UWB devices respectively. "MDS" is the minimum detectable signal level (i.e. noise floor) of this measurement system, determined by replacing the horn antenna with a 50 Ω load.

FIGURE 27

Ambient measurement centred at 1.565 GHz

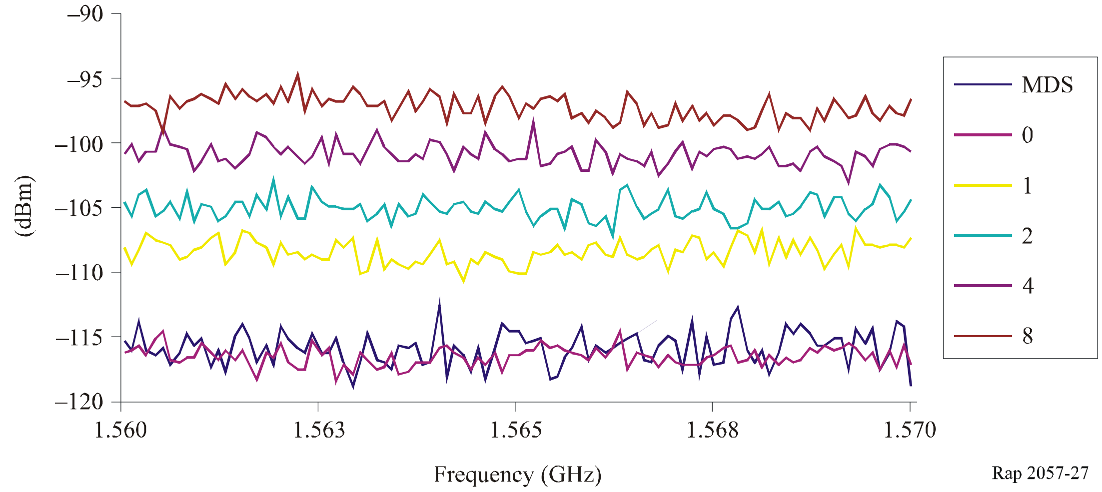


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FIGURE 28

Ambient measurement centred at 1.735 GHz

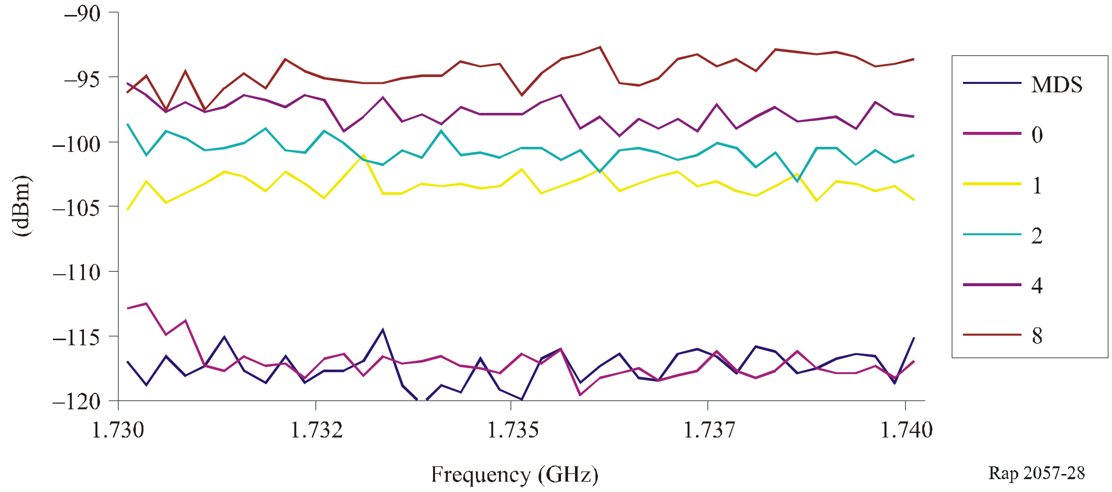

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FIGURE 29

Ambient measurement centred at 1.830 GHz (5 MHz span)

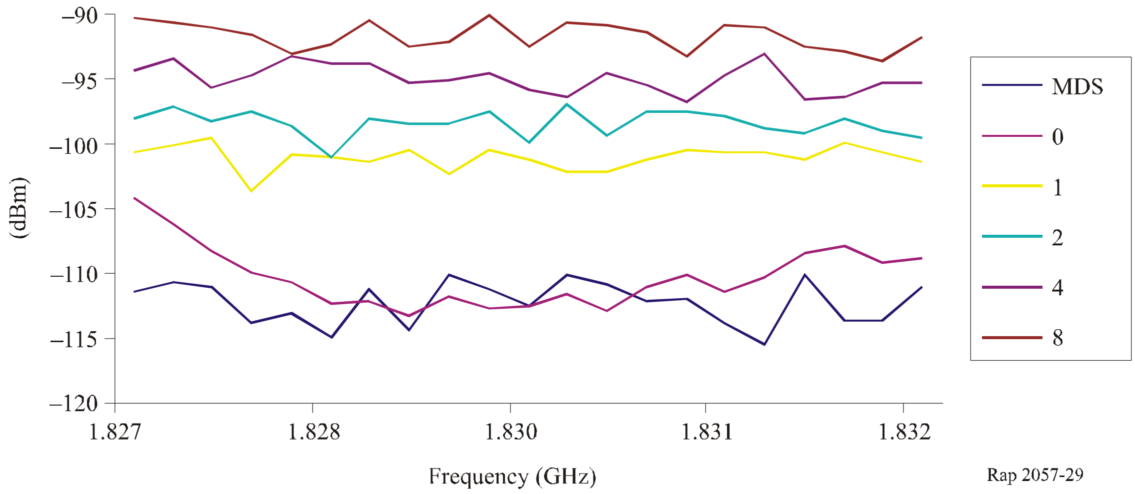

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FIGURE 30

Ambient measurement centred at 1.973 GHz

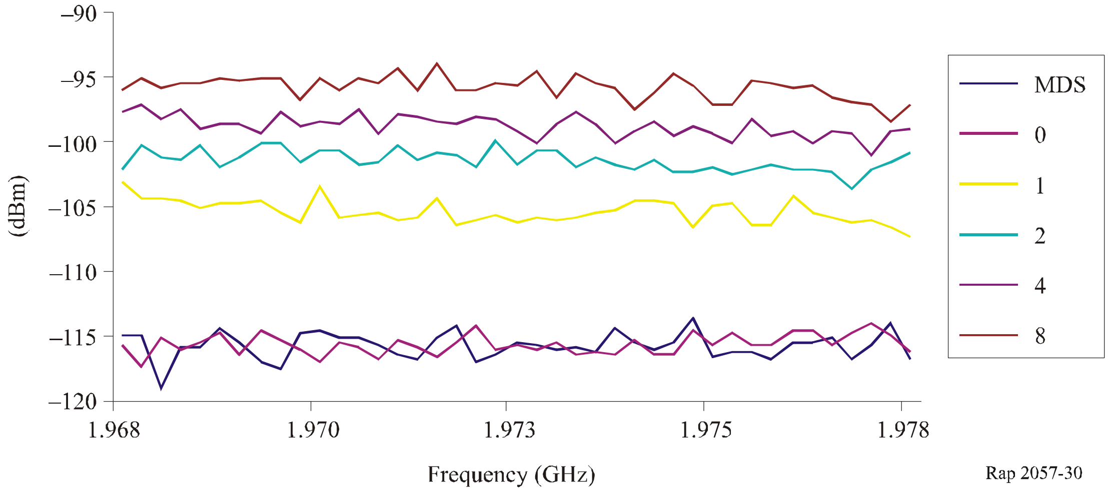


FIGURE 31

Ambient measurement centred at 2.163 GHz

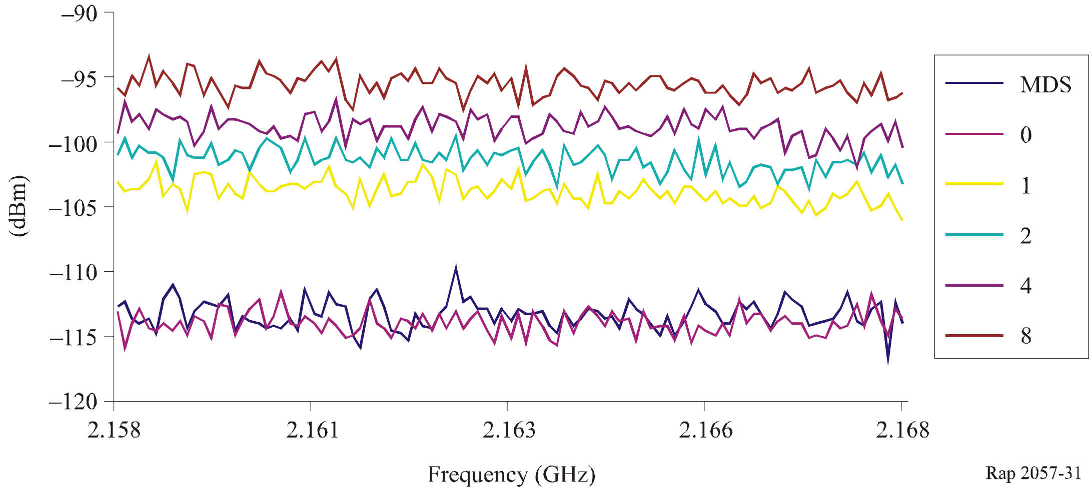


FIGURE 32

Ambient measurement centred at 2.305 GHz

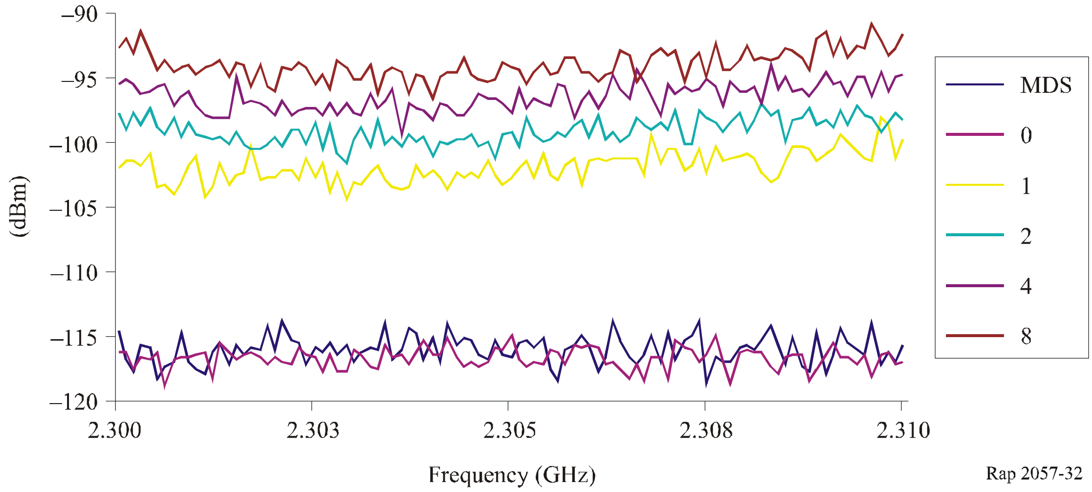


FIGURE 33

Ambient measurement centred at 4.205 GHz

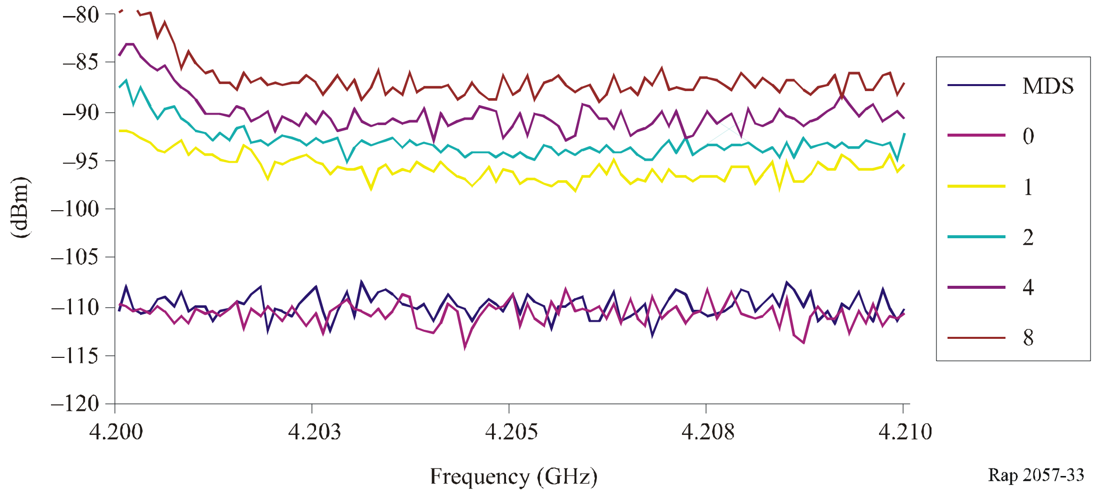


FIGURE 34

Ambient measurement centred at 5.105 GHz

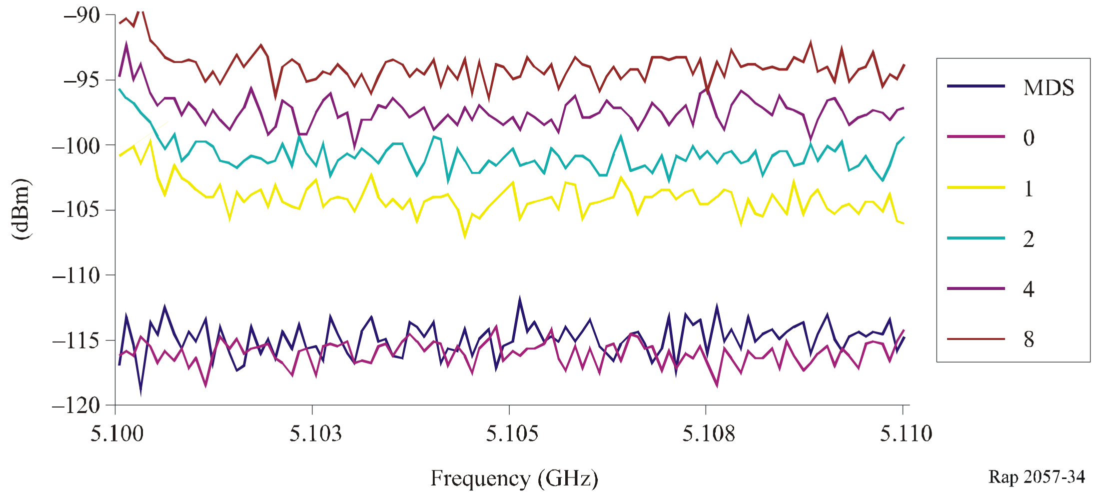


Table 22 shows the log average of the PSD values for all the data points in each trace and for each of the eight selected frequency bands. It is clear from the table that every doubling of the number of active UWB transmitters increases the average PSD across the band by about 3 dB.

TABLE 22

Log average of UWB power spectral density for multiple UWB transmitters

Band No.	Frequency (GHz)	1 UWB (dBm/MHz)	2 UWB (dBm/MHz)	4 UWB (dBm/MHz)	8 UWB (dBm/MHz)
1	1.565	–108.5	–105.1	–100.9	–97.3
2	1.735	–103.4	–100.8	–97.8	–94.6
3	1.83	–101.2	–98.5	–95.0	–91.8
4	1.973	–105.5	–101.5	–98.9	–95.9
5	2.163	–103.9	–101.5	–98.9	–95.7
6	2.305	–101.1	–98.4	–95.8	–93.2
7	4.205	–94.9	–92.3	–89.4	–85.9
8	5.105	–104.1	–100.8	–97.5	–94.1

Table 23 compares our expected PSD levels (column D) for a single UWB transmitter, assuming free-space path loss, with our measured levels (column G) and shows that they are in good agreement.

TABLE 23

Comparison of calculated and measured PSD levels

A	B	C	D	E	F	G
Frequency (GHz)	**UWB signal e.i.r.p. (dBm/MHz)(1)**	**Free-space loss (dB)**	**Calculated PSD at horn antenna (dBm/MHz) (B-C)**	**Gain of measurement system (dB)**	**Log average of spectrum analyser measurements (dBm/MHz)**	**Measured PSD at horn antenna (dBm/MHz) (F-E)**
1.565	–75	36.3	**–111**	42.3	–68.1	**–110**
1.735	–63	37.2	**–100**	44.0	–58.7	**–103**
1.83	–63	37.6	**–101**	39.0	–61.6	**–101**
1.973	–63	38.3	**–101**	42.1	–62.4	**–105**
2.163	–61	39.1	**–100**	39.7	–63.9	**–104**
2.305	–61	39.7	**–101**	42.5	–58.5	**–101**
4.205	–50(2)	44.9	**–95**	35.7	–60.0	**–96**
5.105	–55(2)	46.6	**–102**	41.7	–62.9	**–104**

(1) Based on the United States of America emission mask for hand-held UWB devices.

(2) The UWB transmitter was not able to generate enough spectral power at these frequencies to achieve –41 dBm/MHz.

5 Mitigation techniques

In order to mitigate the impact of devices using UWB on existing radiocommunication systems, various mitigation techniques can be deployed. The purpose of this section is to describe available mitigation techniques and to compare their characteristics.

5.1 Spectral control techniques

These techniques suppress the radiation in the frequency band of the victim systems by controlling the spectrum of the UWB signal. Annex 1 provides three examples of this technique, which can be summarized as follow:

1 Smoothing the power spectral density of UWB signals by an appropriate choice of the timing jitter.

2 Using a pseudo-noise code sequence to decrease the spikiness of the UWB signals and to lower the PSD in certain frequency bands.

3 Using various pulse shapes to control the fractional bandwidth and the spreading PSD of UWB signals.

5.1.1 Cross polarization

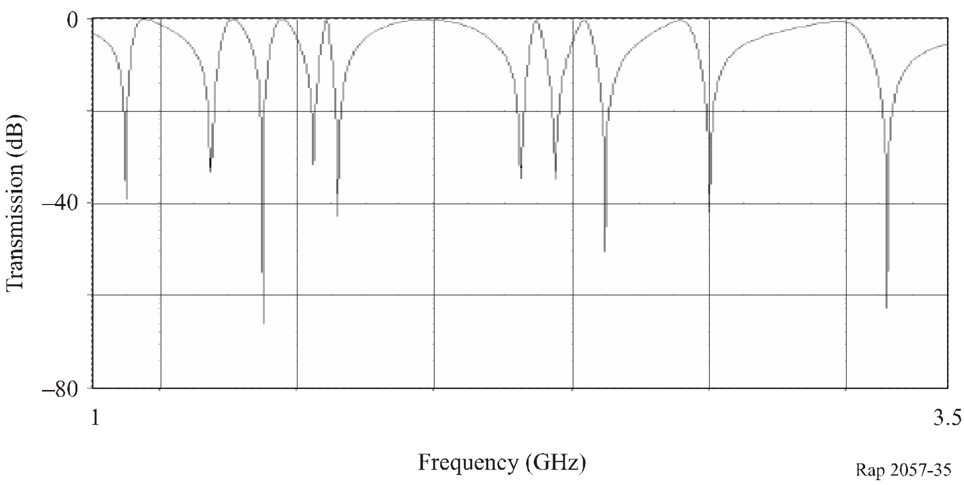
Cross polarization can be effective in mitigating interference from some UWB systems to systems operating under radiocommunication services if polarizations of both systems are well known. As with other mitigation techniques, cross polarization is most effective when coordination is carried out prior to implementation of networks to accommodate all possible affected systems.

5.1.2 Notch filtering

Providing a notch filter to suppress certain spectral contents of the mono-cycle pulse or other UWB pulses could reduce interference to existing radiocommunication services; however, it may be impractical to implement since such in-band notches may impair the performance of UWB systems. Furthermore, the design of wideband notch filters may present certain technical challenges.

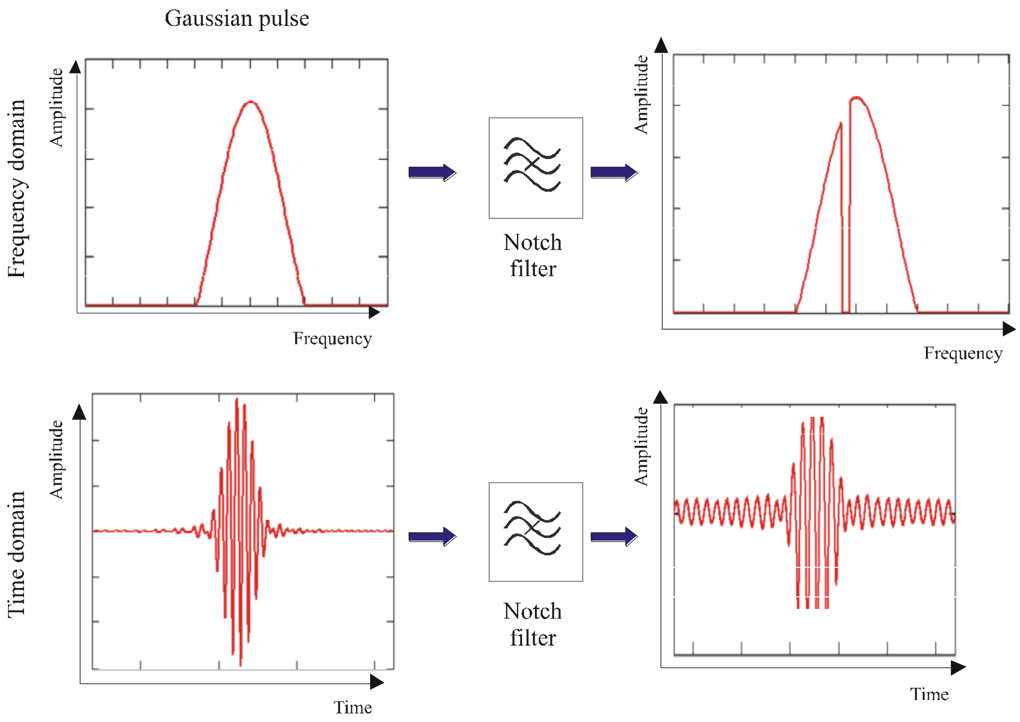
FIGURE 35

Example of an effect of a notch filter on UWB signal



Notch filtering inside the necessary bandwidth of a radar causes "ringing" of the pulse, The magnitude of the ringing increases with steepness of the slope of the filter response at the edges of the notched bandwidth. This reduces the *S*/*N*, and decreases the range resolution of radars, see Fig. 36.

FIGURE 36



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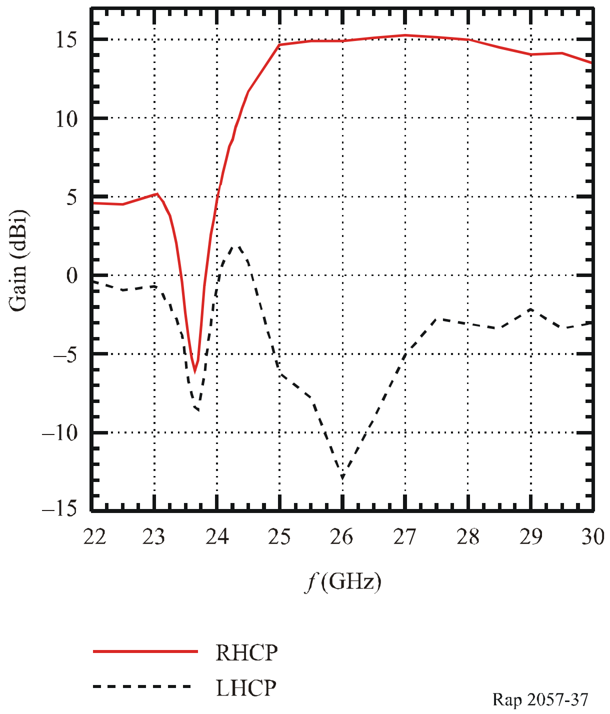
Such spectrum notching can also be provided by the frequency response of the UWB device antenna. A cavity-back spiral antenna, which consists of a square cavity with rims enclosing the spiral antenna is such kind of antenna. Since the antenna consists of a cavity, it may have anti-resonance.

At the anti-resonant frequency, the input VSWR becomes very large and a large reflection occurs at the antenna input terminal. A sharp notch may appear in the antenna gain at the anti-resonant frequency, causing the antenna to act as a band-rejection filter. An antenna can be designed that mitigates interference by choosing the anti-resonant frequency to fall within the victim band.

One example of such cavity-back spiral antenna is shown in Fig. 37. Gain of the antenna at the frequency over 25 GHz is 15 dBi and a sharp notch is seen around 24 GHz.

FIGURE 37

Example of gain of antenna (dBi) with notch filter function



5.1.3 UWB modulation and channelization schemes

The choice of the modulation scheme impacts the PSD of the radiated UWB signal and consequently its impact on radiocommunication services. Certain modulation techniques can offer better coexistence among UWB systems and with other radiocommunication systems. Some modulation schemes exhibit advantages when used for UWB transmission in certain environments.

Several modulation schemes have been studied and implemented for UWB transmissions. These include: (binary) pulse position modulation (PPM), *M*-ary PPM, (binary) pulse amplitude modulation (PAM), *M*-ary PAM, biphase modulation (BPM), on-off keying (OOK), time-shift-keying (TSK), spread spectrum (SS) schemes that use time hopping, and hybrid modulation schemes combining BPM and PPM. Both analogue and digital modulation have been studied and implemented. Digital modulation has been shown to provide much greater capacity compared to analogue modulation schemes.

Some modulation schemes exhibit advantages when used for UWB transmission in certain environments. For example, biphase modulation yields an advantage of 3 to 6 dB over TH-PPM in multipath-free environments. It also has a peak power to average power ratio of less than 3 (compared to a sine wave, with a ratio of 2). This leads to efficient transmitters and use of low-cost, low-power circuitry.

5.1.4 Frequency hopping

It is possible to reduce the emission to the certain frequency bands by hopping the emission band of the UWB signal in a proper manner. Moreover, emission to the specific frequency band to the victim systems is effectively suppressed by disabling the hopping to the corresponding frequency band.

5.1.5 Chirp signalling

It is possible to reduce the emission to the frequency band of the victim systems by continuously changing the frequency of the UWB pulse.

5.1.6 Frequency agile modulation

The frequency agile UWB modulation scheme allows improved coexistence with current and future systems worldwide. Traditional UWB modulation schemes (e.g. pulsed based and direct sequence based) call for flat in-band mask definition with a limit, based on the worst-case victim receiver inside the UWB spectrum.

Frequency agile UWB modulation scheme calls for a mask definition according to actual requirements at each portion of the UWB RF spectrum frequency agile modulation scheme also calls for regional definition of the UWB masks.

Frequency agile UWB devices could support a programmable mask based on regional code transferred to the physical layer from the upper layers.

The least common denominator can serve for communication between devices in the absence of regional knowledge or before transferring regional knowledge over the air, from devices with regional knowledge to devices without regional knowledge.

Frequency agile UWB modulation scheme can allow coexistence with future systems. An example of how frequency agility combined with detect and avoid technique could be applied to protect a specific radiocommunication service is as follows:

For indoor FWA systems, the dominant UWB interference mode is from a single nearby UWB emitter. Both the UWB device, as well as the indoor FWA device are considered to be portable, so the interference offered is bound to be highly variable based on the scenario, and is also likely to change with time.

In Annex 2, it is shown that the UWB e.i.r.p. density level for protection of indoor (portable) terminal stations is −76.5 dBm/MHz.

Therefore, a frequency agile technique should respond to two highly demanding characteristics:

– Ability of reducing the e.i.r.p. density level, in frequency range where FWA signal has been detected.
– Standing that FWA are implemented either in TDD or in FDD mode and. in addition, the TS signal (up-link) might often have a very low activity (e.g. “silent” during downloading and video streaming), the detection of the higher up-link signal might not be enough effective; in addition the UWB device should know the FDD duplex spacing that, even if quite constant (e.g. 50 or 100 MHz) in present implementations, could considerably change in future re-farming of the 4 GHz bands. Therefore, detection threshold should be better tailored on the down-link signal, which would be more weak, reaching, in areas of marginal coverage, power density levels lower than −85 dBm/MHz (e.g. for QPSK formats with efficient error correction codes).

Some contributions have already shown feasibility of detection of up-link signal and of notching 20/30 dB in the UWB signal. Further work is expected in the near future in order to refine the performance for satisfying the most demanding requirements of detecting down-link signal and higher power reduction.

5.1.7 Carrier-leak-free burst oscillator

By using a burst oscillator that does not generate carrier leak at pulse-off, the spectrum of the oscillator at an arbitrary position can be located within the permitted band for UWB radar. Consequently, a UWB radar using this oscillator may effectively mitigate interference with services using the restricted frequency band by locating the spectrum sufficiently far from the band, where the emission is reduced at least 15 dB lower than the spectrum peak.

5.2 Spatial radiation control techniques

These techniques suppress the influence to the victim systems by restricting the radiation of the UWB signal to the unnecessary directions and reducing the total emitting power.

5.2.1 Antenna directivity

In certain UWB applications, the directivity of UWB antennas could help minimize the interference to radiocommunication services. In applications such as ground penetrating radar, the energy is directed towards the ground, limiting the risk of interference with neighbouring wireless systems to only weak reflected signal components. Also in vehicular radars, the use of highly directive antennas with very narrow dispersion angles could minimize the interference to radio communications base stations for example in the vicinity of the vehicular radar, although reflection and scattering of arbitrarily-oriented metal surfaces on other cars may be a potential issue.

5.2.2 Multiple antenna diversity

Multiple antenna diversity can be used to improve the co-existence of ultra-sideband (UWB) devices with other radiocommunication systems. In this section, a few multiple antenna operating principles are presented that provide benefits either by enhancing the link robustness or range, or by reducing the total UWB emitting power.

A number of approaches using multi-element antennas at one or both sides of the radio link can be considered:

– Switched beam (angular) diversity on the receive side. This brings diversity gain.

– Switched beam diversity on the transmit side. Usually this would be considered to bring diversity gain as well. However, to conform to a specific emission mask it is probably more appropriate to keep the e.i.r.p. constant, resulting in a smaller total emitted power with respect to a single antenna and therefore less electromagnetic pollution.

– Spatial diversity on the receive side, or on the transmit side, or on both, using several combining schemes. In this case the antenna elements are basically omnidirectional, and combining at the transmitter or receiver reduces the emitted power or enhances the received *S*/*N*.

5.2.3 Array antenna

An array antenna technique makes it possible to spatially and adaptively restrict the radiation to the victim systems according to the locations of the victim systems. Therefore, it is possible to reduce the total emission power. Various algorithms to control an array antenna are available.

5.3 Combined techniques

It is possible to increase protection more flexibly and effectively by combining multiple mitigation techniques.

5.4 Detect and avoid technique

The detect and avoid (DAA) technique has recently been proposed as a technique to mitigate UWB interference. The general principle is that UWB devices should detect the presence of signals from other radio systems and reduce its transmitted power down to a level where it does not cause interference to these systems. The reliable implementation of such DAA mechanisms based on requirements that need to be defined is not trivial and their effectiveness has not yet been demonstrated. Therefore, further research and investigation of DAA as a mitigation technique is required.

Annex 1
to § 5

Spectral control mitigation techniques

1 Smoothing the PSD of UWB signals

UWB radiocommunication systems spread the signal over a large bandwidth by using narrow pulses, and randomize pulse positions in time or randomize pulse polarity to smooth and whiten the PSD. Commonly used UWB signals generated by PPM and time hopping have numerous spectral peaks and line spectra which may cause interference problems.

A PSD is shaped by an appropriate choice of the modulation technique, timing jitter, and a pseudo-noise code sequence that can allow for a better control of the frequency content of the radiated UWB emission. This may offer improved coexistence with other radiocommunication systems. The use of a pseudo-noise sequence enables the channelization of the transmitted signals, and the servicing of many users.

2 Impact of the pseudo-noise code sequence on UWB PSD

A regularly spaced monocycle pulse train has a PSD that has regularly spaced spikes, or comb lines with an envelope that is the Fourier transform of the pulse shape. Pulse position modulation smoothes the PSD of the signal, but because the pulses are shifted only a fractional part of a pulse width this spectral smoothing is small. The PSD of a UWB signal can be made closer to white by randomizing the actual transmission time of each monocycle pulse by a shift over a large time frame by a code, usually a pseudo-random noise code sequence. This time coding of UWB pulses decreases the spikiness of the UWB signals. The choice of suitable PN sequences can be used to lower the PSD in certain frequency bands to meet specified emission masks.

To channelize the pulse trains (thus providing a multiple access system), the actual transmission time of each monocycle pulse is shifted by a pseudo-random noise code sequence. Channelization is realizable by assigning a unique PN code sequence to each user and using it to apply a relatively large time offset of many nanoseconds to time shift the actual transmission time of each monocycle over a large time frame.

Time-hopping spread spectrum is built around position shift of pulses of a certain pulse shape in the time domain. The PSD of a UWB signal using a framed time hopping by pseudo-random periodic sequence (FTHPPS) has an infinite summation of delta functions separated by the reciprocal of one period $1/T_p$ of the pseudorandomly time-hopped signal that compose the line spectral density.

This narrower spectral line spacing provides an opportunity to spread the power more evenly across the band and to minimize the amount of power in any single spectral line. A pulse modulated train further smoothes the line spectral density. The envelope of the lines in the spectral density has a frequency response that is the product of the square of the magnitude of the Fourier transform of the pulse $w(t)$, and a term given by

$$C(f) = \left| \sum_{n=0}^{N_p - 1} \exp\left\{ -j2\pi f (nT_f + c_n T_c) \right\} \right|^2 \tag{13}$$

$C(f)$ is periodic in f with period $1/T_c$ so changing one part of the PSD by sequence design will affect another part of the PSD.

Some lines in the PSD cannot be reduced by design of the time-hopping sequence. One example is when $T_f/T_c = m'/n'$, where m' and n' are relatively prime integers. Then $C(f) = N_p^2$ for all frequencies that are integer multiples of n'/T_c, and lines exist in the PSD at these frequencies. Their heights are independent of the time-hopping sequence and can only be influenced by the energy spectrum, $|W(f)|^2$, of the monocycle waveform.

A near-white PSD of UWB signals can be generated with period extended PN sequences. The normalized maximum value of the improved PSD for the signal generated by the period-extended m-sequence is $1 + 1/Np$, and thus the PSD envelope is nearly flat (near-white).

For either biphase or hybrid modulation if the period extended PN sequence is used to generate the UWB signal, the average autocorrelation is determined by the periodic autocorrelation of the original PN sequence. The PSDs of UWB signals with biphase modulation, and a hybrid scheme that combines biphase modulation with PPM have no spectral line or discrete spectrum.

Another way to control the PSD of a UWB emission is by using a PPM signal for which the pulse delays are at suitably chosen discrete quantized intervals. Each UWB symbol consists of M chip intervals each of length T. Each chip interval contains a pulse at a pseudo-random delay equal to an integer number of basic resolution steps, each of length T_s. The ratio of chip interval length to basic resolution step length is an integer $N = T/T_s$. To prevent pulses occurring in adjacent chip intervals from overlapping excessively, the pulses are only initiated in the first portion of the chip interval $[0,U]T_s$, where $U<N$. The ratio U/N is called the dithering fraction. As the fraction U/N approaches unity, the PPM signal approaches maximum information capacity and the discrete components at $f = n/T$ are very small and are negligible with respect to the continuous portion of the spectrum.

The PSD of a practical PPM UWB signal will have discrete spectral components and a non-uniform continuous PSD. Consequently the transmitted power will need to be backed off from the maximum power level allowable had the PSD been ideal. The quantitative measure of this transmit power back off is denoted as the power back off penalty (PBP).

The timing jitter smoothes the spectrum of UWB PPM emissions and flattens the spikes.

A unified spectral analysis of a number of special cases of generalized time-hopping spread spectrum TH-SS UWB signals in the presence of timing jitter is given by:

$$s(t) = \sum_{n=-\infty}^{\infty} a_n w(t - nT_1 - b_n T_2 - c_n T_3 - \varepsilon_n) \qquad (14)$$

where a_n and b_n are arbitrary stochastic (randomly chosen) sequences. The sequence c_n is a deterministic periodic sequence with period N_p^c. The sequence ε_n is a discrete-time stationary random process representing timing jitter, but not including long-term drift. It is assumed that a_n, b_n and ε_n are stationary and mutually independent of each other. An expression for $s(t)$ in terms of the Fourier transform, $W(f)$ of $W(t)$, allows one to write the different time-hopping sequences (stochastic or deterministic) as well as the timing jitter as a product of exponentials (i.e., phase modulations).

The PSD of the generalized TH-SS UWB signal $s(t)$ in equation (14) consists of both continuous and discrete components. Irrespective of the properties of the sequences a_n, b_n, c_n, and ε_n, the generalized TH-SS signal $s(t)$ is wide sense cyclostationary (WSCS).

Clocked time hopping by a random sequence (CTHRS) arises from considering a digitally TH-SS signal which produces random transmissions at multiples of the basic clock period T_c,

$$s_{CTHRS} = \sum_{n=-\infty}^{\infty} a_n w(t - nT_c - \varepsilon_n) \qquad (15)$$

where a_n is an unbalanced binary independent identically distributed (i.i.d) random sequence with

$$P_r(a_n) = \begin{cases} p & \text{for} \quad a_n = 1 \\ 1 - p & \text{for} \quad a_n = 0 \end{cases} \qquad (16)$$

framed time hopping by random sequence (FTHRS) arises for the requirement by some time-hopping systems for somewhat regular spacing between pulses, in addition to clocked time locations. The FTHRS signal is modelled as:

$$s_{FTHRS}(t) = \sum_{n=-\infty}^{\infty} w(t - nT_f - b_n T_c - \varepsilon_n) \qquad (17)$$

where T_f is a frame time or average pulse repetition time, and b_n is an integer valued i.i.d. random time-hopping sequence, with:

$$P_r(b_n = m) = \begin{cases} p_m & \text{for} \quad 0 \le N_h \\ 0 & \text{for} \quad \text{otherwise} \end{cases} \qquad (18)$$

The value of the sequence elements are in the range:

$$0 \le b_n < N_h \qquad (19)$$

such that:

$$N_h T_c < T_f \qquad (20)$$

The p_m in equation (18) is a factor, $0 < p_m \le 1$, that can be chosen to study its effect on the shape of the PSD. Thus, the number of possible hop times, N_h, can be any number from 1 for a regular pulse train with pulses spaced T_f apart, to T_f/T_c, i.e., one pulse at any randomly selected clock time within each frame of T_f seconds.

FTHRS removes power from the continuous spectrum by a factor depending on, p_m, but that this factor reappears in the discrete spectrum. Shaping the PSD by choosing, p_m, will not significantly affect the interference in a given frequency band on the order of $1/T_f$ or more in width.

For FTHRPS, the b_n, in equation (17) contains N_p^b i.i.d. random variables. In the absence of timing jitter, the continuous PSD completely disappears regardless of the choice of, p_m, indicating that timing jitter helps to smooth the spectrum.

The FTHPPS arises in multiple access applications for which a previously agreed upon time-hopping sequence is provided to the transmitter and receiver. In this case, the selection of the transmission time in each frame is deterministic. The signal for this case is modelled by:

$$s_{FTHPPS}(t) = \sum_{n=-\infty}^{\infty} w(t - nT_f - c_n T_c - \varepsilon_n) \tag{21}$$

where c_n is a pseudorandomly generated, deterministic periodic sequence, with integer values in the range:

$$0 \le c_n < N_h \tag{22}$$

The period of the pseudorandom sequence is denoted by N_p^c, and therefore the period T_p^c of the transmitted signal is $T_p^c = N_p^c T_f$.

3 Effects of pulse shapes on the PSD of UWB signals

Certain pulse shapes allow for better control of the frequency content of the radiated UWB emission, which can offer better coexistence with radiocommunication systems. Simpler pulse shapes have desirable higher fractional bandwidths, resulting in greater spreading of the UWB spectrum and less interference into narrowband and wideband systems.

Biphase (BPM) and hybrid modulated schemes have only continuous spectra, but the PPM modulated UWB signals always have discrete spectra that can cause interference. The PSD is highly dependent on the impulse train to be modulated. The direct sequence modulated impulse train can result in smoother and lower PSD levels than a time-hopping sequence. The use of hybrid modulation can avoid forming discrete spectra. The interference caused by PPM signals can be reduced by increasing the period of the impulse train.

Pulse shapes that have been proposed or used for UWB communication system include: a Gaussian biphase monocycle that is similar to the first derivative of the Gaussian function for use in PPM, the biphase monocycle, a doublet, and a burst carrier wave which is a number of cycles of a sine wave within an envelope that is a half cycle of a sine wave, both positive and negative, i.e., the negative half cycle is the mirror image of the positive half cycle. It is fundamental that pulse shapes for UWB communications must have a zero mean so that the frequency spectrum is zero at zero frequency and allow the signal to radiate effectively.

Some time modulated ultra-wideband (TM-UWB) signals use a monocycle that is mathematically similar to the first derivative of the Gaussian function or its negative. Its centre frequency and the bandwidth depend only on the monocycle's width. In the time domain this monocycle is given by:

$$V(t) = 6A\sqrt{\frac{e\pi}{3}\frac{t}{\tau}}\exp\left(-6\pi\left(\frac{t}{\tau}\right)^2\right) \tag{23}$$

where:

- A: equals the peak amplitude of the monocycle
- τ: time decay constant that determines the monocycle’s duration
- t: time
- e: Naperian or natural base of logarithms.

In the frequency domain, the spectrum of the monocycle of equation (23) is given by the Fourier transform as:

$$V(f) = -j\frac{2f\tau^2}{3}\sqrt{\frac{e\pi}{2}}\exp\left(\frac{\pi}{6}f^2\tau^2\right) \tag{24}$$

The centre frequency is given by:

$$f_c = 1/\tau \tag{25}$$

and the half power bandwidth is 116% of its centre frequency.

Multiple monocycles are usually coherently summed at the receiver to recover the transmitted bit. PPM is implemented by varying the interval between pulses on a pulse-by-pulse basis according to the data being modulated, and according to an additional shift governed by a pseudorandom channel code that provides channelization. A regularly spaced set of TM-UWB monocycles, equation (23), in the time domain results in a regularly spaced set of pulses superposed on an envelope that is given by the frequency domain representation of the time domain pulse shape, equation (24), and produces energy spikes, or “comb lines” at regular intervals in the frequency spectrum, that might interfere with conventional radio systems at very short ranges. Varying the pulse-to-pulse time intervals using a PN sequence removes the periodicity and hence eliminates these comb lines. This also accomplishes data modulation and channelization.

A Gaussian monocycle and its negative are also used to represent binary symbols and called a biphase monocycle. Biphase pulses are not spiky in the time domain nor in the frequency domain because they transmit information as a representation of a sequence of binary digits. Since the sequence of biphase monocycles carries information, this sequence must result in a continuous PSD. In contrast, PPM results in large gaps in the time domain that carry no information, so the resulting PSD, without randomization, is spiky.

A pair of separated narrow Gaussian shaped pulses, a positive pulse followed by a negative pulse, or vice versa, called a doublet, is also used. With a doublet are the choices of the time separation between pulses in the doublet and the time separation between doublets. The autocorrelation of a data sequence encoded using doublets has a central peak bracketed by two negative peaks. This pattern is easier to recognize than a single peak, particularly when the signal is highly contaminated with noise.

Pulse shapes that are successively higher derivatives of a Gaussian pulse shape have successively lower fractional bandwidths. A pulse that looks like a number of cycles of RF carrier inside a sinusoidal envelope of half a sine wave of much lower frequency and its mirror image in the time axis can also be used. One important feature that this pulse has is a distinct centre frequency. This, combined with manipulation of the waveform envelope, allows for better control of frequency content. This “ringing” pulse typically has a bandwidth of about 400 MHz.

The time-domain representation of the Gaussian monopulse is:

$$P_G(t;\sigma) = [1 - \sigma(t/\sigma)^2]\exp(-t^2/(2\sigma^2))/2\pi\sigma^2)]^{1/2} \tag{26}$$

where σ is a temporal width parameter, and its frequency spectrum is:

$$P_G(f;\sigma) = (2\pi\,\sigma\,f)^2\left[\exp(-2\pi\,\sigma\,f)^2/2\right] \tag{27}$$

The time-domain representation of the Rayleigh monopulse (same as the Gaussian monopulse in equation (23)) is:

$$P_R(t;\sigma) = t/\sigma^2[\exp(-t^2/(2\sigma^2))], \tag{28}$$

and its frequency spectrum is:

$$P_R(t;\sigma) = j(2\pi)^{1/2}(2\pi\sigma f)[\exp(-(2\pi\sigma f)^2)/2] \tag{29}$$

The temporal representations of the Laplacian and cubic monopulses are, respectively:

$$p_L(t;\sigma) = 1/(2\sigma)[1-(t/\sigma)^2]\exp(-2\pi\sigma f)^2)/2] \tag{30}$$

and

$$p_c(t;\sigma) = (t^3/\sigma^4)\exp(-t^2(2\sigma^2)) \tag{31}$$

By studying the power spectral densities of *M*-ary PAM in which temporal diversity is introduced by repeating a Gaussian monopulse waveshape, it is found that the nulls are down at least 30 dB, leaving the potential for a frequency division multiplexed (FDM) signal whose peaks correspond to the nulls. Such a scheme can be superimposed on the temporally orthogonal method of doubling the data rate to further increase the data rate.

DSP linear FIR filters can also be used to shape the PSD to comply with a specific emission mask. This design method enables the precise design of transmit and receive filters that satisfy specific emission mask requirements and minimize the error in reception of the signal.

4 Summary of analytical studies

In the tables presented in this section, the column "UWB e.i.r.p. density (dBm/MHz)" refers to the maximum average e.i.r.p. density limit for a single device using UWB technology. These e.i.r.p. density limits are derived for the given methodology, *I*/*N* protection criteria, activity factor, victim system characteristics, UWB characteristics, interference and deployment scenarios, and other assumptions. Details of relevant studies are given in the Annexes to this Report as listed in column 1.

These results are influenced by the methodology of interference analysis, propagation model, indoor/outdoor deployment, density of devices using UWB technology, UWB activity factor, distribution of UWB emitters, assumptions about wall/roof attenuation, antenna cable loss, difference between interferer(s) and victim receiver bandwidth, UWB pulse repetition frequency (PRF), dithered/non-dithered UWB signal, UWB e.i.r.p. density, and range of input parameters (receive antenna gain, azimuth and elevation angle, antenna height).

Users of these results should note that they were based on the methodologies, interference scenarios, assumptions, and parameters listed. In particular, it should be noted that most studies assumed that emissions from devices using UWB technology behave like additive white gaussian noise (AWGN), which is recognized to offer a worst-case approximation of UWB behaviour with respect to victim radiocommunication services. In most cases, no account was made for bandwidth differences between the device(s) using UWB technology and the victim receiver, pulse repetition frequency (PRF) of the UWB signal, and whether the UWB signal is dithered or non-dithered.

The following summaries are based on currently available data on the UWB technical characteristics and propagation models, bearing in mind that no specific mitigation techniques for UWB applications were taken into account as they are still under development.

4.1 Impact of UWB on the mobile, radiodetermination, amateur and related services

4.1.1 Land mobile services except IMT-2000

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Protection criteria used in study	Interference scenario	UWB e.i.r.p. density (dBm/MHz) or separation distance	Comments
Annex 1, § 1.2	Land mobile services except IMT-2000 (GSM 900 downlink)	925-960 MHz/ 880-915 MHz	GSM handset Bandwidth = 200 kHz Noise floor = −120 dBm Sensitivity = −90 dBm Omnidirectional antenna (0 dBi)	*I*/*N*= 9 dB	Aggregate interference with victim surrounded by UWB interferer R_{min} = 1 m	−75	Mass deployment of UWB devices does not cause disruption to the GSM 900 systems under these conditions. Results are for 950 000 active device/km^2 (outdoor) or 1 500 000 active devices/km^2 (indoor)[(1)]
Annex 1, § 1.1.2	Land mobile services except IMT-2000 (IS-95 CDMA)	1 930-1 990 MHz/ 1 850-1 910 MHz 1 840-1 870 MHz/ 1 750-1 780 MHz	Frequency 1 900 MHz Receiver bandwidth = 1.23 MHz NF = 8 dB Rx antenna gain = 0 dBi Rx cable loss = 2 dB	*I*/*N* = −6 dB	Single interferer 1 m separation Free space path loss Link budget analysis	−73	Test results satisfy FER below 0.5% at desired signal level −100 dBm/ 1.23 MHz[(2)]
Annex 1, § 1.1.1	Land mobile services except IMT-2000 (IS-95 CDMA)	1 930-1 990 MHz/ 1 850-1 910 MHz	Receiver bandwidth = 1.23 MHz NF = 8 dB Handset cable loss = 0 dB Rx noise = −105 dBm	1.5% blocking probability	Aggregate 1 in 10 devices have UWB at 1 m Propagation = $1/r^{3.5}$	−73	[(1), (2)]
Annex 1, § 1.5	Land mobile services except IMT-2000 (IS-95 CDMA)	869-894 MHz/ 824-849 MHz	Receiver bandwidth = 1.23 MHz Commercial terminals	*I*/*N* = −6	Single impulse interferer with centre frequency = 4.7 GHz, bandwidth = 3.5 GHz and PRF = 9.6 MHz Free space path-loss 1.0 m separation	−80	Test results satisfy frame-error-rate (FER) below 0.5% at desired signal level −104 dBm/ 1.23 MHz [(2)]

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Protection criteria used in study	Interference scenario	UWB e.i.r.p. density (dBm/MHz) or separation distance	Comments
Annex 1, § 1.5 (*cont.*)	Land mobile services except IMT-2000 (IS-95 CDMA)	869-894 MHz/ 824-849 MHz		0.4 dB degradation, $I/N = -10$ dB	Single interferer, 36 cm separation	−92.7	Based on CDMA2000 1x frequency scaling(2)
	Land mobile services except IMT-2000 (IS-95 CDMA)	1 930-1 990 MHz/ 1 850-1 910 MHz		0.4 dB degradation, $I/N = -10$ dB	Single interferer, 36 cm separation	−85.8	Based on CDMA2000 1x frequency scaling (2)
Annex 1, § 1.4	Land mobile services except IMT-2000 (WiBro OFDM)	2 300-2 400 MHz	Receiver bandwidth = 9 MHz NF = 7 dB Receiver antenna gain = 0 dBi	1 dB degradation, $I/N = -6$ dB	Single interferer, 36 cm separation Indoor path loss Link budget analysis	−76.9	(2)
Annex 1, § 1.3	LM services except IMT-2000 IS-95/IS-136 PCS 1800 DCS 1900	1 805-1 880 MHz/ 1 930-1 990 MHz	Receiver bandwidth (MHz): IS-95 = 1.25, IS-136 = 0.03, PCS/DCS = 0.2	Interference threshold (dBm): IS-95 = −110 IS-136 = −126 PCS/DCS = −117	Single interferer with indoor emission limits. Free space path loss for 2 m then $1/r^4$	Minimum separation distance 1.8 m to 2.4 m.	(2)

(1) Results assume each device using UWB technology to be active simultaneously. In reality devices using UWB technology may not transmit continuously.

(2) These studies assume that the device using UWB technology transmits continuously. In reality devices using UWB technology may not transmit continuously.

GSM 900 MHz downlink

The interference resulting from the United States emission mask would not result in harmful interference.

CDMA PCS system in the band 1 850-1 990 MHz

This study has provided results showing the increase of blocking probabilities when a CDMA system is in proximity to a device using UWB technology. The study can be used to determine adequate UWB e.i.r.p. density from a device using UWB technology given an acceptable increase to the CDMA blocking probability.

PCS CDMA system in the band 1 805 MHz, 1 880 MHz, 1 930 MHz and 1 990 MHz

The results showed that mobile terminals are impacted, when there is a separation distance of less than 1.8 m-2.4 m between a single active UWB PAN device and an active land-mobile terminal.

WiBro service in the band 2 300-2 400 MHz

The required isolation and minimum separation distance that the UWB device should not give interference to victim service were obtained by applying minimum coupling loss (MCL) approach. The separation distance of 36 cm and 1 m are taken as reference distance between interferer and victim in considering indoor circumstances. The tolerable e.i.r.p. density limit of UWB device is calculated according to the protection criteria of I_{UWB}/N at reference distance.

CDMA system in the band 824-849 MHz, 869-894 MHz

The interference measurement between an impulse UWB signal and a cellular CDMA terminal below 1 GHz, is used in one of the representative mobile communication systems. An Impulse UWB signal with 4.7 GHz centre frequency at 1 m distance and –80 dBm/MHz emission level do not affect the receiver sensitivity following the standard for cellular CDMA. However, this level may be increased if a weak signal area in the general service network is assumed. It means a sector power level of –100 dBm at the cell boundary.

CDMA system in the band 1 750-1 780/1 840-1 870 MHz, and 1 850-1 910/1 930-1990 MHz

The power that caused the FER to deviate from its steady state value was noted as the maximum permissible interference power or interference threshold, I_t, which was found to be –110.9 dBm/MHz at a CDMA input power of –100.9 dBm/MHz. For a protection distance of 1 m, the path loss is 38 dB and the maximum allowed UWB e.i.r.p. is calculated to be –73 dBm/MHz.

With the proliferation of devices using UWB technology, collocation with PCS devices will become increasingly likely. While this study was limited to the impact of a single device using UWB technology on a PCS phone, it is expected that large numbers of UWB interference sources will significantly raise the overall noise floor of wireless receivers. This noise floor has a significant effect on wireless communications system range. Operation of UWB in the PCS bands will therefore have impact on the normal operation of PCS wireless devices in both voice and data modes. In fact, close proximity of a device using UWB technology to a PCS phone operating in the 1 750-1 780/1 840-1 870 MHz and 1 850-1 910/1 930-1 990 MHz range, may degrade the phone's equivalent noise floor.

4.1.2 Maritime mobile service

In all maritime mobile service below, the integral methodology was used with a receiver antenna height = 15 m, antenna gain = 0 dBi, antenna cable loss = 0 dB, and active UWB device density = 50/km^2.

For each of the bands under consideration the worst-case value has been reported in the Table. Where more than one receiver operates within a band, the values for the additional receivers are available in Annex 1, § 1.2 to this Report.

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Service protection criteria used in study	Interference scenario	UWB e.i.r.p. density (dBm/MHz)	Comments
Annex 1 § 1.2	Maritime Loran C	90-110 kHz	Rx bandwidth = 20 kHz	*S*/*I* = 10 dB + 6 dB for multi-system interference	Aggregate (50 active UWB/km^2). Free space path loss	−48.9	(1)
	Maritime DGNSS	285-325 kHz	Rx bandwidth = 0.5 kHz	*S*/*I* = 10 dB + 6 dB for multi-system interference	Aggregate (50 active UWB/km^2). Free space path loss	−44.9	(1)
	Maritime NAVTEX	490-518 kHz	Rx bandwidth = 0.27 kHz	*S*/*I* = 10 dB + 6 dB for multi-system interference	Aggregate (50 active UWB/km^2). Free space path loss	−12.2	(1)
	Maritime MF radiotelegraphy	1.6-3.8 MHz	Rx bandwidth = 3 kHz	*S*/*I* = 10 dB + 6 dB for multi-system interference	Aggregate (50 active UWB/km^2). Free space path loss	−38.7	(1)
	Maritime HF radiotelegraphy	4-27.5 MHz	Rx bandwidth = 3 kHz	*S*/*I* = 10 dB + 6 dB for multi-system interference	Aggregate (50 active UWB/km^2). Free space path loss	−38.7	(1)
	Maritime VHF DSC/ radiotelegraphy	156-163 MHz	Rx bandwidth = 25 kHz	*S*/*I* = 10 dB + 6 dB for multi-system interference	Aggregate (50 active UWB/km^2). Free space path loss	−62.1	(1)
	Maritime UHF radiotelegraphy	457-467 MHz	Rx bandwidth = 12.5 kHz	*S*/*I* = 10 dB + 6 dB for multi-system interference	Aggregate (50 active UWB/km^2). Free space path loss	−44.1	(1)
	Maritime primary radar	2 900-3 100 MHz	Rx bandwidth = 20 MHz	*I*/*N* = −10 dB + 6 dB for multi-system interference	Single interferer, 300 m separation. Free space path loss.	−52.5	(2)

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Service protection criteria used in study	Interference scenario	UWB e.i.r.p. density (dBm/MHz)	Comments
Annex 1 § 1.2 (*cont.*)	Maritime primary radar/search and rescue radar transponder	9 200-9 500 MHz	Rx bandwidth = 20 MHz	I/N = −10 dB + 6 dB for multi-system interference	Single interferer, 300 m separation. Free space path loss	−42.6	(2)

(1) Results assume all devices using UWB technology to be active simultaneously.

(2) The device using UWB technology transmits continuously i.e. 100% activity factor.

For the case of UWB devices carried on board a ship, the most sensitive communication system is the VHF which requires a UWB e.i.r.p. limited to –75 dBm/MHz at 158 MHz. This is less than the US limit of –41.3 dBm/MHz but should be readily achievable by slope mask proposals so there does not appear to be a problem to ship communication systems from UWB devices on board. In the case of navigation systems, the S band radar requires a limit of –82 dBm/MHz at 3 000 MHz and the X band radar requires –72 dBm/MHz at 9 400 MHz. These limits are unlikely to be achievable so preclude the use of UWB devices on board pending further study of the actual effect on ships radars.

For the case of UWB devices on shore, the e.i.r.p. limit at VHF is –45 dBm/MHz and a limit of –72 dBm/MHz is required for an aggregate interference in the urban case of 10 000 devices/km^2. Again therefore there does not appear to be a problem to ship communication systems assuming a slope mask. For the radar systems, the limits are –53 dBm/MHz for S band and –43 dBm/MHz at X band. These limits are not exceeded for aggregate interference until the density exceeds the suburban case. It is very unlikely that ships will be relying on radar systems in situations of such high density of UWB devices so the single interferer is the dominant mechanism. Compared with the US limit of –41.3 dBm/MHz therefore, the X band requirement is marginal and the S band is exceeded by 11 dB. This extra loss can be achieved by increasing the assumed separation distance of 300 m to about a kilometre. In many situations this may be acceptable, although the physical locations where this shore based interference might arise are subject to further study.

For the case of shore/port stations, the effect on communication receivers is similar to the ship case so there should not be a problem assuming a slope mask. In the case of shore based radar systems associated with vessel traffic services, these radars look out to sea and are sector blanked when scanning over the shore so they may not be as affected by UWB devices as the ship case.

4.1.3 Aeronautical service

For each of the bands under consideration the worst-case value has been reported in the table for the indicative model. Where more than one receiver operates within a band, the values for the additional receivers are available in Annex 1, § 3 to this Report.

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Service protection criteria used in study	Interference scenario	UWB e.i.r.p. density (dBm/MHz)	Comments
Annex 1, § 3	Aeronautical NDB/Locator	190-535 kHz	Signal level > 35 dBm. Receiver antenna gain = 0 dBi	*S*/*I* = 15 dB + Aeronautical safety factor = 6 dB and 6 dB multiple interference source factor	Aggregate (50 active UWB/km^2). Outdoor/indoor = 20/80%. Uniform distribution. Airborne methodology. Free space path loss	−44.5	Airborne receiver (1)
	Aeronautical marker beacon	74.8-75.2 MHz	Receiver antenna gain = 0 dBi	*S*/*I* = 20 dB + Aeronautical safety factor = 6 dB and 6 dB multiple interference source factor	Aggregate (50 active UWB/km^2) Outdoor/indoor = 20/80%. Uniform distribution. Airborne methodology. Free space path loss	−25.8	(1)
	Aeronautical ILS localizer	108-117.975 MHz	Receiver antenna gain = 0 dBi	*S*/*I* = 20 dB + Aeronautical safety factor = 6 dB and 6 dB multiple interference source factor	Aggregate (50 active UWB/km^2) Outdoor/indoor = 20/80%. Uniform distribution. Airborne methodology. Free space path loss	−61.3	(1)
	Aeronautical ILS localizer	108-117.975 MHz	$I < -164.3$ dBW/MHz. Receiver antenna gain = 0 dBi	CW Interference threshold which takes into account the aeronautical safety factor of 6 dB as well as the multiple interference source factor of 10 dB and *S*/*I* = 46 dB	Aggregate (100 active UWB/km^2) Uniform distribution. Free space path loss	−97.3	From specific ILS study contained in Annex 1 § 3.2.1.1(1)

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Service protection criteria used in study	Interference scenario	UWB e.i.r.p. density (dBm/MHz)	Comments
Annex 1, § 3 (*cont.*)	Aeronautical air-ground and air-air communications	117.975-137 MHz	Receiver antenna gain = 0 dBi	S/I = 20 dB + Aeronautical safety factor = 6 dB and 6 dB multiple interference source factor	Single interferer 30 m separation. Free space path loss	−63.9	(1)
	Aeronautical emergency frequencies	121.5, 123.1 and 243 MHz	Receiver antenna gain = 0 dBi	S/I = 20 dB + Aeronautical safety factor = 6 dB and 6 dB multiple interference source factor	Single interferer 30 m separation. Free space path loss	−63.9	(1)
	Aeronautical ILS glide path	328.6-335.4 MHz	Receiver antenna gain = 0 dBi	S/I = 20 dB + Aeronautical safety factor = 6 dB and 6 dB multiple interference source factor	Aggregate (50 active UWB/km^2) Outdoor/indoor = 20/80 %. Uniform distribution. Airborne methodology. Free space path loss	−46.5	(1)
	Aeronautical primary radar	590-598 MHz	Receiver antenna gain = 28 dBi	I/N = −6 dB + Aeronautical safety factor = 6 dB and 6 dB multiple interference source factor	Single interferer, 400 m separation. Free space path loss	−75.1	(2)
	Aeronautical DME/TACAN	960-1 215 MHz	Receiver antenna gain = 0 dBi	S/I = 8 dB + Aeronautical safety factor = 6 dB and 6 dB multiple interference source factor	Single interferer, 5 m separation. Free space path loss	−76.8	
	Aeronautical DME/TACAN	960-1 215 MHz	I < −145 dBW/MHz. Receiver antenna gain = 0 dBi	CW Interference threshold which takes into account the aeronautical safety factor of 6 dB as well as the multiple interference source factor of 10 dB	Aggregate (100 active UWB/km^2) Uniform distribution. Free space path loss	−58.0	(2)

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Service protection criteria used in study	Interference scenario	UWB e.i.r.p. density (dBm/MHz)	Comments
Annex 1, § 3 (*cont.*)	Aeronautical primary radar	1 215-1 400 MHz	Receiver antenna gain = 38.9 dBi	$I/N = -6$ dB + Aeronautical safety factor = 6 dB and 6 dB multiple interference source factor	Single interferer, 400 m separation. Free space path loss	−80.3	
	Aeronautical primary surveillance radar	2 700-3 400 MHz	Receiver antenna gain = 34.3 dBi	$I/N = -10$ dB + Aeronautical safety factor = 6 dB and 6 dB multiple interference source factor	Single interferer, 170 m separation. Free space path loss	−79.9	
	Aeronautical radio altimeter	4 200-4 400 MHz	Receiver antenna gain = 0 dBi	$S/I = 6$ dB + Aeronautical safety factor = 6 dB and 6 dB multiple interference source factor.	Aggregate (50 active UWB/km^2). Outdoor/indoor = 20/80%. Uniform distribution. Airborne methodology. Free space path loss	−48.7	
	Aeronautical MLS	5 030-5 150 MHz	Receiver antenna gain = 0 dBi	$S/I = 25$ dB + Aeronautical safety factor = 6 dB and 6 dB multiple interference source factor	Aggregate (50 active UWB/km^2). Outdoor/indoor = 20/80%. Uniform distribution. Airborne methodology. Free space path loss	−44.7	
	Aeronautical precision approach radar	9 000-9 500 MHz	Receiver antenna gain = 38 dBi	$I/N = -6$ dB + Aeronautical safety factor = 6 dB and 6 dB multiple interference source factor	Single interferer, 20 m separation Free space path loss	−87.2	

(1) Results assume all devices using UWB technology to be active simultaneously.

(2) The device using UWB technology transmits continuously i.e. 100% activity factor.

NOTE 1 – Caution must be exercised with respect to the application of the UWB e.i.r.p. density limits given for aeronautical services in the table. These limits may not necessarily be sufficient to provide adequate protection to aeronautical radio services.

Generally aeronautical services operating under the aeronautical mobile (R) and aeronautical radio navigation allocations are regarded as safety of life services. Provision No. 4.10 of the Radio Regulations (RR) recognizes that radionavigation and other safety services require special measures to ensure freedom from harmful interference and that it is necessary to take this factor into account in the assignment and use of frequencies.

Whilst the only method of ensuring that the appropriate level of protection is provided is to carry out practical testing, a lack of availability of UWB devices for testing with aeronautical systems has prevented this from occurring. As actual protection margins have not been measured, the results of the studies contained in this report should not be seen as definitive, but are indicative figures based on theoretical calculation, ITU-R Recommendations and accepted international intra-system protection criteria. Caution must be exercised with respect to the application of the UWB e.i.r.p. density limits given in the tables above, because these limits may not be sufficient to provide adequate protection for the aeronautical radio services.

For all aeronautical systems except aeronautical radar, the effect of multiple UWB interferers will dominate that of a single interferer. Under the condition that the power contributions of all UWB devices can be added arithmetically and further assuming a UWB density of 1000 units/km^2 with a 5% activity factor (50 active devices/km^2) the maximum tolerable e.i.r.p. emission limit of a single UWB device should be as follows:

– below 3.1 GHz –92.5 dBm/MHz

– 3.1-10.6 GHz –87.2 dBm/MHz

– above 10.6 GHz unknown.

Based on the theoretical calculations performed in this study, the masks proposed do not meet the levels required to protect aeronautical systems from harmful interference.

4.1.4 IMT-2000

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Protection criteria used in study	Interference scenario	UWB e.i.r.p density (dBm/MHz) or separation distance	Comments
Annex 1, § 4	IMT-2000	1 710-1 885 MHz		I/N = −6 dB	Single interferer, 36 cm separation	−86.4	Mobile station receiver(1)
	IMT-2000	1 885-2 025 MHz		I/N = −6 dB	Single interferer, 36 cm separation	−85.9	Mobile station receiver(1)
	IMT-2000	2 110-2 170 MHz		I/N = −6 dB	Single interferer, 36 cm separation	−85	Mobile station receiver(1)
	IMT-2000	2 500-2 690 MHz		I/N = −6 dB	Single interferer, 36 cm separation	−83.1	Mobile station receiver(1)
Annex 1, § 4.7.1.1.1	IMT-2000 (CDMA-2000 (1X and 3X), TD-CDMA, W-CDMA, TD-SCDMA, DECT, UWC-136 TDMA).	1 710-1 885 MHz 1 885-2 025 MHz 2 110-2 170 MHz 2 500-2 690 MHz	Receiver antenna gain = 0 dBi Mobile station NF = 9 dB in thermal noise −101 dBm (DECT), −104 dBm (UWC-136 TDMA) to −105 dBm (rest of systems)	I/N = −6 dB	Single interferer 20 cm separation. Link budget. Free space path loss	−80 to −87.5	Mobile station receiver(1)
Annex 1, § 4.7.1.1.2	IMT-2000 IMT-DS (WCDMA)	2 110-2 170 MHz	Rx antenna gain = 16 dBi Feeder loss = 2 dB Head penetration loss = 0 to 3 dB NF = 5 dB	BLER target	Single interferer with data rates 100 to 250 Mbits/s, Methodology = link budget Worst-case indoor IMT-2000 at the edge of an urban cell	No impact at −115 Some degradation at −105 Service failure for CS144 and Voice 12.2 at −85	Mobile station receiver(1)
Annex 1, § 4.7.1.2	IMT-2000 HSDPA (WCDMA)	2 110-2 170 MHz	Head penetration loss = 0 to 3 dB NF = 5 dB G factor = 5 dB	No criterion for capacity and 1% throughput degradation	Aggregate with data rates 100 to 250 Mbits/s, Methodology = link budget Worst-case indoor IMT-2000 at the edge of an urban cell	Minimum separation = 2 m at −65	Mobile station receiver(1)

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Protection criteria used in study	Interference scenario	UWB e.i.r.p density (dBm/MHz) or separation distance	Comments
Annex 1, § 4.7.2	IMT-2000 IMT-DS (WCDMA)	2 110-2 170 MHz	Rx antenna Gain = 18 dBi Head penetration loss = 0 to 3 dB *NF* = 4 dB	No criterion. For single interferer	Single interferer with data rates 100 to 250 Mbits/s, UWB at *h* = 1.5 m. Methodology = link budget Aggregate Randomly distributed UWB with *h* = 0 to 30 m. 100% activity factor. Outdoor urban deployment. UWB density 10 100 000 device/km^2	No capacity reduction and marginal (~ 2%) cell range reduction, −64.7	Base station receiver at 30 m height
			Rx antenna gain = 18 dBi. Head penetration loss = 0 to 3 dB. *NF* = 3 dB	For aggregate: $I_{UWB} < I_{UWBMax}$ = 1% (I_{UWBMax} is for 1% base station density)	Aggregate Randomly distributed UWB with *h* = 0 to 30 m 100% activity factor. Outdoor urban deployment. UWB density 10-100 000 device/km^2. No devices within 30 m	−52.4 to −87 for 10 UWB/km^2 to 100 000 indoor UWB devices/km^2, respectively	Base station receiver at 35 m height(2)
Annex 1, § 4.7.3.1	IMT-2000 IMT-DS (WCDMA)	2 GHz	Head penetration loss = 0 to 3 dB *NF* = 9 dB	% reduction in calls	Aggregate Randomly distributed UWB 1 000 UWB device/km^2. Monte Carlo methodology. Propagation: $1/r^2$ for LoS and $d \leq \lambda$, and $1/r^{3.5}$ for non-LoS and $d > \lambda$ 10 dB wall loss	For −70, call drop rate = 0.085% for 1 000 UWB/km^2 and 0.06% at −60. For −70, call drop rate = 1% for 1 000 UWB/km^2 and 5% at −60, for 10 000 UWB/km^2	Mobile station receiver at 1.5 m height. Base station receiver at 6 m, 15 m, and 20 m height

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Protection criteria used in study	Interference scenario	UWB e.i.r.p density (dBm/MHz) or separation distance	Comments
Annex 1, § 4.7.3.2	IMT-2000 IMT-2000 CDMA direct spread	2 GHz	Feeder loss = 2.5 dB *NF* = 6.6 dB	No criterion	Aggregate. Office hot-spot scenario Monte-Carlo methodology. UWB centre frequency at 4 GHz, and UWB bandwidth = 1.8 GHz. Propagation: $1/r^2$	For −65 and a coupling loss = 20 dB, the minimum separation distance between UWB and MS = 0.1 m	Mobile station (MS) receiver

(1) The device using UWB technology transmits continuously i.e. 100% activity factor.

(2) Results assume all devices using UWB technology are active simultaneously.

4.1.5 Wireless access systems including RLANs

Some of the studies used single interferer, the remaining studies used the "integral methodology" and defined an additional factor called the aggregation factor to take into account the effect of multiple devices, the average activity factor and the victim immunity factor.

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Protection criteria used in study	Interference scenario	UWB e.i.r.p. density (dBm/MHz) or minimum separation distance	Comments
Annex 1, § 5	WAS/RLANs IEEE 802.11a	5 150-5 350 MHz	≤5 dB implementation loss and ≤10 dB receiver noise figure	Single *I*/*N* degradation = 1 dB *I*/*N* = −6 dB	Single interferer. Propagation: $1/r^2$ for the first 5 m then $1/r^4$. UWB-free zone = 1 m	−41.3 Separation distance = 5.8 m	(1)
	WAS/RLAN	5 470-5 725 MHz		1 dB degradation, *I*/*N* = −6 dB	Single interferer, 36 cm separation	−66	
	WAS/RLAN IEEE 802.11b	2 400-2 483 MHz	Receiver sensitivity −84 to −93 dBm. Implementation loss + receiver noise figure = 10 dB	Single *I*/*N* degradation = 1 dB, *I*/*N* = −6 dB	Single interferer. Propagation: $1/r^2$ for the first 5 m then $1/r^4$. UWB-free zone = 1 m	For indoor 5.9 m at −51.3. For outdoor 2.2 m at −61.3. For indoor 2.3 m at −50.6 dBm/ 11 MHz. For outdoor 0.7 m at −60.6 dBm/ 11 MHz	(1)

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Protection criteria used in study	Interference scenario	UWB e.i.r.p. density (dBm/MHz) or minimum separation distance	Comments
Annex 1, § 5 (*cont.*)	WAS/RLAN IEEE 802.11a	5 150-5 350 MHz	≤5 dB implementation loss and ≤10 dB receiver noise figure	Single *I*/*N* degradation of 1 dB	Aggregate: 0.2 UWB transmitters/m^2. Propagation: 1/r^2 for the first 5 m then 1/r^4. Integral methodology. UWB-free zone = 1 m	−59.3 for an aggregation factor = 0.5 −48.3 for an aggregation factor = 0.04	
	WAS/RLAN IEEE 802.11b	2 400-2 483 MHz	Receiver sensitivity −84 to −93 dBm. Implementation loss + receiver noise figure = 10 dB	Single *I*/*N* degradation of 1 dB	Aggregate: 0.2 UWB uniformly distributed transmitters/m^2. Propagation: 1/r^2 for the first 5 m then 1/r^4. Integral methodology. UWB-free zone = 1 m	−71.1 for an aggregation factor = 0.5 −60.1 for an aggregation factor = 0.04	
Annex 1, § 5.5	WAS/RLAN IEEE 802.11a	5 150-5 350 MHz	≤5 dB implementation loss and ≤10 dB receiver noise figure. Receiver sensitivity for IEEE802.11a = −65 to −82 dBm. Omnidirectional antenna *G* = 0 dBi	10% FER	Single interferer. Indoor deployment. Minimum coupling loss method. Propagation-A: 1/r^2 for the first 5 m then 1/r^4. Propagation-B: Rec. ITU-R P.1238	−41.3 Propagation-A: At MUS +10 dB, *d* = 1.13 to 1.79 m At MUS, *d* = 3.58 to 5.67 m. Propagation-B: At MUS +10 dB, *d* = 1.12 to 1.5 m At MUS, *d* = 2.34 to 3.16 m	Tests to measure *C*/*I* then the minimum separation distance is calculated at the minimum usable sensitivity (MUS) level(1)

(1) The device using UWB technology transmits continuously i.e. 100% activity factor.

The most critical case is the WAS/RLAN terminal in the home/office environment. For a single *I*/*N* degradation of 1 dB and for the systems IEEE 802.11a in the 5 GHz range and IEEE 802.11b in the 2.4 GHz ISM-band, minimum separations up to 6 m are required. Assuming a separation distance of 36 cm, as derived for IMT-2000 and free space, the required UWB e.i.r.p. density results in –66 dBm/MHz for the 5 GHz range and –76 dBm/MHz for 2.4 GHz.

Taking into account the aggregate UWB interference and their activity and assuming an exclusive free UWB zone of about 1 m around the victim, then the required UWB e.i.r.p. density limits in the order of up to 20 dB less than the United States emission limits, which corresponds to the single interferer analysis.

4.1.6 Amateur and amateur-satellite service

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Protection criteria used in study	Interference scenario	UWB e.i.r.p. density (dBm/MHz)	Comments
Annex 1, § 6	Amateur and amateur satellite service (terrestrial and space-to-Earth satellite)	1 260-1 300 MHz	Antenna cable loss = 3 dB. Receiver noise temperature < 100 K *NF* = 1 dB Rx bandwidth = 0.4 kHz for Morse and 2.7 kHz for SSB voice. Rx antenna gain = 22 dBi on boresight	1 dB receiver degradation. *S*/*N* = 2 dB for Morse and 6 dB for SSB voice	Single interferer, 100% activity factor. Free space path loss. Minimum coupling loss method	−85.5	For on boresight, off boresight, Earth-Moon-Earth, and space-to-Earth satellite interference scenarios. Polarizations of UWB interferer and victim are different(1)
	Amateur and amateur satellite service (terrestrial and space-to-Earth satellite)	2 300-2 450 MHz	Antenna cable loss = 3 dB. Rx antenna gain = 25 dBi on boresight/0 dBi off boresight. Receiver noise temperature < 100 K *NF* = 1 dB Rx bandwidth = 0.4 kHz for Morse and 2.7 kHz for SSB voice	1 dB receiver degradation *S*/*N* = 2 dB for Morse and 6 dB for SSB voice	Single interferer. Free space path loss 100% activity factor. Minimum coupling loss method	−65	For on boresight, off boresight, Earth-Moon-Earth, and space-to-Earth satellite interference scenarios. Polarizations of UWB interferer and victim are different(1)

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Protection criteria used in study	Interference scenario	UWB e.i.r.p. density (dBm/MHz)	Comments
Annex 1, § 6 (*cont.*)	Amateur and amateur satellite service (terrestrial and space-to-Earth satellite)	3 400-3 500 MHz	Antenna cable loss = 3 dB. Rx antenna gain = 27 dBi on boresight/0 dBi off boresight. Receiver noise temperature < 100 K *NF* = 1 dB. Rx BW = 0.4 kHz for Morse and 2.7 kHz	1 dB receiver degradation *S*/*N* = 2 dB for Morse and 6 dB for SSB voice	Single interferer 100% activity factor. Free space propagation. Minimum coupling loss method	−62 for on boresight and space-to-Earth −55 for off boresight −58 for Earth-Moon-Earth	Polarizations of UWB interferer and victim are different(1)
	Amateur and amateur satellite service (terrestrial and space-to-Earth satellite)	5 650-5 850 MHz	Antenna cable loss = 3 dB. Rx antenna gain = 30 dBi on boresight/0 dBi off boresight. Receiver noise temperature < 100 K *NF* = 1 dB. Rx BW = 0.4 kHz for Morse and 2.7 kHz for SSB voice	1 dB receiver degradation *S*/*N* = 2 dB for Morse and 6 dB for SSB voice	Single interferer 100% activity factor. Free space propagation. Minimum coupling loss method	−57 for on boresight and space-to-Earth −51 for off boresight −53 for Earth-Moon-Earth	Polarizations of UWB interferer and victim are different(1)
	Amateur and amateur satellite service (terrestrial and space-to-Earth satellite)	10-10.5 GHz	Antenna cable loss = 3 dB. Rx antenna gain = 33 dBi on boresight/0 dBi off boresight. Receiver noise temperature < 100 K *NF* = 1 dB. Rx bandwidth = 0.4 kHz for Morse and 2.7 kHz for SSB voice	1 dB receiver degradation *S*/*N* = 2 dB for Morse and 6 dB for SSB voice	Single interferer 100% activity factor. Minimum coupling loss method. Free space path loss	−59 for on boresight −46 for off boresight −48 for Earth-Moon-Earth −52 for space-to-Earth	Polarizations of UWB interferer and victim are different(1)

(1) The device using UWB technology transmits continuously i.e. 100% activity factor.

The analyses suggest that the deployment of the single UWB transmitter may lead to an increase in receiver noise floor of such level as to prevent weak signal communication for both the amateur and amateur-satellite services. Mitigation techniques that reduce the effective received level of the UWB emitter at a distance of 10 m by 20 to 25 dB would appear to be required: of these, the easiest is probably installation such that domestic installation of the UWB equipment is such that wall attenuation reduces the out of building signals. In many cases, the use of vertical polarisation by the UWB systems will provide further mitigation by between 10 and 20 dB. The UWB activity factor cannot be relied upon as a mitigating factor in a suburban domestic situation if UWB is used for streaming audio or video, although in terms of aggregate effects, it is probable that the aggregation will be cancelled by the activity factor. The satellite (Earth-to-space) segment of the amateur satellite service is most unlikely to be affected by UWB.

4.1.7 Meteorological radar

Part of Report	**Service/ applications**	**Frequency bands**	**Victim station characteristics**	**Service protection requirement used in study**	**Interference scenario**	**UWB e.i.r.p. density (dBm/MHz)**	**Comments**
Annex 1, § 7	Meteorological radar	2 700-2 900 MHz	47.5 dBi antenna gain. 30 m antenna height	*I*/*N* = −10 dB Rec. ITU-R M.1464	Aggregate (1 000 active device/km^2). Free space propagation	−61.3	Study A: Representative of meteorological radars in the United States
			45.7, 43 and 39 dBi antenna gain. 7 to 21 m antenna height (13 m average)		Aggregate, suburban 50 active devices /km^2 20% outdoor, 80% indoor. Free space propagation	−71	Study B: Difference with study A relates to the antenna height and antenna gain figures that are by a large amount controlling the level of interference
	Meteorological radar	5 600-5 650 MHz	45.7 and 43 dBi antenna gain 7 to 29 m antenna height (16 m average)	*I*/*N* = −10 dB Rec. ITU-R M.1638	Aggregate, suburban 50 active devices/km^2 20% outdoor, 80% indoor. Free space propagation	−65	Study B
	Meteorological radar	9 300-9 500 MHz	33 dBi antenna gain 5 to 15 m antenna height (10 m average)	*I*/*N* = −10 dB	Aggregate, suburban 50 active devices/km^2 20% outdoor, 80% indoor. Free space propagation	−60	Study B

Even though using similar approaches, studies A and B provide different conclusions on the impact of UWB devices on meteorological radars in the 2 700-2 900 MHz frequency band. Study B concludes on the need to tighten by 10 dB the power density limits as currently regulated in the United States whereas study A, performed by the United States Administration, conclude on the adequacy of these limits to protect meteorological radars.

The main rationale to these different conclusions relates to the antenna height and antenna gain figures used in both studies and that are by a large amount controlling the level of interference. Indeed, lower figures for these two parameters lead to an increase of the relative antenna gain under which UWB devices are seen from the radar and hence to an increase of the interference level.

Study A considers a 30 m antenna height and a 45.7 dBi antenna gain that may be representative of meteorological radars in the United States but that are not representative of typical meteorological radars deployed in Europe where antenna height down to 7 m and antenna gain down to 39 dBi are deployed.

Therefore, the current power density limits as regulated in the United States may be sufficient to protect one specific type of meteorological radar as deployed in the United States but is not sufficient to protect typical meteorological radars such as those deployed in Europe that need a 10 dB tightening, as shown in the above table.

The bands 5 600-5 650 MHz and 9 300-9 500 MHz were not considered in study A since these meteorological radars are not predominantly used in the United States. It can therefore be assumed that the derivation of the United States power density limits did not considered the case of meteorological radars in the 5.6 and 9.4 GHz bands.

Study B clearly shows that there is a need for a large tightening of these United States limits to ensure the protection of meteorological radars. It is important to stress that, unlike the 2 700-2 900 MHz band, these two frequency bands are in the generic band for UWB telecommunications devices (3-10.6 GHz band) in which the United States limits are 20 dB higher than the limits in the 2.8 GHz band.

Hence, the power density limits as currently regulated in the United States are not adequate to ensure protection of meteorological radars in the 2.8 GHz, 5.6 GHz and 9.4 GHz bands such as those deployed in Europe, at the exception of the specific case of radars deployed in the United States in the 2.8 GHz with 30 m antenna height and 45.7 dBi antenna gain.

Apart from this latter case, power density limit as in the table below are necessary to adequately protect meteorological radars.

Power density limit necessary to protect meteorological radars

Frequency band (GHz)	UWB application type	Current United States power density limit (dBm/MHz)	Power density limit necessary to protect meteorological radars (dBm/MHz)
2.8	Imaging (low density)	–41.3	–51
	Telecommunication (indoor)	–51.3	–61
	Telecommunication (outdoor)	–61.3	–71
5.6	Imaging (low density)	–41.3	–51
	Telecommunication (indoor and outdoor)	–41.3	–65
9.4	Imaging (low density)	–41.3	–54
	Telecommunication (indoor and outdoor)	–41.3	–60

4.2 Impact of UWB on the fixed service

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Protection criteria used in study	Interference scenario	UWB e.i.r.p. density (dBm/MHz)	Comments
Annex 2, § 4.2	FS/P-P and P-MP/	1 000-3 000 MHz	P-P antenna gain = 41 dBi CS antenna gain = 16 dBi TS antenna gain (outdoor TS) = 16 dBi TS antenna gain (indoor omnidirectional) = 0 dBi *NF* (outdoor) = 5 dB *NF* (indoor) = 5.5 dB	Rec. ITU-R F.1094 and Radiocommunication WP 9A liaison statement (I/N = −20 dB)	See bands 3 000-6 000 MHz in next row	Same values than in bands 3 000-6 000 MHz in next row	For multiple FS sub-bands within 1-3 GHz, value extrapolated. Wideband peak protection limit in 50 MHz bandwidth was evaluated 42 dB above e.i.r.p. limit (from actual tests)
Annex 2, § 3.5.2	FS/P-MP	3 000-6 000 MHz	P-P antenna gain = 41 dBi CS antenna gain = 16 dBi TS antenna gain (outdoor TS) = 16 dBi TS antenna gain (indoor omni) = 0 dBi *NF* (outdoor) = 5 dB *NF* (indoor) = 5.5 dB	P-P, CS and outdoor TS: Rec. ITU-R F.1094 and Radiocommunication WP 9A liaison statement (I/N = −20 dB). Indoor TS Radiocommunication WP 9A liaison statement (I/N = −13 dB).	Single entry indoor fWA TS at 1 m separation without specific mitigation techniques (e.g. DAA). NOTE – This case overrides all possible aggregation scenarios	−76.5	Wide band peak protection limit in 50 MHz bandwidth was evaluated 42 dB above e.i.r.p. limit (from actual tests)
Annex 2, § 3.2.2	FS/P-P and P-MP/	3 000-6 000 MHz			Single entry to indoor FWA TS at 1 m separation with specific mitigation techniques (e.g. DAA). Single entry of a fixed UWB in LoS along boresight footprint to an outdoor P-P NOTE – This case may override all possible aggregation scenarios	–57	Wideband peak protection limit in 50 MHz bandwidth was evaluated 42 dB above e.i.r.p. limit (from actual tests)

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Protection criteria used in study	Interference scenario	UWB e.i.r.p. density (dBm/MHz)	Comments
Annex 2, § 4.1.2.2.2, § 3.3.3.4, § 4.1.2.1, § 4.1.2.2.2, § 4.1.3	FS/P-P and P-MP/	3 000-6 000 MHz			Aggregate, urban uniform distribution of UWB 10 000 device/km^2. *Case 1 study:* UWB deployment: 80% indoor and 20% outdoor. Free space propagation plus mitigation factors for NLoS portion, indoor-to-outdoor attenuation, activity at 5%. *Case 2 study:* UWB deployment: 100% indoor, 1% activity factor. IEEE802.16 NLoS propagation Monte-Carlo analysis of mixed LoS/NLoS distribution derived from probability distributions of real urban area building height and indoor-to-outdoor attenuations activity at 1%	−60 From –40 to – 48 NOTE – Depending on different confidence assumptions for the large amount of possible variants affecting the studies and the possible inclusion of a 20% population of handheld devices	Wideband peak protection limit in 50 MHz bandwidth was evaluated 42 dB above e.i.r.p. limit (from actual tests) For this scenario, no single outdoor and indoor entries are considered assuming the presence of specific mitigation techniques (e.g. DAA) or regulatory provisions (i.e. no unlicensed UWB fixed outdoor applications)

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Protection criteria used in study	Interference scenario	UWB e.i.r.p. density (dBm/MHz)	Comments
Annex 2, § 4.1.2.2.2	FS/P-P	6 000-7 125 MHz	*NF* = 6 dB P-P antenna gain = 41 dBi	Rec. ITU-R F.1094 and Radiocommunication WP 9A liaison statement ($I/N = -20$ dB)	Only aggregate, urban (10 000 UWB/km^2, 20% outdoor, 5% activity factor). See details in above bands 3 000-6 000 MHz NOTE – Case 2 not evaluated for bands above 4 GHz; however it is assumed that results are at least 6 dB more favourable	–60 (Case 1) –41.3 (Case 2)	Wide band peak protection limit in 50 MHz bandwidth was evaluated 42 dB above e.i.r.p. limit (from actual tests). For this scenario, no single outdoor entries are considered assuming the presence of specific regulatory provisions (i.e. no unlicensed UWB fixed outdoor applications)
		7 125-8 500 MHz		Rec. ITU-R F.1094 and Radiocommunication WP 9A liaison statement ($I/N = -20$ dB)	Same as above bands 6 000-7 125 MHz	–57.5 (Case 1) –41. 3 (Case 2)	Wide band peak protection limit in 50 MHz bandwidth was evaluated 42 dB above e.i.r.p. limit (from actual tests). For this scenario, no single outdoor entries are considered assuming the presence of specific regulatory provisions (i.e. no unlicensed UWB fixed outdoor applications)

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Protection criteria used in study	Interference scenario	UWB e.i.r.p. density (dBm/MHz)	Comments
Annex 2, § 4.1.2.2.2 (*cont.*)	FS/P-P and P-MP	10.15-10.65 GHz	NF (P-P & FWA TS) = 7 dB. P-P and FWA TS antenna gain = 40 dBi	Rec. ITU-R F.1094 and Radiocommunication WP 9A liaison statement ($I/N = -20$ dB)	Same as above bands 6 000-7 125 MHz	–55.5 (Case 1) –41.3 (Case 2)	Wide band peak protection limit in 50 MHz bandwidth was evaluated 42 dB above e.i.r.p. limit (from actual tests). For this scenario, no single outdoor entries are considered assuming the presence of specific regulatory provisions (i.e. no unlicensed UWB fixed outdoor applications)
Annex 2, § 5		21-23.6 GHz 24.25-26.5 GHz 27.5-29.5 GHz	*NF* = 6 dB Min feeder loss = 0 dB P-P antenna gain = 41 dBi FWA sectorial antenna gain = 18 dBi	Rec. ITU-R F.1094 and Radiocommunication WP 9A liaison statement ($I/N = -20$ dB assuming 0.5% apportionment for SRR)	Aggregate short range radar along a main road parallel to FS link: 4 active sensors (2 front 2 rear) per car; up to 4 lanes in each direction). Free space plus shielding effects. Two different studies on the same methodology but using different parameters, impact of mitigation factors and SRR Activity factor of either 0 or 7 dB	Study 1 −50 to −60[(1)] Study 2 −41.3 (even with positive margin)[(2)]	Wide band peak protection limit in 50 MHz bandwidth was evaluated 42 dB above e.i.r.p. limit (from actual tests)

(1) Appropriate for countries where the deployment of PP links, with low FS receiver antenna height and are frequently located along high traffic density roads combined with extensive use of these bands of FS links in mobile network infrastructure; an average SRR e.i.r.p. density limit of at least –50 dBm/MHz is necessary. However, where the joint concurrence probability of the more severe deployment situations (i.e. lower FS antenna heights closer to a road) are considered, an e.i.r.p. density limit of –60 dBm/MHz is necessary for long-term coexistence.

(2) Appropriate for countries, where less stringent infrastructural requirements regarding the FS receiver height and distance to the road might exist, the SRR e.i.r.p. density limit of –41.3 dBm/MHz may be considered appropriate, when other mitigation factors (unpredictable but possibly present) are taken into account. However, this higher e.i.r.p. density increases the risk of interference from SRR to the FS in case where those mitigation factors may not be present.

Bands below 11.6 GHz

The study contained within this Report has been focused on the FS bands between 3 to 10.6 GHz used by both point-to-point (P-P) and fixed wireless access systems; Although it is recognized that frequency bands lower than 3 GHz and above 10.6 GHz, also use fixed service systems. For bands lower than 3 GHz, however, qualitative considerations leading to very close objectives and e.i.r.p. density requirements for protection are presented.

A requirement for wide-band peak e.i.r.p. density has also been defined.

For aggregate interference evaluations, two different approach have been used considering the potential characteristics of the UWB devices that might be found on the consumer market in future years. The principal assumptions of the two aggregate studies are as follows:

Case 1: This case represents the potential interference from "generic" UWB devices which could be used for any possible unknown applications, with safeguard for high activity (up to 5% and up to 20% for hot-spots). Also any additional mitigation factors which are of unpredictable and uncertain in nature will not be taken into account so that the risk of potential interference from SRR to the FS is maintained low in any circumstances.

Case 2: This case uses a different set of parameters that takes into account other specific factors associated with WPAN applications (e.g. as defined within IEEE 802.15.3), with current foreseen average activity over a large population (up to 1%) and average mitigation factors which normally might assure UWB operation free from giving harmful interference to FS links, but may exceed the FS protection objectives by some dB in extreme situations. In addition, it is assumed that the higher impact of "single entry" UWB interference cases are avoided through specific provisions (i.e. mitigation techniques, such as DAA, to protect indoor FWA TS on the same desk and regulations for banning UWB devices deployed on fixed outdoor locations to protect outdoor FS station from LoS situations within their boresight angle footprint). This case was also developed over a real city scenarios using multiple Monte Carlo analysis for UWB distribution over the building height statistics (from satellite views), indoor-to-outdoor attenuation probability and consequent NLoS propagations based on probabilistic Erceg model (adopted by IEEE 802.16 for BWA applications); therefore, the complexity of the model and the huge amount of variables led to slight differences in the two contributions endorsed in the study (here presented as a range of values in the summaries).

The summary table in § 6.2.1.1 above details the assumptions and results (in terms of both average and 50 MHz peak) for all UWB deployment scenarios considered in this Report.

From these UWB deployment scenarios, the e.i.r.p. density limits for coexistence of any generic UWB application considered in this report with the FS systems below 10.6 GHz are:

a) Below 6 GHz:

a1) When no provision is made for avoiding the high-impacting "single entry" indoor UWB interference (Calculation 1):

– e.i.r.p density (r.m.s.) ≤ –76.5 dBm/MHz

– e.i.r.p density (wide-band peak) ≤ –34.5 dBm/50MHz.

a2) When provision is made for avoiding the high-impacting "single entry" indoor UWB interference (e.g. requiring DAA mitigation technique) but no further guess is made on the likelihood of present and future characteristics of consumer UWB devices (Calculation 2 – Case 1):

– e.i.r.p density (r.m.s.) ≤ –60 dBm/MHz

– e.i.r.p density (wide-band peak) ≤ –34.5 dBm/50MHz.

a3) When provision is made for avoiding the high-impacting "single entry" indoor UWB interference (e.g. requiring DAA mitigation technique) and "single entry" outdoor from UWB devices in fixed location; in addition it is considered the likelihood of present and future characteristics of consumer UWB devices based on large majority of WPAN UWB (e.g. based on IEEE 802.15.3a) applications (Calculation 2 – Case 2):

– e.i.r.p density(r.m.s.) ≤ –40/–48 dBm/MHz (see Note 1)

– e.i.r.p density (wide-band peak) ≤ +2/–6 dBm/50MHz (see Note 1).

NOTE 1 – Range depending on variants in the model actual implementation, the consideration of multiple scenario aggregation and the possibility or not of an additional 20% population of handheld UWB devices.

b) Above 6 GHz:

b1) When no provision is made for avoiding the high-impacting "single entry" outdoor UWB interference (Calculation 3) and/or no further guess is made on the likelihood of present and future characteristics of consumer UWB devices (Calculation 2 – Case 1):

– e.i.r.p density (r.m.s.) ≤ –57 dBm/MHz

– e.i.r.p density (wide-band peak) ≤ –15 dBm/50MHz.

NOTE 1 – These values are referred to more sensitive bands up to 7.125 GHz; according to the study, there might be a relaxation of 2.5 dB up to 8.5 GHz and of further 2.5 dB for the 10.5 GHz band.

b2) When provision is made for avoiding the high-impacting "single entry" outdoor from UWB devices in fixed location; in addition it is considered the likelihood of present and future characteristics of consumer UWB devices based on large majority of WPAN UWB (e.g. based on IEEE 802.15.3a) applications (Calculation 2 – Case 2):

– e.i.r.p density (r.m.s.) ≤ –41.3 dBm/MHz (see Note 1)

– e.i.r.p density (wide-band peak) ≤ 0 dBm/50MHz (see Note 1).

NOTE 1 – No specific calculation has been made for Case 2 in bands above 4 GHz; however it is assumed that results would be at least 6 dB more favourable up to 8.5 GHz and 9 dB up to ~11 GHz. Therefore, these levels already proposed as initial reference for the study may be considered appropriate.

A number of assumptions have been made in the study concerning UWB technology concerning its future deployment and scenarios. It is considered that the limits will only apply to UWB systems that are intended for continuous (or systematic along with most part of the day) emissions. A number of different aggregation scenarios have been explored in order to find the most severe one. However, in actual deployment all these scenarios will be additive and not "alternative" to each other and therefore their further potential aggregation has also been taken into account.

The regulation adopted by one Administration (i.e. –41.3 dBm/MHz r.m.s. and 0 dBm/50 MHz peak) was also studied, which leads to a potentially large incompatibility (up to ~ 30 dB) with the FS in the bands below 10.6 GHz unless a number of assumption and regulatory provisions are made for devising the likelihood of UWB devices characteristics based on current large expectance of market for WPAN applications and for avoiding the adverse high-impacts of "single entries" (e.g. requiring DAA implementation and banning use of UWB devices at fixed outdoor locations).

Bands around 24 GHz

The study, while evaluating a number of potentially impacting aggregation scenarios, has shown that the case of FS PP link parallel to a major road or highway is ~ 7 dB worse than the FS P-MP FWA link case; therefore the final conclusions are based on the FS PP link scenario.

The studies have shown that the SRR emission limits, for not impacting on FS, strongly depend on external circumstances that are in any case of imprecise or even unpredictable nature.

Deployment Case 1 study

The FS Deployment Case 1 study, may be appropriate for countries (e.g. in CEPT countries) where the deployment of PP links, with low FS receiver antenna height, is frequent along high traffic density roads, and extensive use of these bands for FS links in mobile network infrastructure may occur. An average SRR e.i.r.p. emission limit of at least –50 dBm/MHz is necessary; however, where the joint concurrence probability of the more severe deployment situations (i.e. lower FS antenna heights closer to a road) is considered, an e.i.r.p. density limit of –60 dBm/MHz is necessary for long-term coexistence.

Deployment Case 2 study

The FS Deployment Case 2 study, may be appropriate for countries, where less stringent infrastructural requirements regarding the FS receiver height and distance to the road might prevail. The SRR e.i.r.p. emission limit of –41.3 dBm/MHz may be considered appropriate, when other mitigation factors (unpredictable but possibly present) are taken into account. However, this higher e.i.r.p. density power increases the risk of interference from SRR to the FS in case those mitigation factors might not be present in full.

Further considerations

It should also be noted that, besides sharing requirements with co-primary services, there are no internationally adopted limitations for the deployment and use of FS systems in their primary allocated bands; risky deployment situations, even if presently considered not existing in some Administrations, might occur at a later stage, unless appropriate guidance will be given for future FS use and deployment. Therefore, the recommended limits would also depend on the degree of risk that Administrations wish to take on the probability of incurring interference in their assumed reasonable worst case and on possible measures taken for minimising that risk also in the future.

Finally, attention should be given to the "single car" contribution studied in this report showing that, with an unfavourable (which, nevertheless, could happen) placement of a car (e.g. when a small portion of busy road would cross, with any angle, the FS P-P link direction in full LoS of its antenna), the given interference is very close or, in case of lower antenna heights (≤ 20 m), is already exceeding the objective, giving small or no room for any aggregation.

4.3 Impact of UWB on the fixed-satellite service

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Protection criteria used in study	Interference scenario	UWB e.i.r.p. density (dBm/MHz)	Comments
Annex 3	FSS-Satellite (uplink)	5 725-7 075 MHz 7 900-8 400 MHz	35 dBi satellite antenna gain. 600 K noise temperature	Rec. ITU-R S.1432 (I/N = −20 dB)	Aggregate methodology 10-20 simultaneously active devices/km^2 50% of UWB devices are indoors $1/r^2$ path loss plus 10 dB building loss	−41.3	UWB has negligible impact in the uplink direction in these bands and at this e.i.r.p. level
	FSS – Earth station, Urban deployment (downlink)	3 400-4 200 MHz 4 500-4 800 MHz	Exclusion zone = 10 m, any antenna size or elevation(1), receiver noise temperature = 100 K	Rec. ITU-R S.1432 (I/N = −20 dB)	Satellite downlink methodology (aggregate). Uniform distribution of UWB devices, 100% indoor, 1.5 simultaneously active UWB devices/m^2 (office block "hotspot") $1/r^2$ path loss + 10 dB per obstruction (wall, ceiling)	−77	The computed maximum UWB e.i.r.p.device density for a given study depends on the methodology, parameters and assumptions. The studies selected for documentation here reflect the upper and lower bounds of those studies considered
					Satellite downlink methodology (aggregate). Uniform distribution of UWB devices, 100% indoor, 100 active UWB devices/km^2. Propagation model: $1/r^2$ path loss + distribution of attenuation for obstructions	−61.9	

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Protection criteria used in study	Interference scenario	UWB e.i.r.p. density (dBm/MHz)	Comments
Annex 3 (*cont.*)	FSS – Earth station, Suburban deployment (downlink)	3 400-4 200 MHz 4 500-4 800 MHz	Exclusion zone = 50 m, any antenna size or elevation(1), receiver noise temperature = 100 K	Rec. ITU-R S.1432 (I/N = −20 dB)	Satellite downlink methodology (aggregate). Uniform distribution of UWB devices, 80% indoor, 50 active UWB devices/km^2. Propagation model: $1/r^2$ path loss + 10 to15 dB building attenuation	−63	The computed maximum UWB e.i.r.p. device density for a given study depends on the methodology, parameters and assumptions. The studies selected for documentation here reflect the upper and lower bounds of those studies considered
					Satellite downlink methodology (aggregate). Uniform distribution of UWB devices, 80% indoor, 10 active UWB devices/km^2. Propagation model: $1/r^2$ path loss + distribution of attenuation for obstructions	−47.3	
	FSS – Earth station, Rural deployment (downlink)	3 400-4 200 MHz 4 500-4 800 MHz	Exclusion zone = 100 m, any antenna size or elevation(1), receiver noise temperature = 100 K	Rec. ITU-R S.1432 (I/N = −20 dB)	Satellite downlink methodology (aggregate). Uniform distribution of UWB devices, 80% indoor, 5 active UWB devices/km^2. Propagation model: $1/r^2$ path loss + 10 to15 dB building attenuation	−53	The computed maximum UWB e.i.r.p. device density for a given study depends on the methodology, parameters and assumptions. The studies selected for documentation here reflect the upper and lower bounds of those studies considered

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Protection criteria used in study	Interference scenario	UWB e.i.r.p. density (dBm/MHz)	Comments
Annex 3 (*cont.*)					Satellite downlink methodology (aggregate). Uniform distribution of UWB devices, 80% indoor, 1 active UWB devices/km^2. Propagation model: $1/r^2$ path loss + distribution of attenuation for obstructions	−41.2	
	FSS – Earth station, feeder link for MSS (downlink)	3 550-3 700 MHz	10º elevation 11 m dish size 53 K noise temp	Rec. ITU-R S.1432 (I/N = −20 dB)	Single entry methodology. 10 m separation distance. Propagation model: $1/r^2$ 1 MHz pulse repetition frequency	−63.6	
	FSS – Earth station, feeder link for MSS (downlink)	6 700-7 075 MHz	100 K noise temp, any antenna size or elevation(1) 5 km/10 km study radii with 20 m/40 m exclusion zones respectively	Rec. ITU-R S.1432 (I/N = −20 dB)	Integral methodology 500/50 active UWB devices per km^2 respectively 80% indoor 10 dB through-wall attenuation	−65.2 to −55.2	The computed maximum UWB e.i.r.p. device densities (left) were calculated for two sets of assumptions, and reflect the upper and lower bounds considered

NOTE 1 – It was assumed in all studies that no UWB devices were present in the main beam of the earth station.

4.4 Impact of devices using UWB technology on the mobile-satellite services and the radionavigation satellite service

4.4.1 Mobile-satellite service (MSS)

4.4.1.1 Search and rescue systems

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Protection criteria used in study	Interference scenario	UWB e.i.r.p. density (dBm/MHz)	Comments
Annex 4, § 1.1	MSS search and rescue systems (EPIRP Earth-to-space)	406-406.1 MHz	Satellite antenna gain = 3.9 dBi, minimum elevation = 5º	$I < −120.1$ dBm/ MHz (Rec. ITU-R M.1478)	Aggregate; UWB deployment: 20% outdoor, 80% indoor Free space path loss 5 dB wall attenuation	−40 to −70 for 10 to 10 000 active UWB devices/km^2, respectively	
	MSS search and rescue systems (Cospas/ Sarsat earth station)	1 544-1 545 MHz	Antenna gain = 21 dBi towards horizon	$I < −113.2$ dBm/MHz	Aggregate; UWB deployment: 20% outdoor, 80% indoor Propagation: Rec. ITU-R P.1238-2 and 9 dB wall attenuation. Interference method: Integral (R = 10 km)	−75 Separation distance = 10 m for 1 000 active UWB devices/km^2	
	MSS search and rescue systems (GSO earth station)	1 544-1 545 MHz	Antenna gain = 25 dBi towards horizon	$I < −133.2$ dBm/MHz	Aggregate; UWB deployment: 20% outdoor, 80% indoor. Propagation: Rec. ITU-R P.1238-2 and 9 dB wall attenuation. Interference method: Integral (R = 10 km)	−75 Separation distance = 0.1 km to 9.4 km for 100 to 1 000 active UWB devices/m^2, respectively	

The results for MSS search and rescue are independent of the PRF value.

At 406 MHz, using the slope mask, it is unlikely to have compatibility problems.

A protection distance of 6 km is required around each earth station in the band 1 544-1 545 MHz.

4.4.1.2 Service links of GSO MSS systems

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Protection criteria used in study	Interference scenario	UWB e.i.r.p. density (dBm/MHz)	Comments
Annex 4, § 1.2	Service links of GSO MSS (uplink)	1 626.5-1 660.5 MHz	Bandwidth = 34 MHz. System noise temp = 501 K to 708 K. Antenna peak gain 18.5 dBi to 41 dBi	I/N = −20 dB	Aggregate, Global beam. Propagation: Free space 10 dB wall attenuation. Indoor/outdoor: 80/20%. Airborne aggregate interference model	−75.3 to −85.3 for 10 to 10 000 active UWB devices/ km^2, respectively	
	Service links of GSO MSS (downlink)	1 525-1 559 MHz	Bandwidth = 60 kHz to 200 kHz. System noise temp = 316 K to 355 K. Peak gain 18 dBi	I/N = −20 dB	Single interferer, 20 m separation. Free space path loss for MES terminals deployed in rural areas. Rec. ITU-R P.1411 for MES terminals deployed in urban areas 10 dB wall attenuation	−98.4	
	Service links of GSO MSS (downlink)	1 525-1 559 MHz	Aero MES terminals Bandwidth = 60 kHz to 200 kHz. System noise temp = 316 K to 355 K. Receive gain 0 dBi	I/N = −20 dB	Airborne aggregate interference model	−75.3 to −98.0 for 10 to 10 000 active UWB devices/km^2, respectively	

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Protection criteria used in study	Interference scenario	UWB e.i.r.p. density (dBm/MHz)	Comments
Annex 4, § 1.2.10.3	GSO MSS (Hand-held MES terminals downlink)	2 170-2 200 MHz	Bandwidth 4.84 MHz Noise figure = 9 dB Antenna gain = 0 dBi	$I/N = -20$ dB	Single interferer. Free space path loss	−96.2 to −85.8 for 0.3 m to 1 m separation, respectively	
Annex 4, § 1.2.10.4	Non-GSO MSS (downlink)	2 170-2 200 MHz	Bandwidth = 1.4 kHz (min) and 30 MHz (max). Noise temp = 158 K	$I/N = -20$ dB for average UWB emissions $I/N = -20 + 10 \log_{10}(B_{IF}/158 \text{ kHz})$ dB for peak UWB emissions	Single interferer. Free space path loss	−106.3 for average UWB emissions −98.3 for peak UWB emissions at 0.36 m separation distance	

The following conclusions can be drawn from the results of the impact analysis with regard to interference from single UWB emitter, with PRF not less than 1 MHz, into MES terminal in the 1.5 GHz band (downlink).

Land-based MES terminals

Separation distances

– A maximum separation distance of about 286 m is required for the protection of land-based MES terminals.

Maximum permissible e.i.r.p. density in 1 MHz at 20 m distance

– The permissible e.i.r.p. density is equal to –98.39 dBm/MHz from non-dithered emissions with PRF not less than 1 MHz.

– The permissible e.i.r.p. density is equal to –86.17 dBm/MHz from dithered emissions with PRF not less than 1 MHz.

Hand-held MES terminals

Maximum permissible e.i.r.p. density in 1 MHz at 0.36 m distance

– The permissible e.i.r.p. density is equal to –85 dBm/MHz.

MES terminals of Non-GSO MSS system

Maximum permissible e.i.r.p. density in 1 MHz at 0.36 m distance

– The permissible e.i.r.p. density is equal to –106.3 dBm/MHz for average UWB emissions.

– The permissible e.i.r.p. density is equal to –98.3 dBm/MHz for peak UWB emissions.

Aero MES terminals

The aggregate interference analysis is performed with 4% activity factor and 20% of UWB devices deployed outside. The aggregate interference into the aeronautical MES terminal is unlikely to be problematic.

Maritime MES terminals

It is expected that there may not be a problem with regard to interference from single UWB device into a maritime MES terminal deployed on board the ships in international waters.

Aggregate interference in 1.6 GHz band (uplink)

The aggregate interference analysis is performed with 4% activity factor and 20% of UWB devices deployed outside. The aggregate interference into the satellite receiver is unlikely to be problematic.

4.4.2 Radionavigation satellite service (RNSS)

<table>
<tr><th rowspan="2">Part of Report</th><th rowspan="2">Service/ applications</th><th rowspan="2">Frequency bands</th><th rowspan="2">Victim station characteristics</th><th rowspan="2">Protection criteria used in study</th><th rowspan="2">Interference scenario</th><th rowspan="2" colspan="2">UWB application</th><th colspan="2">UWB e.i.r.p. density</th><th rowspan="2">Comments</th></tr>
<tr><th>Average (dBm/MHz)</th><th>Spectral line (dBm)</th></tr>
<tr><td rowspan="6">Annex 4, § 2</td><td rowspan="5">RNSS − GPS</td><td rowspan="5">1 164-1 300 MHz,
1 559-1 610 MHz</td><td rowspan="5">Noise power density = −111.5 dBm/ MHz.
0 dBi antenna gain</td><td rowspan="5">I/N = −3 dB</td><td rowspan="5">Single interferer, 2 m separation, E-911 operational scenario.
Free space path loss</td><td colspan="2">Indoor communications, Handheld (including outdoor) communications.
Vehicular radar</td><td>−75.3</td><td>−85.3</td><td rowspan="5">FCC R&O 02-48 notes an additional 0.2 dB decrease to align PSD values with other unlicensed devices in the United States. Also assumed a −3 dB UWB uncertainty factor and −10 dB difference between noise-like and CW interference (1),(2)
The spectral lines are measured within 1 kHz bandwidth</td></tr>
<tr><td colspan="2">Ground-penetrating and wall-imaging radar, medical imaging</td><td>−65.3</td><td>−75.3</td></tr>
<tr><td rowspan="2">Through-wall imaging</td><td>BW < 960 MHz</td><td>−65.3</td><td>−75.3</td></tr>
<tr><td>BW > 960 MHz</td><td>−46.3</td><td>−56.3</td></tr>
<tr><td colspan="2">Surveillance systems</td><td>−53.3</td><td>−63.3</td></tr>
<tr><td>RNSS – Galileo Safety of Life applications</td><td>1 164-1 300 MHz,
1 559-1 610 MHz</td><td>Noise power density = −111.3 dBm/ MHz.
5 dBi antenna gain</td><td>I/N = −20 dB</td><td>Single interferer, 30 m separation.
Free space path loss</td><td colspan="2"></td><td>−79</td><td>−97</td><td>(1), (2)
The spectral lines are measured within 1 kHz bandwidth</td></tr>
</table>

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Protection criteria used in study	Interference scenario	UWB application	UWB e.i.r.p. density		Comments
							Average (dBm/MHz)	**Spectral line (dBm)**	
Annex 4, § 2 (*cont.*)	RNSS – Galileo non-safety of life applications	1 164-1 300 MHz, 1 559-1 610 MHz	Noise power density = −111.3 dBm/ MHz. 0 dBi antenna gain	*I*/*N* = −6 dB	Single interferer, 1 m separation. Free space path loss		−83.5	−101.5	(1), (2), (3) The spectral lines are measured within 1 kHz bandwidth
	RNSS – GLONASS Safety of life applications	1 164-1 300 MHz, 1 559-1 610 MHz	Noise power density = −112.0 dBm/ MHz. 5 dBi antenna gain	*I*/*N* = −20 dB	Single interferer, 30 m separation. Free space path loss		−79.0	−94.0	(1), (2), (3) The spectral lines are measured within 1 kHz bandwidth
					Aggregate interferers, 30 m separation. Free space path loss		−84.7	−99.7	
	RNSS – GLONASS Non-safety of life applications	1 164-1 300 MHz, 1 559-1 610 MHz	Noise power density = −112.0 dBm/ MHz. 3 dBi antenna gain	*I*/*N* = −6 dB	Single interferer, 1 m separation. Free space path loss		−87.0	−102.0	(1), (2), (3) The spectral lines are measured within 1 kHz bandwidth

(1) The device using UWB technology transmits continuously i.e. 100% activity factor.

(2) The assumptions used with similar methodologies to determine the impact of emission of UWB devices on RNSS systems are not based on similar considerations, and have resulted in different values.

(3) Results assume all devices using UWB technology to be active simultaneously.

4.5 Impact of UWB on the broadcasting service

4.5.1 Terrestrial broadcasting

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Protection criteria used in study	Interference scenario	UWB e.i.r.p. density (dBm/MHz)	Comments
Annex 5, § 1.1	Digital audio (T-DAB)	174-230 MHz (VHF)	Outdoor fixed reception /Outdoor and indoor portable reception. Receiver bandwidth = 1.536 MHz, sensitivity = −91 dBm. Omnidirectional antenna gain = 0 dBi	(1) (*I*/*N* = –20 dB is recommended by Radiocommuni-cation Study Group 6)	Single interferer with a centre frequency at 1.38 GHz, bandwidth (−15 dB) = 3.8 GHz, PRF > 1 MHz. MCL and free space propagation 30 cm indoor/1 m outdoor separation	−97 (1)	(2), (3)
	Digital audio (T-DAB)	1 452-1 492 MHz (UHF)	Indoor portable reception/outdoor and indoor portable and mobile reception. Receiver bandwidth = 1.536 MHz, sensitivity = −91 dBm. Omnidirectional antenna gain = 2.15 dBi	(1) (*I*/*N* = –20 dB is recommended by Radiocommuni-cation Study Group 6)	Single interferer with a centre frequency at 1.38 GHz, bandwidth (−15 dB) = 3.8 GHz, PRF > 1 MHz. MCL and free space propagation. 30 cm indoor/1 m outdoor separation	−85 (1)	(2), (3)
Annex 5, § 1.2	ISDB-T_{SB}	170-222 MHz	Mobile, portable/fixed receiver bandwidth = 429, 500, 571 kHz (one segment). 1.29, 1.50, 1.71 MHz (three segments). Omnidirectional antenna gain = −0.85 dBi	*I*/*N* = −20 dB	Single interferer. Free space propagation 50 cm indoor/3 m outdoor separation	−114.7	(2), (3)
				I/*N* = −20 dB	Aggregate. Free space propagation. 4 interferers 50 cm indoor/3 m outdoor separation	−120.7	(2), (3)

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Protection criteria used in study	Interference scenario	UWB e.i.r.p. density (dBm/MHz)	Comments
Annex 5, § 1.2 (*cont.*)	ISDB-T_{SB}	470-770 MHz	Mobile, portable/fixed receiver bandwidth = 429, 500, 571 kHz (one segment) 1.29, 1.50, 1.71 MHz (three segments). Omnidirectional antenna gain = −0.85 dBi	*I*/*N* = −20 dB	Single interferer. Free space propagation. 50 cm indoor/3 m outdoor separation	−106.1	(2), (3)
				I/*N* = −20 dB	Aggregate. Free space propagation. 4 interferers 50 cm indoor/3 m outdoor separation	−112.1	(2), (3)
Annex 5, § 1.3	Digital TV (DVB-T)	174-230 MHz (VHF)	Outdoor fixed reception/ outdoor and indoor portable reception. Receiver bandwidth = 7/8 MHz, sensitivity = −80 to −90 dBm. Omnidirectional antenna gain = 0 dBi	(1) (*I*/*N* = – 20 dB is recommended by Radiocommuni-cation Study Group 6)	Single interferer with a centre frequency at 1.38 GHz, bandwidth (−15 dB) = 3.8 GHz, PRF > 1 MHz. MCL and free space propagation. 50 cm indoor / 3 m outdoor separation	−94 (1)	(2), (3)
	Digital TV (DVB-T)	470-862 MHz (UHF)	Outdoor fixed reception/ outdoor and indoor portable reception. Receiver bandwidth = 7/8 MHz, sensitivity = −80 to −90 dBm. Omnidirectional antenna gain = 2.15 dBi	(1) (*I*/*N* = – 20 dB is recommended by Radiocommuni-cation Study Group 6)	Single interferer with a centre frequency at 1.38 GHz, bandwidth (−15 dB) = 3.8 GHz, PRF > 1 MHz. MCL and free space propagation. 50 cm indoor/3 m outdoor separation	−89 (1)	(2), (3)
Annex 5, § 1.4	ATSC digital television	54-88 MHz (Low VHF)	Outdoor fixed reception/ outdoor and indoor portable reception. Receiver bandwidth = 6 MHz. Omnidirectional antenna gain = 0 dBi	*I*/*N* = −20 dB	Single interferer. Free space propagation. 50 cm indoor/3-m outdoor separation	−122	(2), (3)

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Protection criteria used in study	Interference scenario	UWB e.i.r.p. density (dBm/MHz)	Comments
Annex 5, § 1.4 (*cont.*)					Aggregate. Uniform distribution. 5 km radius. Outdoor $1/r^2$, $1/r^3$, $1/r^4$ 5 active devices/km^2 3 m minimum separation	−91	(2), (3)
		174-216 MHz	Outdoor fixed reception/ outdoor and indoor portable reception. Receiver bandwidth = 6 MHz. Omnidirectional antenna gain = 0 dBi	I/N = −20 dB	Single interferer. Free space propagation. 50 cm indoor/3-m outdoor separation	−113	(2), (3)
					Aggregate. Uniform distribution. 5 km radius. Outdoor $1/r^2$, $1/r^3$, $1/r^4$ 5 active devices/km^2 3 m minimum separation	−84	(2), (3)
		470-806 MHz	Outdoor fixed reception/ outdoor and indoor portable reception. Receiver bandwidth = 6 MHz. Omnidirectional antenna gain = 0 dBi	I/N = −20 dB	Single interferer. Free space propagation. 50 cm indoor/3 m outdoor separation	−106	(2), (3)
					Aggregate. Uniform distribution. 5 km radius. Outdoor $1/r^2$, $1/r^3$, $1/r^4$ 5 active devices/km^2 3 m minimum separation	−78	(2), (3)

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Protection criteria used in study	Interference scenario	UWB e.i.r.p. density (dBm/MHz)	Comments
Annex 5, § 1.5	ISDB-T	170-222 MHz	Mobile, portable/fixed receiver bandwidth = 429, 500, 571 kHz (one segment). 1.29, 1.50, 1.71 MHz (three segments). Omnidirectional antenna gain = −0.85 dBi	I/N = −20 dB	Single interferer. Free space propagation. 50 cm indoor/3 m outdoor separation	−114.7	(2), (3)
					Aggregate. Free space propagation. 4 interferers. 50 cm indoor/3 m outdoor separation	−120.7	(2), (3)
	ISDB-T	470-770 MHz	Mobile, portable/fixed receiver bandwidth = 429, 500, 571 kHz (one segment) 1.29, 1.50, 1.71 MHz (three segments). Omnidirectional antenna gain = −0.85 dBi	I/N = −20 dB	Single interferer. Free space propagation. 50 cm indoor/3 m outdoor separation	−106.1	(2), (3)
					Aggregate. Free space propagation. 4 interferers 50 cm indoor/3 m outdoor separation	−112.1	(2), (3)
Annex 5, § 1.6	Analogue TV	54-88 MHz (Low VHF)	Outdoor fixed reception/outdoor and indoor portable reception	I/N = −20 dB	Single interferer. Free space propagation. 50 cm indoor/3 m outdoor separation	−115	(2), (3)
		174-216 MHz (High VHF)	Outdoor fixed reception/outdoor and indoor portable reception	I/N = −20 dB	Single interferer. Free space propagation. 50 cm indoor/3 m outdoor separation	−106	(2), (3)
		470-806 MHz (UHF)	Outdoor fixed reception/outdoor and indoor portable reception	I/N = −20 dB	Single interferer. Free space propagation. 50 cm indoor/3 m outdoor separation	−98	(2), (3)

(1) These studies were done using a I/N = 0 dB (C/I = C/N). However, in case of interference from devices using UWB technology to broadcast services, the protection criteria provided by Radiocommunication Study Group 6, which is I/N = −20 dB found in Annex 8 to the Report, should be used.

(2) The device using UWB technology transmits continuously i.e. 100% activity factor.

(3) Results assume all devices using UWB technology to be active simultaneously.

T-DAB

A large number of interference scenarios have been simulated to assess the impact of UWB devices on the T-DAB systems, in the VHF/UHF bands. For each of the considered scenarios, the protection distance, d_{min}, from the T-DAB receiver to the UWB transmitter has been calculated by using alternatively, as UWB radiated power density level, the United States UWB emission limits and the UWB slope emission masks proposed for UWB applications in the band 3.1-10.6 GHz. The obtained protection distances have been compared with two threshold values d_{min}^{in}= 0.3 m and d_{min}^{out} = 1 m, which are respectively the protection distances required to ensure a high protection to the T-DAB system in indoor and outdoor environments, for mobile and portable receptions.

The analyses of the results clearly show that the United States UWB emission limits do not guarantee the protection of the T-DAB system in the VHF band (33 m ≤ d_{min} ≤ 520 m), while the UWB slope emission masks reduce significantly the interference probability (d_{min} ≈ 0 m) As for the UHF band (band L), in the majority of the considered scenarios, the United States UWB emission limits do not guarantee the protection of the T-DAB system (0.79 m < d_{min} < 5.66 m), while the UWB slope emission masks still ensure a better protection to T-DAB system (d_{min} < 1.75 m).

An UWB e.i.r.p. density limit has been calculated to guarantee the protection of the DAB-T system in the presence of UWB emissions. This limit is:

In indoor environment

– –85 dBm/MHz (e.i.r.p.) in the UHF band (1 452-1 492 MHz)

– –97 dBm/MHz (e.i.r.p.) in the VHF band (174-230 MHz).

In outdoor environment

– –75 dBm/MHz (e.i.r.p.) in the UHF band (1 452-1 492 MHz)

– –87 dBm/MHz (e.i.r.p.) in the VHF band (174-230 MHz).

On the grounds of these results, a single generic UWB e.i.r.p. density limit can be defined to ensure the protection of the T-DAB in indoor as well as in outdoor environments:

– –85 dBm/MHz (e.i.r.p.) in the UHF band (1 452-1 492 MHz)

– –97 dBm/MHz (e.i.r.p.) in the VHF band (174-230 MHz).

ISDB-T$_{SB}$

An UWB e.i.r.p. density limit has been calculated to guarantee the protection of the ISDB-T$_{SB}$ system in the presence of UWB emissions. This limit is:

– –114.7 dBm/MHz (e.i.r.p.) in the VHF band (at 200 MHz)

– –106.1 dBm/MHz (e.i.r.p.) in the UHF band (at 600 MHz).

DVB-T

A large number of interference scenarios have been simulated to assess the impact of UWB devices on the DVB-T systems, in the VHF and UHF bands. For each of the considered scenarios, the protection distance, d_{min}, from the DVB-T receiver to the UWB transmitter has been calculated by using alternatively, as UWB radiated power density level, the United States UWB emission limits in force and the UWB slope emission masks. The obtained distances have been compared with two threshold values d_{min}^{in}= 0.5m and d_{min}^{out}= 3 m, which are respectively the protection distances required to ensure a high protection to the DVB-T system in indoor and outdoor environments, for fixed and portable reception.

The analyses of the results clearly show that the United States UWB emission limits do not guarantee the protection of the DVB-T system in the presence of UWB emissions (5 m ≤ d_{min} ≤ 1 284 m), while the UWB slope emission masks reduce significantly the interference probability (d_{min} < 0.5 m).

An UWB e.i.r.p. density limit has been calculated to guarantee the protection of the DVB-T system in the presence of UWB emissions. This limit is:

In indoor environment

– –89 dBm/MHz (e.i.r.p.) in the UHF band (470-862 MHz)

– –94 dBm/MHz (e.i.r.p.) in the VHF band (174-230 MHz).

In outdoor environment

– –86 dBm/MHz (e.i.r.p.) in the UHF band (470-862 MHz)

– –91 dBm/MHz (e.i.r.p.) in the VHF band (174-230 MHz).

On the grounds of these results, a single generic UWB e.i.r.p. density limit can be defined to ensure the protection of the DVB-T, in indoor as well as in outdoor environments:

– –89 dBm/MHz (e.i.r.p.) in the UHF band (470-862 MHz)

– –94 dBm/MHz (e.i.r.p.) in the VHF band (174-230 MHz).

ATSC

The worst single entry case is the indoor installation low very high frequency (VHF) example where the UWB e.i.r.p. density limit would have to be –122 dBm/MHz. The single entry scenario is much worse in the case of an indoor installation because a UWB device can be located so closely to a victim ATSC DTV receiver and can directly affect the TV performance.

The worst aggregate case examined is the scenario where 1 000 UWB devices are normally distributed about a victim very high frequency (VHF) ATSC DTV receiver out to a range of 1 000 m radius. In this case, the e.i.r.p. density limit for each UWB device is –108 dBm/MHz.

On the basis of the results, a UWB e.i.r.p. density limit for each band can be defined to ensure the protection of the ATSC DTV, in both indoor and outdoor environments:

– –122 dBm/MHz (e.i.r.p.) in the low VHF band (54-88 MHz)

– –113 dBm/MHz (e.i.r.p.) in the high VHF band (174-216 MHz)

– –106 dBm/MHz (e.i.r.p.) in the UHF band (470-806 MHz).

ISDB-T

An UWB e.i.r.p. density limit has been calculated to guarantee the protection of the ISDB-T system in the presence of UWB emissions. This limit is:

– –114.7 dBm/MHz (e.i.r.p.) in the VHF band (at 200 MHz)

– –106.1 dBm/MHz (e.i.r.p.) in the UHF band (at 600 MHz).

Analogue TV broadcasting

The worst single entry case is the indoor installation low VHF example where the UWB e.i.r.p. density limit would have to be –115 dBm/MHz. The single entry scenario is much worse in the case of an indoor installation because a UWB device can be located so closely to a victim analogue receiver and can directly affect the TV performance.

On the basis of the results, a UWB e.i.r.p. density limit for each band can be defined to ensure the protection of analogue TV, in both indoor and outdoor environments:

– –115 dBm/MHz (e.i.r.p.) in the low VHF band (54-88 MHz)

– –106 dBm/MHz (e.i.r.p.) in the high VHF band (174-216 MHz)

– –98 dBm/MHz (e.i.r.p.) in the UHF band (470-806 MHz).

4.5.2 Broadcast-satellite service (BSS)

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Protection criteria used in study	Interference scenario	UWB e.i.r.p. density (dBm/MHz)	Comments
Annex 5, § 2.1	BSS (S) SDARS	1 452-1 492 MHz and 2 320-2 345 MHz	Receiver bandwidth = 4.2 MHz T = 158 K Receiver noise = −110.4 dBm Receiver antenna gain = 0 to 5 dB	I/N = −20 dB	Aggregate. Free space path loss. Deterministic methodology. Indoor is based on two UWB devices	−90.3 dBm/MHz for indoor UWB devices	The antenna gain is on an elevation of 25° to 90°
					Outdoor is based on four devices, all distances of 3 m	−93.3 dBm/MHz for outdoor UWB devices	
Annex 5, § 2.2	BSS(S) E-SDR	1 467-1 492 MHz	Receiver bandwidth = 5 MHz, G/T = −24.6 dB/K. Receiver antenna gain = 0 to 5 dB	I/N = −20 dB	Single UWB devices at 0.5 m separation	−104.2 dBm/MHz	
					Aggregate of two devices at 3 m separation (3 dB for multiple devices)	−93.4 dBm/MHz	
Annex 5, § 2.3	BSS (S) SDMB	2 605-2 655 MHz	Receiver bandwidth = 25 MHz T = 150 K BER = 2×10^{-4}. Noise figure = 3 dB. Receiver noise = −112.2 dBm/MHz	I/N = −20 dB	Single UWB device at 3 m separation	−81.9 dBm/MHz	
					Aggregate. Monte-Carlo methodology. 5% activity factor on $100/km^2$ of interferer density	−88	

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Protection criteria used in study	Interference scenario	UWB e.i.r.p. density (dBm/MHz)	Comments
Annex 5, § 2.4	BSS (S)	1 452-1 492 MHz	Receiver bandwidth = 25 MHz. T = 100 K. Receiver antenna gain = 5 dBi for all angles	$I/N = -20$ dB	Single UWB device at 36 cm separation. Free-space loss. Deterministic methodology	−116.8	Note – Study based on very close proximity of UWB devices to the receiver and conservative assumptions
Annex 5, § 2.3	BSS (S)	2 310-2 360-MHz	Receiver bandwidth = 25 MHz. T = 100 K. Receiver antenna gain = 5 dBi for all angles	$I/N = -20$ dB	Single UWB device at 36 cm separation. Free-space loss. Deterministic methodology	−112.5	Note – Study based on very close proximity of UWB devices to the receiver and conservative assumptions
	BSS (S)	2 535-2 655 MHz	Receiver bandwidth = 25 MHz. T = 100 K. Receiver antenna gain = 5 dBi for all angles	$I/N = -20$ dB	Single UWB device at 36 cm separation. Free-space loss. Deterministic methodology	−111.7	Note – Study based on very close proximity of UWB devices to the receiver and conservative assumptions

4.6 Impact of UWB on the science services

4.6.1 Earth exploration-satellite service (EESS)

Part of Report	Service/ applications	Frequency band	Victim station characteristics	Protection criteria used in study	Reference analysis	UWB e.i.r.p. density (dBm/MHz) or minimum separation distance	Comments
Annex 6, § 1.2.1.1	EESS (Earth-to-space)	2 025-2 110 MHz	Satellite antenna gain = 0 dBi	Rec. ITU-R SA.609-1	Aggregate interference UWB deployment: 20% outdoor and 80% indoor. Free space path loss 12 dB wall attenuation	−15 to −55 for 10 to 10 000 UWB devices/km^2 respectively	(1)
Annex 6, § 1.2.1.2	EESS (space-to-Earth)	2 200-2 290 MHz	Typical earth station Antenna gain = 31 dBi	Rec. ITU-R SA.609-1	Aggregate interference. UWB deployment: 20% outdoor and 80% indoor. Free space path loss 12 dB wall attenuation Interference method: Integral (R_1 = 10 km)	For −52 (indoor), −62 (outdoor), the protection distance 3 km to 9.9 km for 10 to 1 000 UWB devices/km^2 respectively	(1)

Part of Report	Service/ applications	Frequency band	Victim station characteristics	Protection criteria used in study	Reference analysis	UWB e.i.r.p. density (dBm/MHz) or minimum separation distance	Comments
Annex 6, § 1.2.2	EESS (space-to-Earth)	8 025-8 400 MHz	Earth station antenna gain included in the protection criteria. Max. antenna gain = 55 dBi	Rec. ITU-R SA.1026-3	Aggregate interference. Rural (1 000 active devices/km^2) 10 m separation. Free space path loss UWB deployment: 20% outdoor and 80% indoor. Interference method: Integral (R_1 = 10-30 km)	−41	(1)
	EESS (space-to-Earth)	8 025-8 400 MHz	Antenna gain = 0 dBi in all directions	System noise temperature = 130 K. I/N = −20 dB	Aggregate, interference, free space path loss, UWB deployment: 20% outdoor and 80% indoor; 10 dB indoor attenuation, Integral methodology. Urban: 500 active devices/km^2 with 20 m exclusion zone and 5 km radius. Suburban: 50 active devices/km^2 with 40 m exclusion zone and 10 km radius	Urban: −63.7 Suburban: −53.7	(1)

Part of Report	Service/ applications	Frequency band	Victim station characteristics	Protection criteria used in study	Reference analysis	UWB e.i.r.p. density (dBm/MHz) or minimum separation distance	Comments
Earth exploration-satellite service (active)							
Annex 6, § 1.1.1	EESS (active): spaceborne altimeter	5 140-5 460 MHz 5 250-5 570 MHz	Nadir instrument. Antenna gain = 32.2 dBi	−113 dBm/MHz	Aggregate interference. UWB deployment: 20% outdoor and 80% indoor. Free space path loss. 17 dB wall attenuation	−3 to −33 for 10 to 10 000 UWB devices/km^2 respectively	(1)
Annex 6, § 1.1.2	EESS (active): synthetic aperture radar	5 250-5 570 MHz	Satellite nadir angle of 32.5°. Antenna gain = 42.7 dBi	−115.3 dBm/MHz	Aggregate interference. UWB deployment: 20% outdoor and 80% indoor. Free space path loss 17 dB wall attenuation	−11 to −41 for 10 to 10 000 UWB devices/km^2 respectively	(1)
Earth exploration-satellite service (passive)							
Annex 6, § 1.4	EESS (passive)	1 400-1 427 MHz	Characteristics of instruments used in impact analysis. Satellite antenna gain = 9 to 35 dBi	Rec. ITU-R SA.1029-2 1 to 5% apportionment of the interference criteria from a liaison statement from Radiocommunication WP 7C	Aggregate interference. Free space path loss. 9 dB wall attenuation. UWB deployment: 20% outdoor and 80%	−91 to −121 for 10 to 10 000 UWB devices/km^2 respectively	(1)

Part of Report	Service/ applications	Frequency band	Victim station characteristics	Protection criteria used in study	Reference analysis	UWB e.i.r.p. density (dBm/MHz) or minimum separation distance	Comments
Annex 6, § 1.4 (*cont.*)	EESS (passive)	64.25-70.75 MHz 70.75-72.50 MHz	Characteristics of conical scan instruments used in impact analysis. Satellite antenna gain = 38.8 dBi	Rec. ITU-R SA.1029-2 5% apportionment of the interference criteria. See above	Aggregate interferer. Free space path loss 17 dB wall attenuation. UWB deployment: 20% outdoor and 80%	−64 to −94 for 10 to 10 000 UWB devices/km^2 respectively	(1)
	EESS (passive)	10.6-10.7 GHz	Characteristics of conical scan instruments used in impact analysis. Satellite antenna gain = 36 to 45 dBi	Rec. ITU-R SA.1029-2 5% apportionment of the interference criteria. See above	Aggregate interferer. Free space path loss 17 dB wall attenuation. UWB deployment: 20% outdoor and 80%	−60 to −90 for 10 to 10 000 UWB devices/km^2 respectively	(1)
	EESS (passive)	23.6-24 GHz	Characteristics of conical scan and nadir instruments used in impact analysis. EESS antenna gain = 52 dBi	Rec. ITU-R SA.1029-2 1% to 5% apportionment of the interference criteria. See above	Aggregate interference, density of 123 (rural case), 330 (suburban case) and 453 (urban case) cars/km^2. Cars are equipped with up to 8 short range radars (SRR) 100% of cars use SRR. Free space path loss	−70.6 for rural case −74.8 for suburban case −76.2 for urban case	100% deployment of SRR operating at −41.3 dBm/MHz results in interference exceeding the EESS threshold up to 34.9 dB with a 1% apportionment of the interference criteria

(1) Results assume all devices using UWB technology to be active simultaneously with an activity factor of 5%.

4.6.2 Space research service

Part of Report	Service/ applications	Frequency band	Victim station characteristics	Protection criteria used in study	Reference analysis	UWB e.i.r.p. density (dBm/MHz)	Comments
Annex 6, § 2.1	SRS (Earth-to-space)	2 025-2 110 MHz	Satellite antenna gain = 0 dBi	Rec. ITU-R SA.609-1 1% apportionment of the interference criteria	Aggregate interference. 20% indoor. 80% outdoor. Free space path loss. 12 dB wall attenuation	−45 to −75 for 10 to 10 000. UWB devices/km^2 respectively	(1)
Annex 6, § 2.2	SRS (space-to-Earth)	2 200-2 290 MHz	Typical earth station	Rec. ITU-R SA.609-1 1% apportionment of the interference criteria	Aggregate interference. Free space path loss. Interference method: Integral (R_1 =10 to 30 km)	For −70, the separation distance is 6 km to 29.5 km for 10 to 1 000. UWB devices/km^2 respectively	(1)
	SRS (Space-to-Earth)	8 400-8 450 MHz	Typical earth station	Rec. ITU-R SA.1157 1% apportionment of the interference criteria	Aggregate interference. Rural (100 active devices/km^2) 4 km separation. Free space path loss. Interference method: Integral (R_1 = 10 to 30 km)	For −70, the separation distance is 10 m to 12 km for 10 to 10 000. UWB devices/km^2 respectively	(1)

(1) Results assume all devices using UWB technology to be active simultaneously with an activity factor of 5%.

4.6.3 Radio astronomy service (RAS)

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Protection criteria used in study	Interference scenario	UWB e.i.r.p. density (dBm/MHz)	Comments
Annex 6, § 3	RAS Continuum observations (broadband)	608-614 MHz	Single-dish Antenna gain = 0 dBi	Rec. ITU-R RA.769	Aggregate, (5 active UWB/km^2, 20% outdoor)(1)	−113.2	(2)
	RAS Continuum observations (broadband)	1 330.0-1 400.0 MHz	Single-dish Antenna gain= 0 dBi	Rec. ITU-R RA.769	Aggregate, (5 active UWB/km^2, 20% outdoor) (1)	−111.4	(2)
	RAS Continuum observations (broadband)	1 400.0-1 427.0 MHz	Single-dish Antenna gain = 0 dBi	Rec. ITU-R RA.769	Aggregate, (5 active UWB/km^2, 20% outdoor) (1)	−111.4	(2)
	RAS Spectral line observations (narrow-band)	1 610.6-1 613.8 MHz	Single-dish Antenna gain = 0 dBi	Rec. ITU-R RA.769	Aggregate, (5 active UWB/km^2, 20% outdoor) (1)	−90.6	(2)
	RAS Continuum observations (broadband)	1 660.0-1 670.0 MHz	Single-dish Antenna gain = 0 dBi	Rec. ITU-R. RA.769	Aggregate, (5 active UWB/km^2, 20% outdoor) (1)	−103.8	(2)
	RAS Spectral line observations (narrow-band)	1 718.8-1 722.2 MHz	Single-dish Antenna gain = 0 dBi	Rec. ITU-R RA.769	Aggregate (5 active UWB/km^2, 20% outdoor) (1)	−90.2	(2)
	RAS Continuum observations (broadband)	2 655.0-2 690.0 MHz	Single-dish Antenna gain = 0 dBi	Rec. ITU-R RA.769	Aggregate, (5 active UWB/km^2, 20% outdoor) (1)	−100.0	(2)
	RAS Continuum observations (broadband)	2 690.0-2 700.0 MHz	Single-dish Antenna gain = 0 dBi	Rec. ITU-R RA.769	Aggregate, (5 active UWB/km^2, 20% outdoor) (1)	−100.0	(2)
	RAS Spectral line observations (narrow-band)	3 260.0-3 267.0 MHz	Single-dish Antenna gain = 0 dBi	Rec. ITU-R RA.769	Aggregate, (5 active UWB/km^2, 20% outdoor) (1)	−82.9	(2)
	RAS Spectral line observations (narrow-band)	3 332.0-3 339.0 MHz	Single-dish Antenna gain = 0 dBi	Rec. ITU-R RA.769	Aggregate, (5 active UWB/km^2, 20% outdoor) (1)	−82.9	(2)

Part of Report	Service/ applications	Frequency bands	Victim station characteristics	Protection criteria used in study	Interference scenario	UWB e.i.r.p. density (dBm/MHz)	Comments
Annex 6, § 3 (*cont.*)	RAS Spectral line observations (narrow-band)	3 345.8-3 352.5 MHz	Single-dish Antenna gain = 0 dBi	Rec. ITU-R RA.769	Aggregate, (5 active UWB/km^2, 20% outdoor) (1)	−82.9	(2)
	RAS Continuum observations (broadband)	4 800.0-4 990.0 MHz	Single-dish Antenna gain = 0 dBi	Rec. ITU-R RA.769	Aggregate, (5 active UWB/km^2, 20% outdoor) (1)	−93.4	(2)
	RAS Continuum observations (broadband)	4 990.0-5 000.0 MHz	Single-dish Antenna gain = 0 dBi	Rec. ITU-R RA.769	Aggregate, (5 active UWB/km^2, 20% outdoor) (1)	−93.4	(2)
	RAS Spectral line observations (narrow-band)	6 650.0-6 675.2 MHz	Single-dish Antenna gain = 0 dBi	Rec. ITU-R RA.769	Aggregate, (5 active UWB/km^2, 20% outdoor) (1)	−77.9	(2)
	RAS Continuum observations (broadband)	23.6-24 GHz	Single-dish Antenna gain = 0 dBi	Rec. ITU-R RA.769	Aggregate, (100 active SRR/ km^2) (1)	−109.2	(2)
	RAS Continuum observations (broadband)	~79 GHz	Single-dish Antenna gain = 0 dBi	Rec. ITU-R RA.769	Aggregate, (100 active SRR/km^2)(1)	−97.4	(2)

(1) Analyses used the summation methodology (R_I = 30 m R_o = 500 km), path loss calculated with Recommendation ITU-R P.452 with a percentage of time of 10%, and 2% fraction of data loss due to interference.

(2) Results assume all devices using UWB technology to be active simultaneously.

NOTE 1 – The study conducted by one administration shows that the maximum UWB e.i.r.p. density depends on site specific factors and needs to be calculated on a case by case basis (see an example in § 3.2.1.5.2 of Annex 6 to this Report).

It can be seen from the initial results that for UWB transmissions a spectrum mask that offers protection to the radio astronomy service is required. It is also noted that the geographic separation distances required to meet the RAS protection criteria are substantial and clearly highlight the sharing difficulties between UWB and radio astronomy. The separation distance depends on site specific factors and needs to be calculated on a case by case basis (see an example in § 3.2.1.5.2 of Annex 6).

If all possible mitigation factors (see § 3.2.1.5 of Annex 6), including sufficiently large exclusion zones around radio astronomy antennas, can be applied then sharing between automotive SRR at ~24 GHz and radio astronomy could be possible. Site specific studies have indicated exclusion zone radii of up to 35 km for a uniform density of 100 SRR devices per km^2 from which emission is received by a radio telescope.

If all possible mitigation factors (see § 3.2.1.5 of Annex 6) can be applied then sharing between automotive SRR at ~79 GHz and radio astronomy could be possible.

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Annex 1

Studies related to the impact of devices using ultra-wideband technology on systems operating within the mobile service

1 Land mobile service except IMT-2000

The studies concerning the impact of devices using UWB technology on land mobile systems excluding IMT-2000 systems, received by TG 1/8 to date, have focused on CDMA PCS systems operating in the 800 MHz and 1 900 MHz bands, GSM systems operating in the 900 MHz and 1 800 MHz bands, and WiBro in the 2 300 MHz band. There are other land mobile systems that may require interference analyses with the use of devices using ultra-wideband (UWB) technology. These systems include paging systems, public mobile radio (PMR) systems, trunked mobile systems and other cellular radio systems. Typical system characteristics of many of these systems are in Annex 8 to this Report and contained in Recommendation ITU-R M.1808[9].

1.1 PCS land mobile services

1.1.1 Blocking probabilities in a CDMA PCS system

1.1.1.1 Introduction and approach

If a UWB transmitter is close enough to interfere with a PCS handset, it can have one of two effects:

– it may cause the forward link to allocate more power to the traffic channel assigned to the handset to compensate for the interference; or

– it may cause blockage and dropping of the traffic channel if the maximum allowable power allocation is inadequate to compensate for the interference.

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[9] Technical and operational characteristics of conventional and trunked land mobile systems operating in the mobile service allocations below 869 MHz to be used in sharing studies.

The extent of the required power allocation increase to compensate for the interference will depend on the total forward link power received by the handset from its PCS base station, the PSD radiated by the UWB transmitter within the PCS band, and the distance between the handset and the UWB transmitter. For a CDMA handset close to a device using UWB technology, the cellular call may or may not be affected depending on the received signal strength from the base station. If the handset is close to a base station and the received signal is strong, the handset will compensate for the UWB interference by requesting more power from the base station. This may or may not drop the call depending on whether the maximum power has been allocated. In either case, as more power is allocated, more in-cell interference occurs with a cascading effect of more handsets requesting for more power to compensate. Calls that are already operating close or at the maximum power limit may be dropped. Thus the fact that a handset is close to a device using UWB technology may not necessarily cause that call to be dropped but may cause other calls to be dropped. The approach then is to look at the blocking probability of the whole cell area assuming a uniform distribution of callers.

1.1.1.2 Assumptions

Key assumptions used in simulations are given below:

1 Free-space loss applies for the path between PCS handset and UWB transmitter. This is appropriate given the close spacing required between the UWB transmitter and the PCS handset for any significant impact. The PCS handset and the UWB transmitter antennas are assumed to be aligned with respect to polarization.

2 Up to the limit α_{max}, the forward link will adjust its power allocation just enough to meet the E_b/N_0 requirement. This assumption reflects the power control used in the CDMA forward link.

3 Only the nearest active device using UWB technology affects the PCS handset. With randomly distributed UWB devices, the interference impact on the handset will be dominated by the closest active device. Even when active, it is expected that many types of devices using UWB technology will not transmit continuously, but rather transmit bursts or packets as necessary. In that case, it would not be realistic to sum interference contributions from multiple UWB transmitters, which normally would not all be transmitting simultaneously.

4 There is a uniform distribution of users over the cell area.

1.1.1.3 Results

Applying the blocking methodology in Recommendation ITU-R SM.1757, Table 24 shows the blocking probabilities over a CDMA sector with respect to the UWB transmit power and distance from the device using UWB technology. Table 24 assumes that each PCS handset is exposed to a device using UWB technology at a distance of *X* m. Thus at a UWB PSD of –53.3 dBm, assuming every handset is 1 m away from a device using UWB technology, and a uniform distribution of callers over the cell area, there is a 64.9% probability of blocking within that cell. Fig. 38 shows the same results in a graphical format.

As it is not very probable that all handsets would be exposed to a device using UWB technology within a sector, a more realistic assumption would be that 1 in 10 handsets are exposed. This is certainly probable especially in meeting rooms where one or several devices using UWB technology may be operating. Table 25 and Fig. 39 show the results. Thus at a UWB PSD of –53.3 dBm, assuming 1 in every 10 handsets is 1 m away from a device using UWB technology, there is 6.5% additional probability that calls will be blocked.

TABLE 24

Blocking rates assuming every handset has a device using UWB technology at *X* m
Path-loss component gamma = 3.5 and handset antenna loss = 7.5 dB

UWB PSD (dBm)	Distance from PCS receiver to UWB transmitter (m)					
	No UWB (%)	10 (%)	4 (%)	3 (%)	2 (%)	1 (%)
–41	0.0	30.5	65.9	74.5	83.4	92.4
–53.3	0.0	2.9	15.0	23.1	38.1	64.9
–61	0.0	0.5	3.0	5.3	10.9	30.5
–66	0.0	0.2	1.0	1.7	3.8	13.2
–73	0.0	0.0	0.2	0.4	0.8	3.1

FIGURE 38

Blocking rates assuming every handset has a device using UWB technology at *X* m

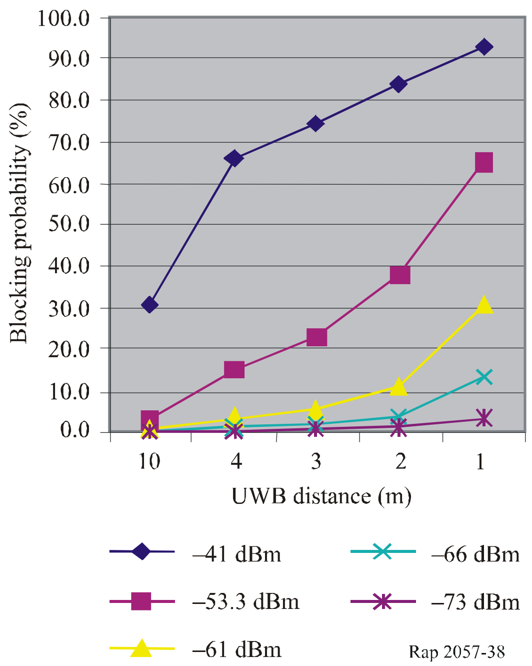


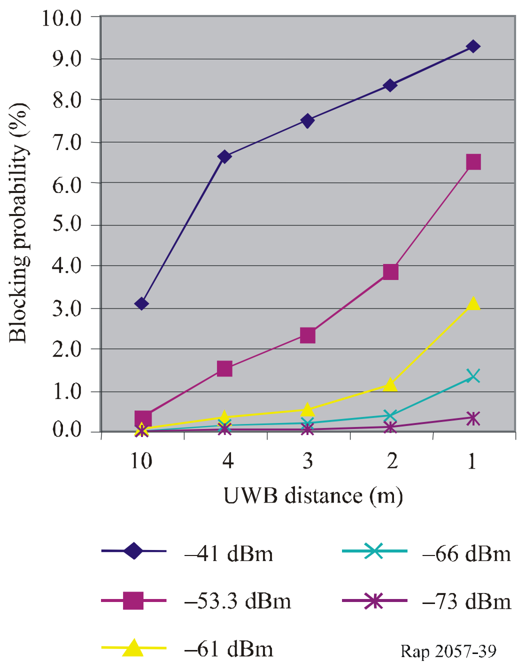
TABLE 25

Blocking rates assuming 1 in 10 handsets has a device using UWB technology at *X* m
Path-loss component gamma = 3.5 and handset antenna loss = 7.5 dB

UWB PSD (dBm)	Distance from PCS receiver to UWB transmitter (m)					
	No UWB (%)	10 (%)	4 (%)	3 (%)	2 (%)	1 (%)
–41	0.0	3.1	6.6	7.4	8.3	9.2
–53.3	0.0	0.3	1.5	2.3	3.8	6.5
–61	0.0	0.1	0.3	0.5	1.1	3.1
–66	0.0	0.0	0.1	0.2	0.4	1.3
–73	0.0	0.0	0.0	0.0	0.1	0.3

FIGURE 39

Blocking rates assuming 1 in 10 handsets has a device using UWB technology at *X* m



The above tabulations assume a handset antenna loss of 7.5 dB. Using the ITU-R recommended antenna loss of 0 dB, Table 26 and Fig. 40 provide the blocking probabilities when 1 in 10 handsets is exposed to the device using UWB technology. In this case with a UWB PSD of –53.3 dBm, and assuming 1 in every 10 handsets is 1 m away from a device using UWB technology, there is 8.6% additional probability that calls will be blocked.

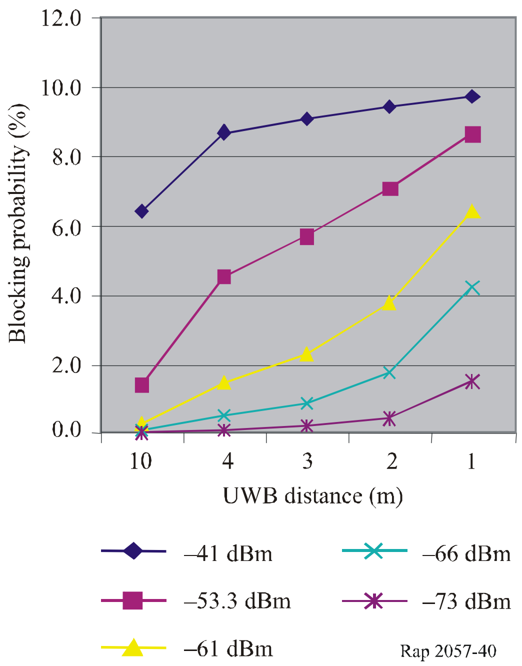
TABLE 26

Blocking rates assuming 1 in 10 handsets has a device using UWB technology at *X* m
Path-loss component gamma = 3.5 and handset antenna loss = 0 dB

UWB PSD (dBm)	Distance from PCS receiver to UWB transmitter (m)					
	No UWB (%)	10 (%)	4 (%)	3 (%)	2 (%)	1 (%)
–41	0.0	6.4	8.6	9.0	9.4	9.7
–53.3	0.0	1.4	4.5	5.6	7.0	8.6
–61	0.0	0.3	1.4	2.2	3.7	6.4
–66	0.0	0.1	0.5	0.9	1.7	4.2
–73	0.0	0.0	0.1	0.2	0.4	1.5

FIGURE 40

Blocking rates assuming 1 in 10 handsets has a device using UWB technology at *X* m



1.1.1.4 Conclusions

The results in the above section show the increase of blocking probabilities when a CDMA system is in proximity of a device using UWB technology. This can be used to determine an adequate UWB PSD from a device using UWB technology given an acceptable increase to the CDMA blocking probability.

1.1.2 Impact tests of devices using UWB technology on PCS land mobile services

This section provides a summary of a series of laboratory tests conducted to assess the impact of UWB emission on PCS phones. The tests, performed in a controlled laboratory environment using conducted tests, evaluate the impact of a single UWB interferer on a single generic receiver (antenna gain and receiver noise figure) and determine the maximum permitted e.i.r.p. level and minimum separation distance to ensure protection of other licensed wireless systems from devices using UWB technology. The laboratory tests were conducted using a CDMA (ANSI-95) compliant PCS phone operating in the 1 750-1 780/1 840-1 870 MHz and 1 850-1 910/1 930-1 990 MHz range.

Although CDMA was the mobile technology used, it is expected that similar results will occur for other PCS technologies. Moreover, the methodology and nature of the results presented here is relevant to all CDMA based land mobile services known to date.

1.1.2.1 Impact of UWB emissions on PCS phones

With regards to the impact of UWB emissions on PCS phones, the tests show that close proximity of devices using UWB technology to a PCS phone operating in the 1 750-1 780/1 840-1 870 MHz and 1 850-1 910/1 930-1 990 MHz range, may degrade the phone’s equivalent noise floor to the extent of rendering its operation useless, especially in marginal coverage areas.

Even at its relatively low transmit level, the emissions from UWB transmitters that are in the victim receiver’s pass band can be large enough to harm the normal operation of the wireless device. If a 1 dB rise in the noise floor is used as a criterion, then the interference power should be 5.85 dB below the noise floor. Table 27 is an interference link budget for CDMA 1 900 MHz phone with an 8 dB noise figure. For illustration purposes, the interference budget has been developed for the current United States UWB emission limit rules for indoor which is –53.3 dBm/MHz.

TABLE 27

Link budget analysis: UWB impact on PCS mobiles

Parameter	Value	Units	Symbol or equation
Frequency	1 900	MHz	F
Thermal noise density	–174	dBm/Hz	KT
Reference bandwidth	1	MHz	B_{ref}
Victim receiver bandwidth	1.23	MHz	B
Victim receiver noise figure	8	dB	NF
Noise floor	–105	dBm	$N = k\,T + B + NF$
Allowed interference level in victim receiver bandwidth	–111	dBm	$I = N – 6$
Allowed interference level in reference bandwidth	–111.9	dBm/MHz	$I + 10 \log(B_{ref}/B)$
UWB e.i.r.p. (United States limits)	–53.3	dBm/MHz	P
Victim receiver antenna gain	0	dBi	G_R
Victim receiver line loss	2	dB	L_R
Path loss required	56.6	dB	$L_p = P + G_R – L_R – \mathrm{I}$
Minimum distance	8.5	m	$20 \log(d) = L_p – 20 \log(f) + 27.5$

The degree to which a CDMA phone is susceptible to interference from a nearby device using UWB technology is dependent on the strength of the CDMA signal. The weaker the CDMA signal, the more susceptible the phone is to the interference from the devices using UWB technology.

The degradation in the wireless device noise floor can be translated into shrinkage in the coverage, which in turn can be translated into an increase in the number of base stations required.

It can be shown that for a propagation exponent *n*, the number of base stations required in the case of UWB interference is:

$$N_2 = 10^{\Delta/(5n)} N_1 \qquad (32)$$

where:

- Δ: degradation in noise floor
- N_2: number of base station in the presence of interference
- N_1: number of base station in the absence of interference.

1.1.2.2 Laboratory tests

A series of laboratory tests were conducted to assess the impact of UWB emission on PCS phones. The focus of this investigation was to assess whether the UWB technology is able to share the spectrum with existing users without serious interference. The assessment of that claim is critical to decisions regarding the deployment and potential ubiquitous use of devices using UWB technology for both communications and sensing.

The primary laboratory test equipment used in the tests included off-the-shelf handsets, compliant with the ANSI-95 CDMA Air Interface Standard. Other equipment used in the tests included an arbitrary waveform generator, a spectrum analyser, a sampling oscilloscope, and a base station emulator (8924C/8960 Mobile Communication Test Set by Agilent Corporation). A Pulse 200 TM UWB signal generator by Time Domain Corporation, which has 4.7 GHz centre frequency, a 3.2 GHz bandwidth and a 9.6 MHz PRF impulse signal satisfying the United States spectral regulations, and a Hyperlabs HL9200 pulse source, is used as UWB sources for the experiment. According to IS-98E for the standard PCS, FER criteria of a receiver are required below 0.5% when the emission level of base station is –104 dBm/1.23 MHz. Using the step attenuator, we increased the power level of the UWB signal in each step by 1 dB and recorded the handset-reported FER and BER at each power level. In order to get reliable data, the measurement was conducted five times under the same conditions.

1.1.2.3 Conclusion

Figures 42 and 43 represent the PCS interference characteristic by impulse UWB. The emission level at 1 m should be given below –72 dBm/MHz to satisfy 0.5% FER when the received power is –104 dBm/1.23 MHz for PCS. In Fig. 43, the maximum allowable UWB emission level is –67 dBm/MHz when sector power is –100 dBm and –61 dBm/MHz when sector power is –95 dBm. Assuming a certain UWB device density, an aggregate interference level should be considered and it will lead to more stringent emission limits of the device using UWB technology.

Figure 41 depicts the degradation in FER as a function of UWB power. The power that caused the FER to deviate from its steady state value was noted as the maximum permissible interference power or interference threshold, I_t, which was found to be –110.9 dBm/MHz (far left plot in Fig. 41) at a CDMA input power of –100.9 dBm/MHz. For a protection distance of 1 m, the path loss is 38 dB and the maximum allowed UWB e.i.r.p. is calculated to be –73 dBm/MHz.

With the proliferation of devices using UWB technology, collocation with PCS devices will become increasingly likely. While this study was limited to the impact of a single device using UWB technology on a PCS phone, it is expected that large numbers of UWB interference sources will significantly raise the overall noise floor of wireless receivers. This noise floor has a significant effect on wireless communications system range. Operation of UWB in the PCS bands will therefore have harmful impact on the normal operation of PCS wireless devices in both voice and data modes. In fact, close proximity of a device using UWB technology to a PCS phone operating in the 1 750-1 780/1 840-1 870 MHz and 1 850-1 910/ 1 930-1 990 MHz range, may degrade the phone's equivalent noise floor to the extent of rendering its operation useless, especially in marginal coverage areas.

FIGURE 41

UWB impact on FER at different CDMA power levels

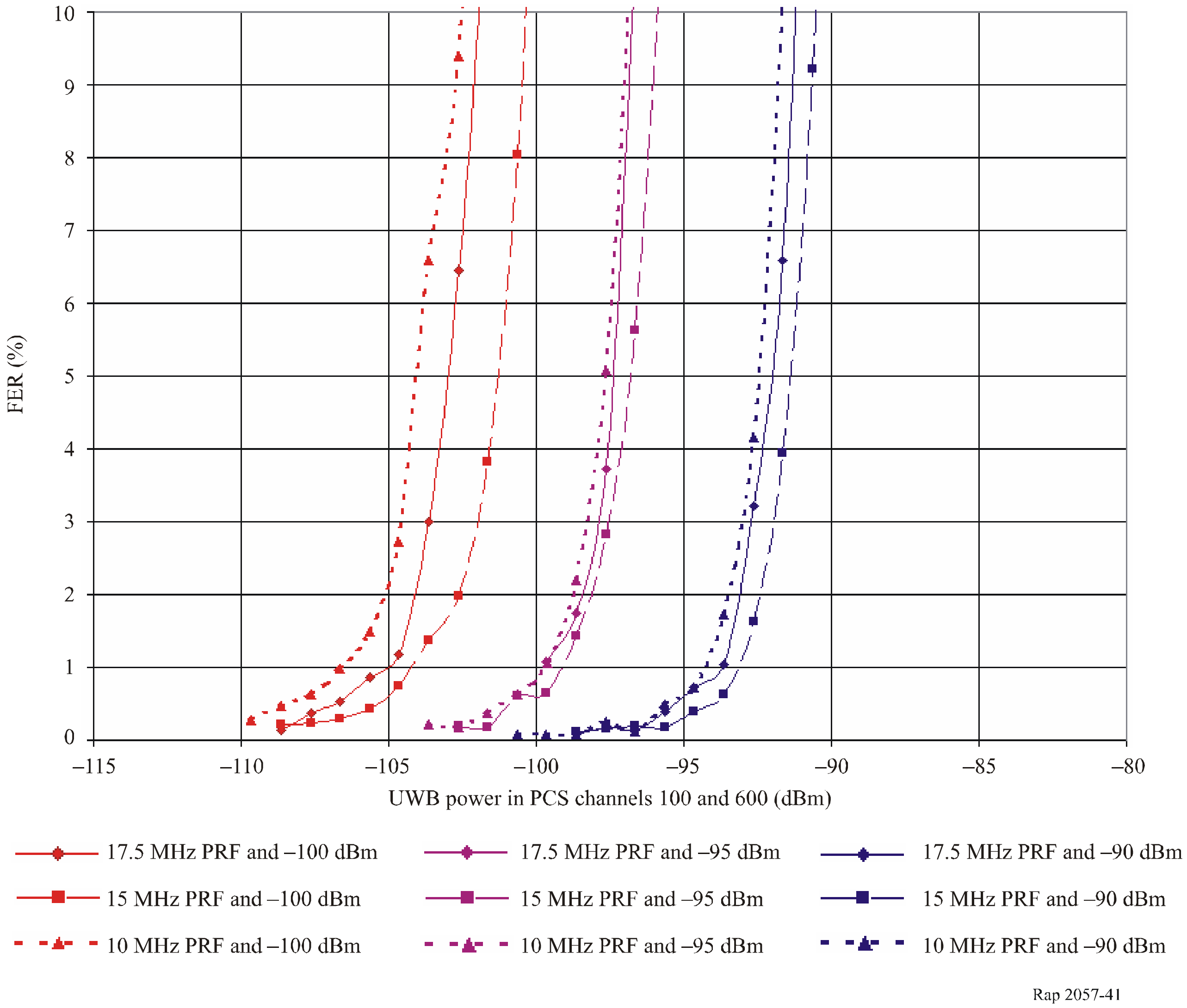


FIGURE 42

Maximum allowable UWB power level at 1 m with PCS sector power

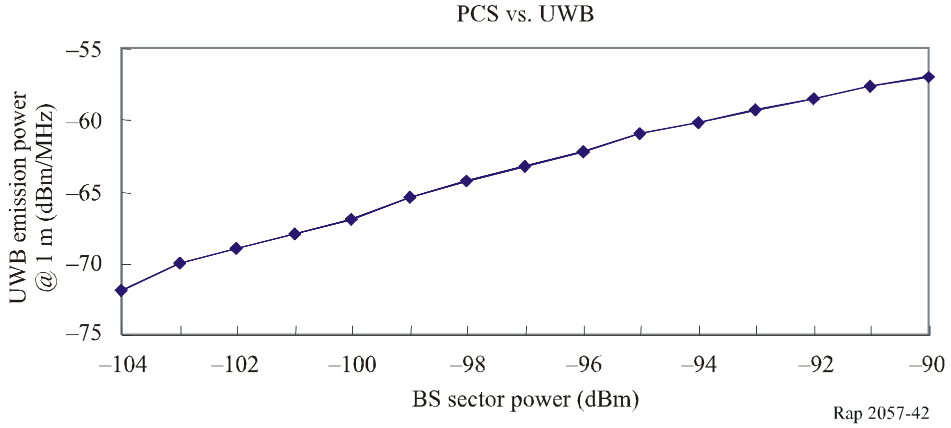


FIGURE 43

FER variation with in-band maximum allowable UWB power level at 1 m
(BS sector power: solid line: –104 dBm, dotted line: –100 dBm, dashed line: –95 dBm)

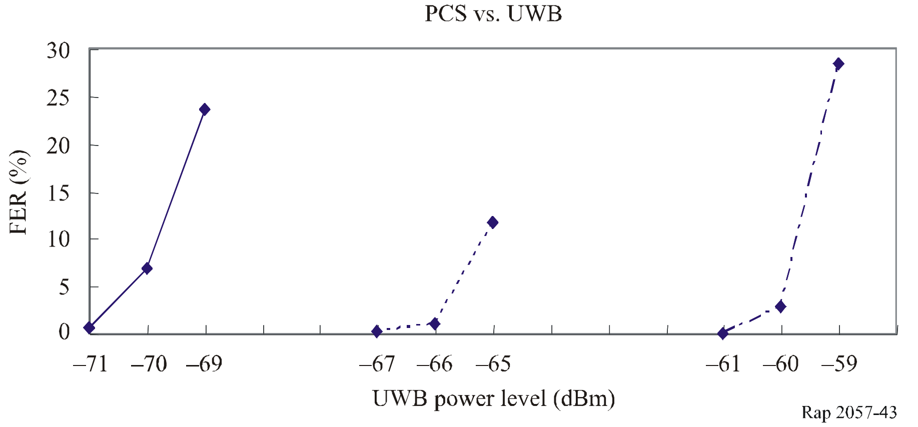


TABLE 28

UWB interference measurement results (UWB power level at 1 m)

	Maximum UWB level (dBm/MHz) at –100 dBm for PCS sector power	United States indoor limit	Slope mask limit
PCS	–73	–53.3	–70.8

1.2 Interference effect of UWB mass deployment on GSM 900 MHz systems

This section assesses the impact of mass deployment of devices using UWB technology on GSM networks in the 900 MHz bands. To evaluate the interference potential, both current United States regulations as well as proposed ETSI regulations (slope mask) were considered. This study is based on free space propagation and does not take into account multipath fading, and assumes LoS for all UWB devices.

The negative effects of extra interference on a GSM system can most clearly be investigated by considering the downlink situation of a mobile terminal, located at the cell edge, i.e. at the limit of coverage. Interference-induced performance loss is much harder to assess in the interior of the cell as there is power control in GSM systems that will adapt the transmission power at the base station, should the *S*/*N* ratio fall below an acceptable value. At the cell edge, however, the base station is already transmitting at maximum power and cannot further increase the transmit power. Therefore, the mobile station has to cope with whatever signal strength may be available. Depending on the level of interference, the GSM performance will be more or less degraded at the edge of the cell, which effectively is equivalent to a reduced cell coverage radius.

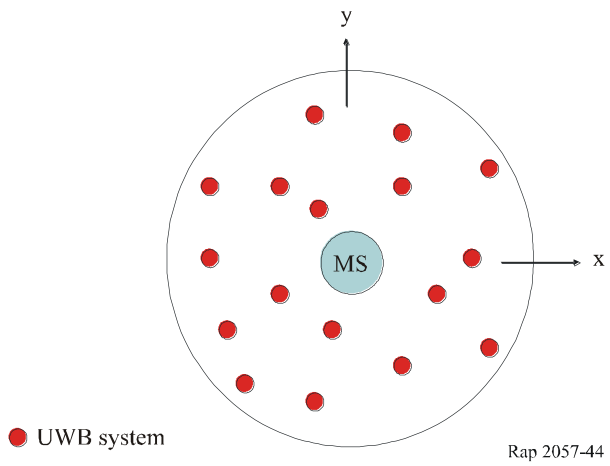
A model to compute the aggregate interference resulting from a mass deployment of devices using UWB technology for different scenarios such as indoor, outdoor or varying UWB device densities is shown below. The method to investigate the effect of the interference from devices using UWB technology is based on a loss with respect to an absolute target single *I*/*N*.

1.2.1 UWB transmitter distribution and resulting interference model

The victim receiver, the mobile station, is located amongst multiple devices using UWB technology. Devices using UWB technology are distributed uniformly over a circular area centred at the victim receiver. Furthermore, UWB transmitters are distributed in a plane, i.e. at the same level as the victim receiver. This permits us to consider a two dimensional situation rather than a three dimensional situation in space, as shown in Fig. 44. The victim receiver is placed at the centre of two concentric circles with radius R_{min} and R_{max}, respectively, with $R_{min} < R_{max}$.

FIGURE 44

A mobile station located amongst UWB transmitters



The resulting interference model using two-ray propagation loss is given by the following equation:

$$UWB\ Interference = 2\pi\rho \mathrm{I}(R_{min}, d_0) P_0 \tag{33}$$

where:

$$I(R_{min}, d_0) = \frac{(d_0 + R_{min})(\ln(d_0 + R_{min}) - \ln(R_{min})) - d_0}{(d_0 + R_{min})}$$

$$P_0 = P_T \left(\frac{\lambda}{4\pi} \right)^2$$

where:

- ρ: density of UWB transmitters within R_{min} and R_{max} (users/m^2)
- P_0: received power using free space loss (mW)
- P_T: UWB transmit power (mW)
- d_0: breakpoint distance (m).

1.2.2 Results for GSM 935-960 MHz

1.2.2.1 Using United States mask

The GSM 900 band is outside of the main UWB band and therefore will receive only sidelobe emissions. The maximum power can be assumed to be limited to −75 dBm/MHz for both indoor and outdoor applications. UWB devices for communications are constrained to have their intended transmission bandwidth in the 3.1 to 10.6 GHz range. Therefore, in the GSM 900 bandwidth the maximum UWB transmit power will be −82 dBm/200 kHz (for both indoor and outdoor).

FIGURE 45

Maximum UWB density with single *I*/*N* = 9 dB (outdoor environment)

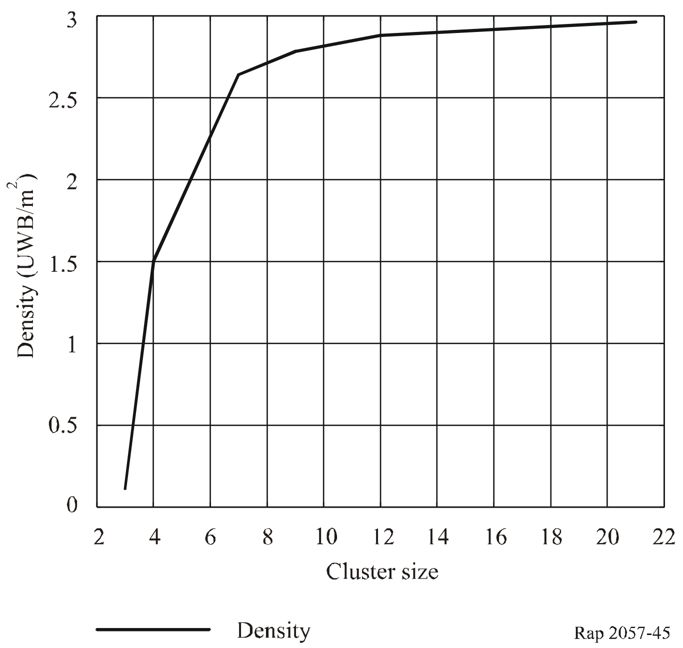


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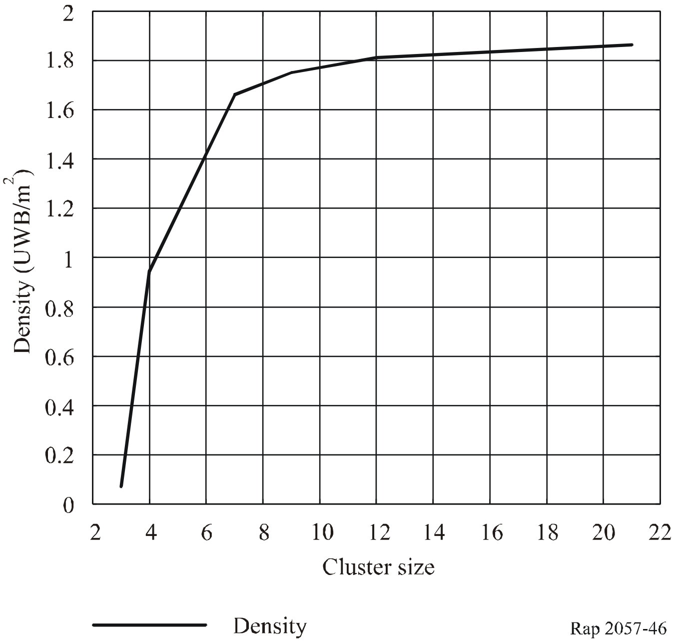
FIGURE 46

Maximum UWB density with single I/N = 9 dB (indoor environment)



In summary, the risk of a mass deployment of UWB devices operating under United States regulations does not pose any serious threat nor result in harmful interference to the GSM 900 system as long as the inband UWB power spectral density is < −82 dBm/200 kHz.

1.2.2.2 Using slope mask

In the GSM 900 bandwidth the maximum UWB transmit power will be –105 dBm/200 kHz (for both indoor and outdoor).

FIGURE 47

Maximum UWB density with single I/N = 9 dB (outdoor environment)

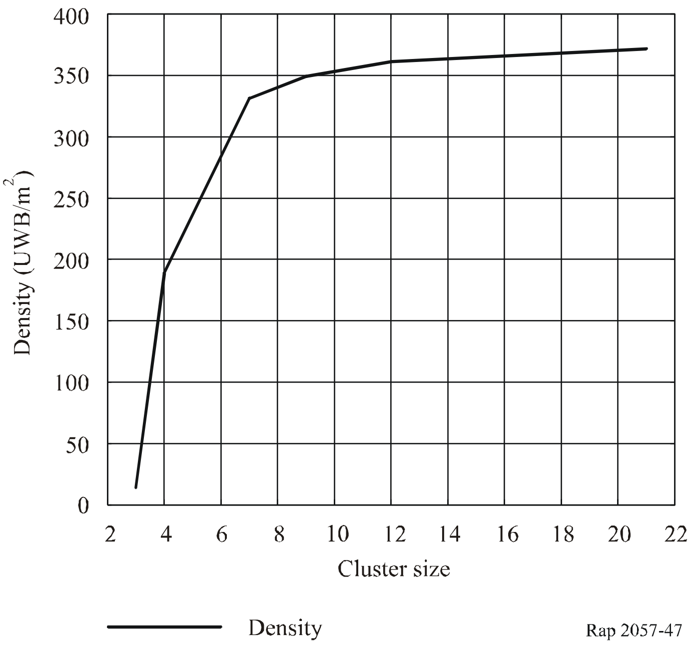
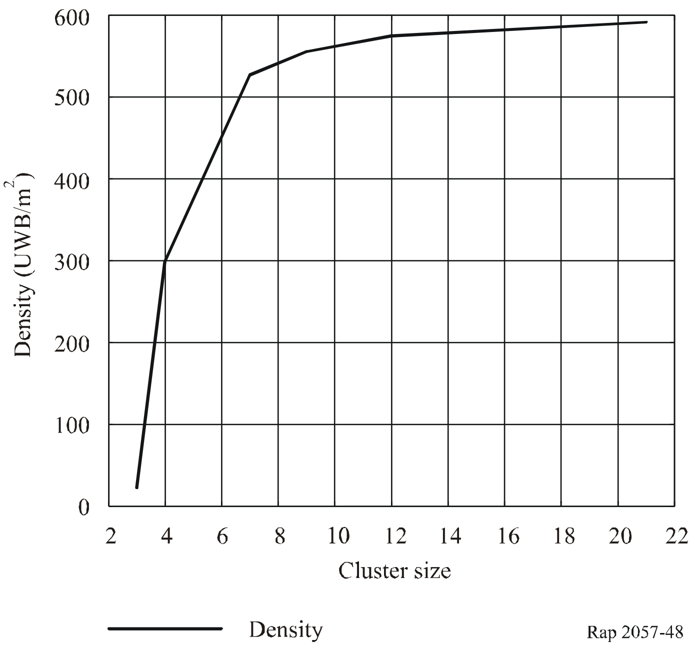


FIGURE 48

Maximum UWB density with single I/N = 9 dB (indoor environment)



In summary, the interference effect in the case of the ETSI power spectral density mask is negligible, even under the most extraordinary UWB deployment assumptions as long as the inband UWB power spectral density is < −105 dBm/200 kHz. This result is intuitively evident due to the 23 dB lower emission limit of ETSI with respect to the United States limits.

1.3 Impact on the land mobile service

Potential interference from a single WPAN device using UWB technology into a 2G/3G mobile station has been estimated. From the interference spectral density and the victim interference threshold (e.g. –111 dBm/MHz), the minimum separation distance needed to avoid excess impact from interference is calculated. Simple propagation models ($1/R^2$ for the first 2 m, then $1/R^4$ for greater, partly-obscured, separation distances) are assumed between the interferer and victim. The results show that mobile terminals will be impacted when there is a separation distance of less than 1.8 m – 2.4 m between a single active UWB WPAN device and an active land-mobile terminal.

2G mobile station required separation distance from handheld devices using UWB technology

				Interpolated UWB emissions			
		Frequency (MHz)		1 805	1 880	1 930	1 990
		Wavelength (m)		0.166	0.159	0.155	0.151
		Interference (dBm/MHz)		–73.47	–72.76	–72.29	–71.73
		Peak/average factor (dB)		6.0	6.0	6.0	6.0
Technology	**Interference threshold (dBm)**	**Bandwidth (MHz)**	**Interference (dBm/MHz)**	**Interference distance (m)**			
IS-95	–110	1.25	–111.0	2.0	2.0	2.1	2.1
IS-136	–126	0.03	–110.8	1.9	2.0	2.0	2.1
PCS1900/DCS1800	–117	0.2	–110.0	1.8	1.8	1.9	2.0

2G mobile station required separation distance from indoor devices using UWB technology

				Interpolated UWB emissions			
		Frequency (MHz)		1 805	1 880	1 930	1 990
		Wavelength (m)		0.166	0.159	0.155	0.151
		Interference (dBm/MHz)		–73.47	–72.76	–72.29	–71.73
		Peak/average factor(dB)		6.0	6.0	6.0	6.0
Technology	**Interference threshold (dBm)**	**Bandwidth (MHz)**	**Interference (dBm/MHz)**	**Interference distance (m)**			
IS-95	–110	1.25	–111.0	2.1	2.3	2.3	2.4
IS-136	–126	0.03	–110.8	2.1	2.2	2.3	2.4
PCS1900/DCS1800	–117	0.2	–110.0	2.0	2.1	2.2	2.3

1.4 WiBro service

1.4.1 Introduction

This section explains how much impact does UWB device give on WiBro mobile station (MS) under indoor environment. The WiBro (high speed mobile Internet service) allocated in the band of 2 300 ~2 400 MHz is being deployed in Korea. The study on the impact of a single UWB device on a single WiBro MS has been accomplished through MCL methodology under consideration of the worst case of scenarios. The I_{UWB}/N of –6 dB is used as the protection requirement criteria. The required isolation and minimum separation distance that the UWB device should not give interference to victim service were obtained by applying MCL approach. The separation distance of 36 cm and 1 m was taken into account for practical indoor environment and then allowable maximum e.i.r.p. density of UWB device was calculated on the basis of I_{UWB}/N protection criteria.

1.4.1 Analysis of the impact of single UWB device on single WiBro MS

In order to analyse how much does a UWB device have impact on a WiBro MS, the system parameters are defined as in Table 29. The interference scenario and methodology to get minimum distance and isolation between interferer and victim so as to protect a WiBro MS service from a UWB device are described as follows:

A. Scenario

- a) Service environment; indoor environment
- b) Interference source; single UWB device
- c) Victim receiver; single WiBro MS
- d) UWB operation conditions
  - 1) UWB e.i.r.p. density; –51.3 dBm/MHz at 2.3 GHz bands (United States indoor)
  - 2) In-band; 3.1 ~ 10.6 GHz
  - 3) Antenna; omnidirection
  - 4) Reference distance; 36 cm or 1 m
  - 5) Reference bandwidth; 1 MHz

e) WiBro operation conditions
   1) Operating frequency; 2 385.5 MHz
   2) Channel bandwidth; 9 MHz
   3) Noise figure; 7 dB
   4) Noise floor; –107 dBm/MHz
   5) Antenna; omnidirection
   6) Implementation loss; 5 dB

f) Pass loss
   1) Indoor path loss
   2) Free-space loss

B. MCL calculation

a) Required isolation calculation

b) Minimum separation distance calculation

TABLE 29

Link budget analysis with MCL methodology

Parameters	Value	Units	Comments
Frequency	2 385.5	MHz	F
Thermal noise power density	–174	dBm/Hz	T = 290 K
Reference bandwidth	1	MHz	B_{ref}
Victim channel bandwidth	9	MHz	B
Victim noise figure	7	dB	N_f
Victim noise floor	–97.3	dBm	$N = kTBN_f$
Protection criteria	-6	dB	I_{UWB}/N
Tolerable interference at victim receiver	–113	dBm/MHz	I_{UWB}+10 log (B_{ref}/B)
UWB e.i.r.p. density (United States indoor limit)	–51.3	dBm/MHz	
Victim receiver antenna gain	0	dBi	
Victim receiver implementation loss	5	dB	
Required isolation	56.7	dB	CL
Path loss (Free space)	LoS		
Minimum separation distance	6.8	m	d
Path loss (Indoor)	CL = 20 log 10(f) + 29 log 10(d)		
Minimum separation distance	3.77	m	d

1.4.2 Allowable maximum e.i.r.p. density of UWB at reference distance

The separation distance of 36 cm and 1 m are taken as reference distance between interferer and victim in considering practical circumstances. The tolerable e.i.r.p. density emission limit of UWB device is calculated according to the protection criteria of I_{UWB}/N at reference distance. The results are summarized in Table 30.

TABLE 30

Tolerable UWB e.i.r.p. density transmission limit at reference separation distance

Reference distance	I_{UWB}/N (dB)	Tolerable UWB e.i.r.p. density transmission limit (dBm/MHz)
36 cm	–6	–76.9
	–10	–80.9
	–13	–83.9
	–20	–90.9
1 m	–6	–68.0
	–10	–72.0
	–13	–75.0
	–20	–82.0

1.5 Cellular mobile services (824-849 MHz/869-894 MHz)

1.5.1 Approach

This section points out impact/interference issues between cellular (824-849 MHz/869-894 MHz) as victim receiver and a single device using impulse UWB technology. The spectral characteristics of the impulse UWB source follow the UWB spectral emission mask of the United States. In this interference experiment, other types of interfering sources such as DS-UWB and MB-OFDM UWB devices are considered as well. However, we observe that low emission level in OoB (below 3 GHz) is very low compared to the current mobile environments and it does not affect current mobile communication service. This is because that DS-UWB and MB-OFDM devices use a very sharp low pass filter in the OoB domain.

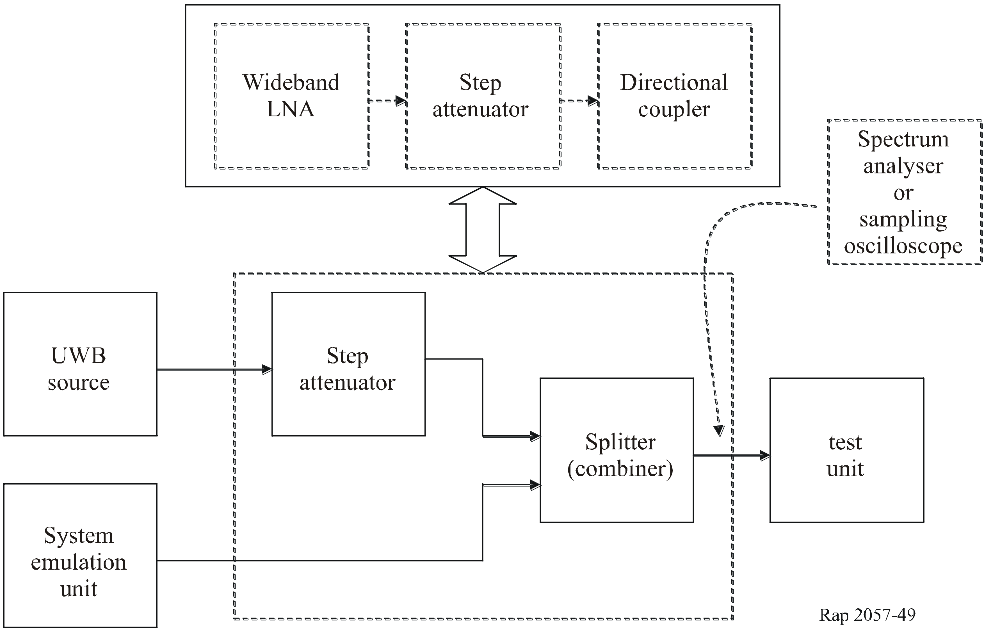
1.5.2 Conducted tests

The impact of impulse UWB signal interference on the cellular downlink signal received by a mobile handset is studied through measurements in the laboratory. A Pulse 200TM UWB signal generator, which has 4.7 GHz centre frequency, 3.2 GHz bandwidth and 9.6 MHz PRF impulse signal satisfying the United States spectral regulation, is used as UWB source for our experiment.

In Fig. 49, the block diagram is represented for the interference measurement between the UWB source and the cellular victim. The victim systems use commercial cellular phones which satisfy the minimum sensitivity of international standards. The 8 960 mobile communication test set by Agilent Corporation is used for the cellular base station. The shield box is used to prevent interference from other communication systems. For the performance evaluation, we used the FER.

FIGURE 49

Setup for UWB interference measurement



According to the standard specifications IS-98E, FER criteria of a receiver below 0.5% are required when the minimum threshold level of the downlink signal is –104 dBm/1.23 MHz. Using the step attenuator, we increased the power level of the UWB signal in each step by 1 dB and recorded the handset-reported FER and BER at each power level. In order to get reliable data, the measurement was conducted five times under the same conditions.

1.5.2.1 Results and analysis

The fact that any UWB interference at all was tolerable even in the case that the total received power from the base station was at the reference sensitivity level indicates that the actual sensitivity of the terminal is better then the reference sensitivity. Had a terminal be used that just meets the reference sensitivity requirement, no UWB interference at all would have been tolerable.

Figure 50 shows the maximum allowable UWB e.i.r.p. density curves for the sector power level to meet the cellular FER criteria. UWB emission levels below –111 dBm/MHz are required in order to satisfy 0.5% FER when the received power of cellular CDMA handset is at –104 dBm/1.23 MHz. If 1 m free-space loss is applied, the maximum allowable UWB emission level will be –80 dBm/MHz or below at 1 m distance. The FER curves are shown in Fig. 51 as the function of the UWB power level for three different sector power levels. We measured the maximum UWB e.i.r.p. density level for the three case of sector power levels: –104 dBm as the worst level, –100 dBm as the cell boundary level, and –95 dBm as level of typical cell environment. Among these sector power levels, it is reasonable to consider –100 dBm as a reference for interference criteria, which is assumed to be weak signal area near cell boundary, because actually –104 dBm is a theoretically derived value and the real environment below –100 dBm only occupies around 1% of the total cell region. At –100 dBm, the UWB emission level is –68 dBm/MHz at 1 m distance. In Fig. 52, E_c/I_0 decreased 0.9 dB for impulse signal, which shows the variation of E_c/I_0 generated when UWB switches from OFF to ON.

FIGURE 50

Maximum allowable UWB power level at 1 m with cellular sector power under the condition of connected call

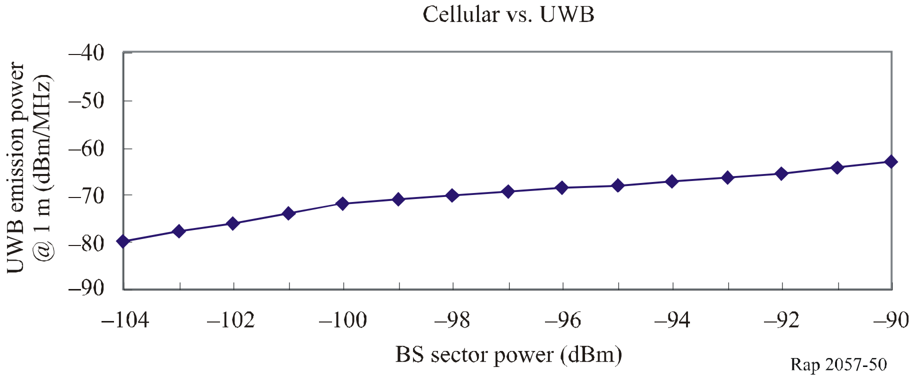


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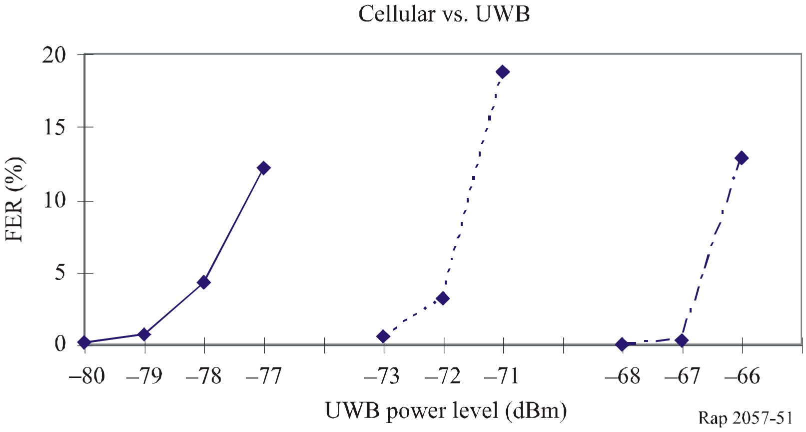
FIGURE 51

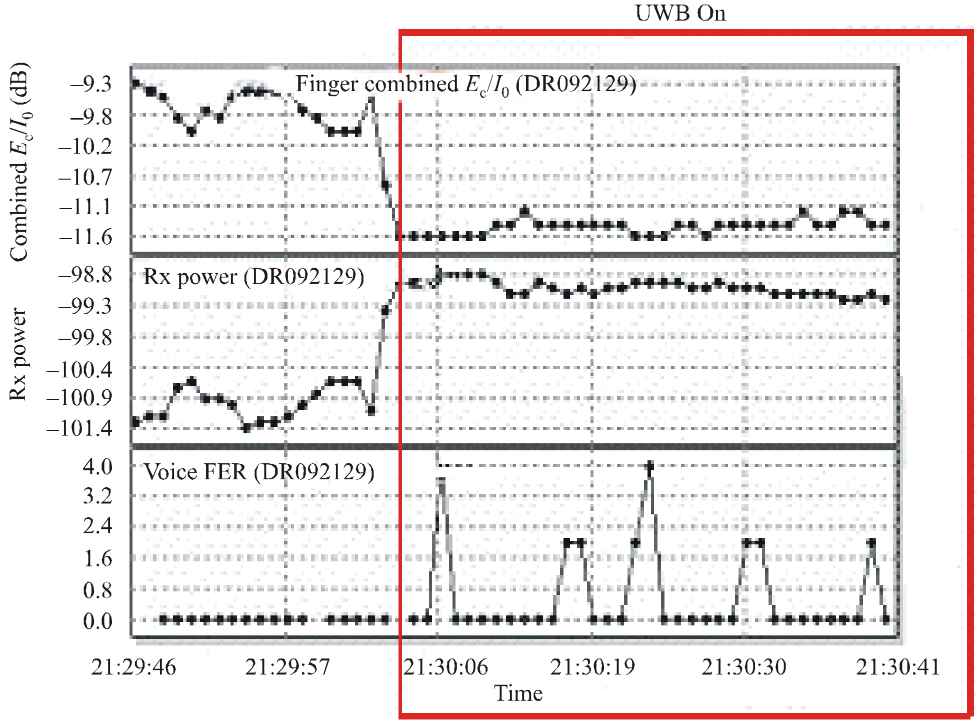
FER variation with in-band maximum allowable UWB power level at 1 m (BS sector power: solid line: –104 dBm, dotted line: –100 dBm, dashed line: –95 dBm)



Rap 2057-51

FIGURE 52

E_c/I_0 change with UWB interference OFF and ON



Rap 2057-52

TABLE 31

UWB interference measurement results (UWB power level at 1 m)

	Maximum UWB level (dBm/MHz) at –104 dBm for cellular			Maximum UWB level (dBm/MHz) at –100 dBm for cellular			United States indoor limit	Sloped mask limit
	Impulse	DS-UWB	MB-OFDM	Impulse	DS-UWB	MB-OFDM		
Cellular	–80	–95	–95	–72	–95	–95	–75.3	–95.6

1.5.2.2 Conclusions

The interference measurement between an impulse UWB signal and a cellular CDMA terminal below 1 GHz, which is used in one of the representative mobile communication systems. Impulse UWB signal with 4.7 GHz centre frequency at 1 m distance and –80 dBm/MHz emission level do not affect the receiver sensitivity following the standard for cellular CDMA. However, this level may be increased if the weak signal area in general service network is assumed. It means the sector power level, –100 dBm, at the cell boundary. DS technique and MB-OFDM which uses OFDM technique were measured, there is no interference between mobile communication services because they use sharp band rejection filters so that the noise level is too low.

It must be noted that the conclusions are based on the assumption of a single UWB interference source per victim receiver. Assuming a certain density of devices using UWB technology, an aggregate interference level should be considered which will lead to more stringent UWB emission limits.

1.6 Impact of devices using UWB technology on both IMT-2000 and land mobile except IMT-2000 terminals

1.6.1 Introduction

A study by one administration assessing the "Compatibility between devices using UWB emissions and both IMT-2000 and land mobile devices operating in the 1 750-1 780/1 840-1 870 and 1 850-1 910/1 930-1 990 MHz frequency band" was considered. Concerns were expressed on this study and a Correspondence Group (CG) of experts was established to progress the work and improve the dialogue between members on the issues raised. The terms of reference of the CG are provided below:

– To identify fully the elements involved in the analysis presented in Document 1-8/294 on the basis of straightforward block diagram of the analysis.

– To commence work on identifying appropriate values for these elements.

– To take into account the outlines of questions, issues and concerns related to Document 1-8/294 as prepared by the Drafting Group Chairmen and the United States.

The final version of this study included in this Report contains some new material that was not considered by the CG. In addition, there are concerns over some of the material added in Appendix 1 to this Annex.; in particular, doubts were expressed on the relevance of the results of the "Average fading sensitivity" test method to operational mobile networks.

The final version of the revised study (§ 1.6.2) and the results of the CG (§ 1.6.3) follow.

1.6.2 A study by one Administration on the impact of UWB emissions on both IMT-2000 and other land mobile devices operating in the 1 750-1 780/1 840-1 870 and 1 850-1 910/1 930-1 990 MHz frequency band

This study draws from one administration's ultra-wideband (UWB) regulations, which were adopted in February of 2002 and refined in 2003[10]. The analysis provided herein demonstrates compatibility between both IMT-2000 and land mobile stations which operate in the 1 750-1 780/ 1 840-1 870 and 1 850-1 910/1 930-1 990 MHz frequency bands and UWB emissions at very close proximities. Further, the methodology used in our analysis is general in nature and therefore applies to all PCS[11] technologies (known to date) without exception. Using the approach discussed in this paper, it is expected that similar results will occur irrespective of the PCS technology considered.

1.6.2.1 Analysis

The initial step in assessing impact of UWB emissions on IMT-2000 and other land mobile receivers is the determination of the receiver signal level, measured at the mobile station antenna connector, at which the FER does not exceed 0.5% FER with 95% confidence – the exact value of this signal

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[10] See FCC document entitled "ET Docket No. 98-153, First Report and Order, Potential interference to PCS from UWB Transmitters," February 14, 2002. https://ecfsapi.fcc.gov/file/6513194036.pdf

[11] In the United States, the second generation cellular system is called Broadband personal communications services (Broadband PCS). Broadband PCS is an FDD system that operates in the bands 1 850-1 910 MHz (mobile station transmit) and 1 930-1 990 MHz (base station transmit). Recently, Broadband PCS was expanded to include the bands 1 910-1 920 MHz (mobile station transmit) and 1 990-2 000 MHz (base station transmit).

depends on the environment in which it is measured[12,13]. In a controlled environment (e.g. an anechoic chamber or conducted testing, where the base station and the mobile handset are connected through a cable – suitable only for testing purposes and not for conducting actual sharing or compatibility studies) this value is equal to –105 dBm/MHz[14]. However, in real world operation, where multipath fading[15] and noise from various sources are present, the minimum operational signal level, measured at the mobile station antenna input, at which the FER does not exceed 0.5% FER with 95% confidence, is typically in the order of –80 ~ –84 dBm, which is supported by the measurement data presented in Appendix 1 to this Annex[16].

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[12] The telecommunications industry standard, ANSI/TIA-98 requires that the RF sensitivity of the mobile station receiver, measured at the mobile station antenna connector is at least equal –104 dBm/1.23 MHz or –104.9 dBm/MHz.

[13] This information is necessary in determining the actual noise floor of the device under test (DUT). The noise floor is then used to solve for the maximum separation distance between UWB and DUT for proper coexistence.

[14] In the IS-98 standards, this received power is measured under conducted testing, which simulates perfect conditions (e.g. no interference either self generated or caused by external sources; perfect channel; LOS; no head/body losses), achievable only in a laboratory environment.

[15] See § 4.6.1.1.2 of this Annex which explains that:

"an indoor environment may reasonably be regarded as quasi-static, meaning little or no movement of the IMT-2000 receiver and principal reflectors. This is known as a slow faded environment, having significantly different fading parameters compared with the outdoor, mobile environment. There is no requirement for a Rayleigh fading margin in the quasi-static case; instead we will need to consider a shadow-fading margin and a slow faded margin. The analysis shows that the slow fading component dominates, giving a net fade margin of 13 dB, under worst-case conditions."

Since this Report is mostly concerned with indoor operation, 13 dB for fade margin is used to be consistent with the documents referenced above.

[16] Using another measurement approach, different from that presented in Appendix 1 to this Annex, two CDMA2000 phones from different manufacturers were tested under fading conditions. The test performed were based on the Rohde and Schwarz application note 1MA64_15e, entitled "cdma2000 receiver tests under fading conditions. The preliminary measurements were –81 dBm/MHz and –86 dBm/MHz.

The application note and other related information is available at:
http://www.rohde-schwarz.com/www/appnotes_files.nsf/ANFileByANNoForInternet/CE6F9CEB5EFA7872C1256F90005981B4/$file/1MA64_15e.pdf.

Additional support is provided by the following references:

ORLENIUS C., KILDAL P. S., and POILASNE G., [2005] Measurements of total isotropic sensitivity and average fading sensitivity of CDMA phones in reverberation chamber (Orlenius is with Bluetest AB, Gothenburg, Sweden, Poilasne is with Kyocera Wireless Corp., San Diego, CA, United States of America), IEEE AP-S International Symposium, Washington D.C., 3-8 July 2005. Additional results are provided at: http://www.bluetest.se/.

This following measurement document was presented before IEEE 802.15 group (wireless PANs), under the title Susceptibility of GSM and CDMA2000 cell phones to UWB signal" at: ftp://ieee:wireless@ftp.802wirelessworld.com/15/05/15-05-0526-02-003a-coexistence-uwb-and-mobile-phones.pdf .

The effect of multipath propagation on a particular CDMA cellular system is presented next. Specifically, for a CDMA system operating outdoors, the RAKE receiver plays the dominant role in mitigating the effects of fading, as illustrated in Figs. 53 and 54[17].

FIGURE 53

Rayleigh-faded PCS signal for a speed of 2 mph

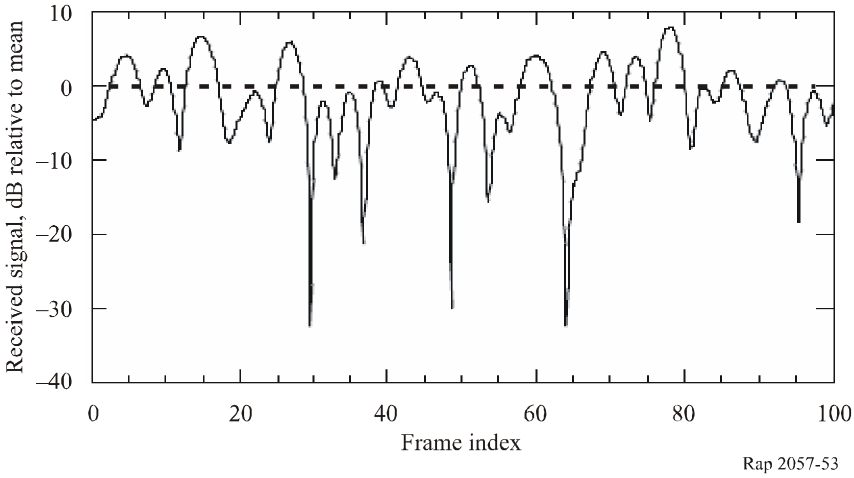
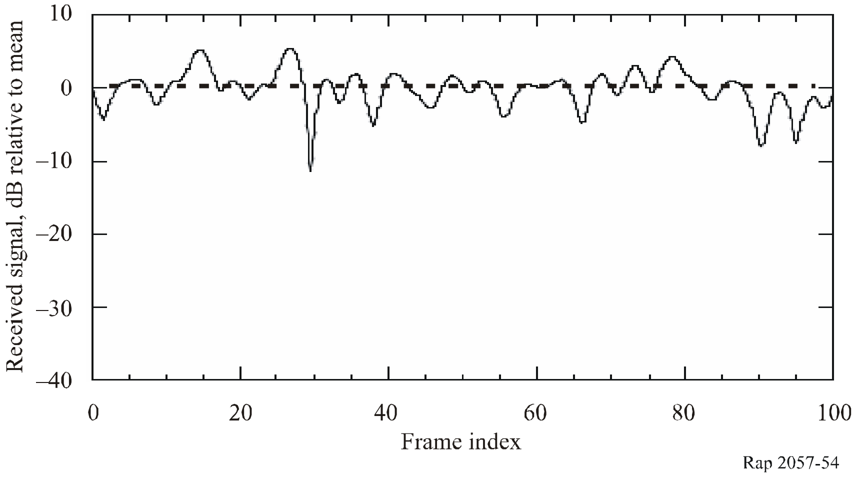


FIGURE 54

Output of 3-branch maximal ratio combiner, 3 independent Rayleigh paths



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[17] For more information on the performance of a Rake receiver, see operational overview of the IS-95 CDMA downlink, Attachment 1, at pages 19-20.

https://ecfsapi.fcc.gov/file/6513198007.pdf.

In addition, the work published on rake receivers is extensive and a significant portion of it has been in existence for a long time. See for example: CHAN, L. B. [1994], Multipath propagation effects on a CDMA cellular system, IEEE Trans. Veh., Technol., Vol, 43, p. 848-855.

Figure 53, is an example of a Rayleigh-faded PCS signal for a walking speed of 2 mph; Fig. 54 shows the response of the RAKE receiver. We note that the response of the Rake is not flat and therefore some fade margin is necessary in order to compensate for the RAKE performance.

A number of studies found that the Rake receiver in IS-95 CDMA performs poorly in indoor environments, due to multipath delay spreads in indoor channels (≈ 100 ns) that are much smaller than an IS-95 chip duration (≈ 800 ns). [Rappaport, 2002]. That is, multipath components with relative delays of less than $\Delta t = 1/B_w$ (i.e. 814 ns, where $B_w = 1.23$ MHz) cannot be resolved and if, present, contribute to fading. [GARG, 2000]. Accordingly, with Fig. 44 likely to resemble the response of the Rake receiver in an indoor environment, a fade margin greater than 20 dB is necessary for a communication link to be possible.

1.6.2.2 Discussion

The analysis presented in the preceding section shows that a significant fade margin is necessary for indoor operations. Further, if the power received, *X* (dBm) must be increased by some margin *Y* dB due to multipath fading, then the effective noise floor, *Ne*, is equal to *Ne* + *Y* (dBm). The operation of a PCS land MS is determined by the interaction of a number of key factors (e.g. nature of channel, self generated noise, interference, components that make up the device, network). The thermal noise floor of the MS – a CDMA handset (TIA/EIA-95, also known as ANSI-95 and cdmaOne) is about equal to –106 dBm/MHz[18]. Another factor is the handset's receive in-cell and other-cell interference, which according to 3GPP TR 25.942 standard contributes a 6 dB rise to the system noise floor. Other factors, include the handset's antenna gain, which in the receive mode is equal to –3 dB[19], the receiver line loss equal to 2 dB[20], and implementation loss[21]. These factors and others result in the following link budget analysis:

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[18] The land mobile receiver has a thermal noise floor, *N*-th = 10 * log (*k T B*) + *NF*, where: *T* = 290 and *NF* = 8 dB (this value has been cited in a number of technical documents and standards), *k* is Boltzmann's constant of 1.38×10^{-23} W/Hz/K, *T* is the device noise temperature (K), and *B* is the bandwidth (Hz). The thermal noise floor = –135.98 dBW/MHz = –106 dBm/MHz.

[19] The –3 dBi value for mobile station antenna gain is reported in a number of technical studies including the following two documents: RE: Written Ex-Party Presentation ET Docket Number 98-155, of March 5, 2001, p. 8, https://ecfsapi.fcc.gov/file/6512561396.pdf.

Also, the wireless telecommunications industry (CTIA) filing also used –3 dBi as the typical value for mobile station antenna gain. See CTIA-The Wireless Association™ Ex Parte Presentation, ET Docket No. 00-258, at 8, July 29, 2004.
https://ecfsapi.fcc.gov/file/6516286222.pdf.

The only measured data provided to the FCC showed that the handset antenna tested had a 0.8 dBi peak gain in the transmit mode; in the receive mode, the antenna gain measured –4.6 dB – the results of the test were consistent with manufacture's antenna datasheet. See ET Docket No. 98-153, comments of September 12, 2000, Attachment 2, "Summary of testing performed to characterize the effect of ultra-wideband (UWB) devices on an IS-95 PCS system," at p. 2, 11 and 12.

[20] This is also known as the cable/connector loss. The value used is consistent with the 3GPP standard TR 25.942 on radio frequency (RF) scenarios at p. 12. The value used is also consistent with the studies in § 1 and § 4 of this Annex.

[21] Implementation loss is due to digital processing in the receiver and includes losses due to clipping at DAC, DAC precision, ADC degradation, channel estimation, carrier tracking, and packet acquisition, among others. Typical values, provided by handset manufacturers, are in the 3 to 5 dB range. These values are also consistent with data provided in this Report. In these analyses, as it is customary done, the implementation loss is treated separate from the receiver noise figure. For a mobile handset, the implementation loss is in order of 2 ~ 5 dB.

TABLE 32

Parameters	Value	Units	Equation
Frequency	1 900	MHz	F
Victim bandwidth	1.23	MHz	B
Reference bandwidth	1	MHz	B_{ref}
Victim receiver noise figure(1)	8	dB	NF
Victim receiver thermal noise [Garg, 2000]	–106	dBm/MHz	$N\text{-}th = 10 \log(k\ t\ b) + NF + 30$
In cell and other cell interference(2)	6	dB	I_{icoc}
Fading loss(3)	13	dB	MF
Noise floor(4)	–86.98	dBm/MHz	$N\text{-}th + I_{icoc} + MF$
Allowed IX level	–92.98	dBm/MHz	$IX = I_{icoc} + N\text{-}th + MF - 6$
UWB emission limit	–53.3	dBm/MHz	I_{UWB}
Head/body loss(5)	6	dB	HBL
Other losses	0	dB	OL
Receiver antenna gain(6)	–3	dBi	G_r
Antenna polarization mismatch(7)	1	dB	AM
Receiver line loss(8)	2	dB	LL
Implementation loss(9)	3	dB	IML
Path loss required(10)	24.68	dB	$Lp = I_{UWB} + G_r - IX - HBL - OL - AM - LL - IML$
Separation distance	0.22	m	$20 \log (D) = L_p - 20 \log (F\ (\text{MHz})) + 27.56$

(1) According to § 1.1.1.2 of this Annex, a typical noise figure for a land mobile station is 8 dB. According to ITU-R M.2039, the noise figure for IMT-2000 is in the 9 to 10 dB range. This noise figure does not include implementation loss. See also Appendix 2 to this Annex for additional details.

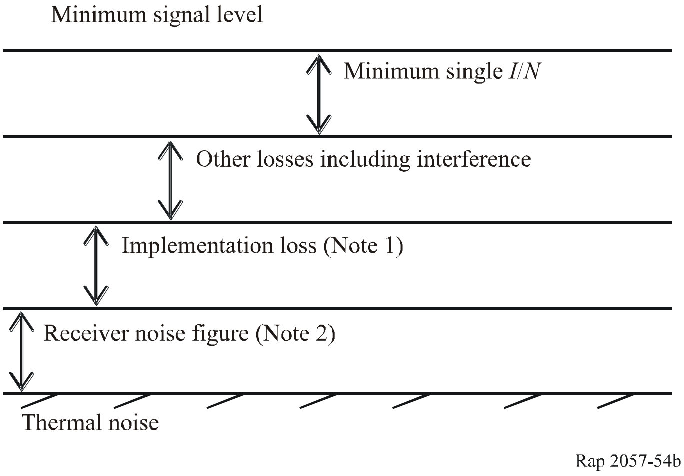
Further, a block diagram depicting the front end of a receiver can be shown to have a noise figure of about 10 dB. This is does not include the implementation loss or and line loss. The insertion loss associated with duplexers, currently used in today's handsets is around 4 dB. For example, a popular duplexer, used in current CDMA handsets (i.e. DFYK series (CDMA1.9) and DFYG series (AMPS/CDMA800)) has an insertion loss in the 4.1 to 4.6 dB range. More information on these filters is found in page 17 of the datasheet, accessible through the following link: http://www.murata.com/catalog/el0260.pdf.

(2) According to United States industry, the handset's receive in-cell and other-cell interference is equal to –98 dBm/1.25 MHz. This is equivalent to –99 dBm/MHz or an increase to system noise floor by about 8 dB. For more details, see, Operational overview of the IS-95 CDMA Downlink, Attachment 1, at p. 4 at https://ecfsapi.fcc.gov/file/6513198007.pdf. We used a lower value to be conservative and consistent with the recommendations of §§ 1 and 4 of this Annex and 3GPP TR 25.942 technical report.

(3) See footnote 16 and 17 [Rapport, 2002; Fujimoto *et al*., 2001a]. See also FUJIMOTO K. and JAMES J.R. [2001] *Mobile Systems Handbook*, 2nd Ed., Norwood, MA: Artech House, Inc., p. 140.

Notes to Table 32 (cont.):

(4) The true noise floor, *N*, of the MS receiver is given by: $N = N\text{-}th + NF + LIMP + I_{icoc} + MF$, where:



N-th is the thermal noise, *NF* represents the noise figure of the receiver, and *LIMP* is the implementation loss due to digital processing in the receiver. *MF* is the fading loss.

NOTE 1 – Exact values depending on manufacturers, typically in the 3 ~ 5 dB range.

NOTE 2 – Exact values depending on manufacturers, typically in the 8 ~ 10 dB range.

(5) Head loss is signal blockage from the head and body of the person holding the MS handset. A number of studies found that the attenuation level may reach 9 and 15 dB for a 5 cm and 1 cm antenna-head distance, respectively. See Chuang H. R. [April, 1994] Human operator coupling effects on radiation characteristics of a portable communication dipole antenna. *IEEE Trans. Ant. Prop.*, Vol. 42, p. 556-560. Further, to understand the impact on UWB on CDMA systems, see Attachment 2, p. 3 (item 4) and p. 9 of a study, jointly conducted by a number of expert parties at: http://gullfoss2.fcc.gov/cgi-bin/websql/prod/ecfs/comsrch_v2.hts?ws_mode=retrieve_list&id_proceeding=98-153&applicant_name=sprint&start=31&end=32&first_time=N.

The Report states that head loss can range between 12 to 15 dB. We used 6 dB to be conservative. For additional references, see for example, http://www.bluetest.se/TCPreport-Bluetest-020204s.pdf.

(6) See footnote 19. See also [Fujimoto *et. al.*, 2001b]. FUJIMOTO K. and JAMES J.R. [2001] *Mobile Systems Handbook*, 2nd Ed., Norwood, MA: Artech House, Inc., pp. 326.

(7) The power received by the handset over a free-space, when held by a user, varies slightly with the handset antenna polarization (roughly 1.5 to 2.5 dB of total variation). See footnote 21 Attachment 2, p. 3. for reference.

(8) This is also known as the cable/connector loss. The value used is consistent with the 3GPP standard TR 25.942 on RF scenarios, at p. 12. The value used is also consistent with some studies in § 1 and § 4 of this Annex.

(9) See footnote 20.

(10) This value is based on the presumption of free space propagation. However, in real world operation, even under worst conditions, loss due to propagation is likely to be much greater than that given by free space. For example, the proximity of the handset to the human body/head, irrespective of angle of incident wave, introduces multipath components – that is because of the inherent ability of the human body/head to reflect energy at certain frequencies. The reference below shows that human skin/muscle and fat (bone) have reflection coefficient equal to 0.76 and 0.41 successively. Therefore, any increase in propagation loss results in reducing the required separation distance between UWB devices and devices operating in the bands studied.

POLK, C. and POSTOW, E. Eds. [1996] *Handbook of biological effects of electromagnetic Fields*, 2nd edition, p. 339.

The UWB emission limit used Table 32 above is taken from one administration's rules for GPRs, wall imaging systems, low frequency through-wall imaging systems, medical imaging systems and indoor UWB devices. Surveillance systems are permitted to place emissions in these bands at a level of –51.3 dBm/MHz, resulting in an increase in the separation distance of 26%, i.e. to 0.28 m. However, we note that surveillance systems are unlikely to be in close proximity to MS handsets. Taking into account the 9 dB attenuation provided by the wall through which the signal must first pass, UWB public safety imaging systems within the United States would place emissions in these bands at a level as high as –50.3 dBm/MHz, resulting in an increase in the separation distance of 41%, i.e. to 0.31 m. However, these devices will be operated under the control of a licensed public safety operator in emergency circumstances. Any equipment located within 0.31 m of the UWB operator also would be under the control of that operator[22]. Vehicular radar systems and hand held (outdoor) UWB devices are permitted to place emissions in these bands at a level of –63.3 dBm, resulting in a decrease to the maximum separation distance of 68%, i.e. to 0.07 m[23].

1.6.2.3 Summary of the study

Our conservative approach resulted in a separation distance of 0.22 m, which demonstrates that the emissions from nearby UWB devices will not cause disruption to the operation of either IMT-2000 or land mobile devices operating in the PCS spectrum. The above interference analysis applies to all PCS IMT-2000 and land mobile devices operating in either indoor or outdoor environments. Accordingly, the United States UWB emission mask sufficiently protects against disruption to the operation of both IMT-2000 and land mobile devices.

1.6.3 Output of the Radiocommunication TG 1/8 Correspondence Group (CG)

Most of the parameters contained in the study by one Administration (see § 1.6.2) were considered in detail by the CG and significant progress was made during the discussion period. The CG started its work by identifying the elements involved in the analysis on the basis of a block diagram, commenced on identifying appropriate values for these elements taking into consideration the source documents, and arrived at consensus on most of the parameters involved in the analysis.

A brief summary of the work of the CG and the related outcomes on the parameters follow. The contributions that were made to the CG are contained in the Appendixes to this Annex.

Note by the Administration of the United States of America – The United States disagrees with the conclusions and general agreement of this Correspondence Group.

1.6.3.1 Summary of CG

1.6.3.1.1 PCS receiver block diagram

The block diagram of the PCS receiver was considered in order to determine the reference point within the PCS receiver at which the I/N analysis should be performed. The information is necessary to understand whether the overall NF of the receiver already takes into account noise contributed by various elements, such as the line loss (LL), the implementation loss (IL), RF front-end components

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[22] Without taking into account the attenuation from the building walls through which the UWB public safety imaging signals must pass, the level permitted from the imaging system is –41.3 dBm/MHz and the separation distance increases to 0.88 m, a distance that still is well within the control of the public safety operator.

[23] In this analysis, UWB devices do not operate within these frequency bands, so it is unlikely that they will produce emissions across the spectrum at the maximum permitted limits. Accordingly, the actual separation distances needed to avoid interference to MS handsets from UWB devices should be smaller than those calculated under theoretical worst case conditions.

etc. Appendices 1 and 3 to this Annex contain two input documents on the PCS receiver design and a detailed discussion on the reference point for the measurement of *I*/*N* as well as the interpretation of NF took place in the CG.

It was therefore concluded that the reference point for *I*/*N* analysis should be at the antenna connector.

1.6.3.1.2 Receiver NF

Information was requested on the values of the various components, such as the diplexer, duplexer, LNA, image reject BPF, mixer, IF filter, comprising a typical PCS receiver chain (see Appendix 2 to this Annex). The purpose of the requested information was to calculate the overall NF of the receiver. Several participants responded by stating that the information about the manufacturer, part number, and gain/loss of the individual components is hard to obtain due to its proprietary nature. In addition, a point was raised that the NF analysis assumes that the RF components are impedance matched and does not fully address the noise figure of mixers but these factors are taken into account in simulation tools used by handset manufacturers. Therefore, provided the system NF is known, it is not necessary to know the performance of individual components beyond the reference point in order to perform the interference analysis. No objection was raised and it was pointed out that the value and interpretation is consistent with what is being used in this Radiocommunication TG 1/8 Report on the impact of devices using UWB technology on radiocommunication services.

It was therefore concluded that the overall NF value should be 8 dB (including noise contributions by the various components comprising the receiver chain).

1.6.3.1.3 Implementation loss (IML)

The authors of the study by one Administration, described in § 1.6.2, defines IML as the losses due to the front-end filtering, clipping at DAC, DAC precision, ADC degradation, channel estimation, carrier tracking, and packet acquisition. Its use in the interference analysis is tied to the interpretation of the NF (see § 1.6.3.1.2). Several participants stated that the overall NF of the receiver already takes into account noise contributed by various RF components in the receiver chain, such as the RF front end, line losses, filters, ADC etc. In addition, a majority of participants stated that the inclusion of additional losses such as the implementation loss and the line loss would further degrade the NF by 6-8 dB bringing the total value of the NF to 14-16 dB, which is not supported by practical implementations and industry experience.

There was a general agreement that implementation loss is not applicable to interference analysis as its effects are taken into account in the overall NF of the receiver.

1.6.3.1.4 Multipath fading

The multipath fading parameter was discussed at length. Several participants raised concerns about the use of the parameter in the interference analysis. It was noted that the multipath fading margin is a design parameter. It is applied to the desired signal to account for the fading effects (destructive interference) of mobile received signals and is used to guarantee coverage at the cell edges with a certain degree of probability. The use of the margin by UWB would mean that the margin does not exist and hence the system would no longer perform as designed. Therefore most participants suggested that the UWB interference impact should be based on the desired receiver sensitivity value. In addition, several participants also suggested that in order to be conservative the additive effects of the UWB interfering signals should be considered at the desired receiver. This would ensure protection of the desired receiver when two UWB signals would add (constructive interference) causing greater interference to the desired receiver. No objections were raised.

It was therefore concluded that multipath fading is not applicable to interference analysis as it is a system design parameter.

1.6.3.1.5 In-cell and outer-cell interference

The study by one Administration, in § 1.6.2, includes a value of –100 dBm/MHz for in-cell and outer-cell interference. The analysis applies a 6 dB noise rise to the baseline thermal noise floor of a PCS CDMA system to take into account the effects of the in-cell and outer-cell interference. The item was discussed and all of the responses to the CG were unanimous in stating that the in-cell and outer-cell interference is a system design parameter and is already taken into account in the desired link budget analysis. One response noted that a possible way to use the in-cell and outer-cell interference is in conjunction with the processing gain of the CDMA system. There was no support for the idea. However, several respondents claimed that the in-cell and outer-cell parameter is only applicable to CDMA and UMTS/W-CDMA technologies. For other technologies in the PCS band such as OFDM and GSM/GPRS/EDGE the in-cell and outer-cell interference does not even apply to the desired signal. All of the responses suggested that the effect of the in-cell and outer-cell interference should not be taken into account in assessing the impact of UWB interference. There were no objections expressed.

It was therefore concluded that in-cell and outer-cell parameter is not applicable to the interference analysis as it is a design parameter. In addition, the parameter is not applicable to all technologies that are operational in the PCS band.

1.6.3.1.6 Receiver antenna gain and receiver line loss

The receiver antenna gain and the receiver line loss parameters were discussed jointly in the CG. Several participants claimed that the net effect of the two parameters is usually included in the measured overall antenna gain of the receiver. It was pointed that typically the PCS receivers exhibit an overall antenna gain in the range of 0-2 dBi since both the conduced and radiated powers are measured and any losses are already included in the measurement. Furthermore, it was noted that although typically the antenna gain measurement is referenced at the transmit chain of the device the overall performance is similar in the receive chain. One reason is that the manufacturers design the VSWR to be similar at both ports. In addition, it was stated that the line loss at the receiver is negligible since the transmission line is only an inch or two in length. One respondent claimed that the line loss of 2 dB used in the study by one Administration in § 1.6.2 is representative of the loss at the base station receiver as specified in 3GPP TR 25.942.

Appendix 3 to this Annex contains actual measurement data on the overall antenna gain of three recent PCS mobiles, which confirmed the arguments that were made earlier by the various participants. The average peak antenna gain in both directions was measured to be in the range of –1 to +3 dBi.

Due to the variability in the measurement of the parameters and in line with the various inputs, a range of values was suggested to represent the combined effect of the receiver antenna gain and the line loss: –1 to +2 dBi.

1.6.3.1.7 Head/body loss

The head/body loss parameter used in the study by one administration was discussed in the CG. Most participants expressed that in indoor environments the head/body will not necessarily be in between the interfering signal and the victim receiver. In most case there will be a direct line of sight between the UWB signal and the PCS receiver. Examples include wireless headsets, phone placed on a desk or in a jacket/purse, hands free mode etc. Thus the head/body loss is not relevant to the interference analysis. Further a comment was raised that the head/body loss should only be considered in the desired link budget analysis. No objections were raised.

It was therefore concluded that the head/body loss is not applicable to the interfering analysis.

1.6.3.2 Summary of conclusions

The table below utilizes the values that were agreed in the CG and derives the separation distance to protect PCS receivers in the presence of an interfering UWB device, for a UWB Emission limit of –53.3 dBm/MHz.

Parameters	Conclusions reached by Radiocommunication TG 1/8 CG	Values in the study by one Administration	Units	Equation
Frequency	1900	1 900	MHz	F
Victim bandwidth	1.25	1.23	MHz	B
Reference bandwidth	1	1	MHz	B_{ref}
Victim receiver noise figure	8	8	dB	NF
Victim receiver thermal noise	–106	–106	dBm/MHz	$N = 10 \log (k\ t\ b) + NF + 30$
In cell and other cell Interference	Not applicable	–100	dBm/MHz	I_{icoc}
Multipath fading	Not applicable	5	dB	MF
Noise floor	–106	–94	dBm/MHz	$I_{icoc} + N + MF$
Allowed IX level	–112	–100	dBm/MHz	$IX = I_{icoc} + N + MF - 6$
UWB emission limit	–53.3	–53.3	dBm/MHz	I_{UWB}
Head/body loss	Not applicable	6	dB	BL
Receiver average antenna gain	+0.5 (averaged)	–3	dBi	G_r
Receiver line loss	Accounted in the overall antenna gain	2	dB	LL
Receiver diplexer loss		0	dB	IL
Antenna polarization mismatch		0	dB	AM
Implementation loss	No conclusions reached but a general agreement	0	dB	Not contained
Path loss required	59	35.72	dB	$L_p = I_{UWB} + G_r - IX - LL - IL - BL - AM$
Minimum distance	11.2	0.77	m	$20 \log (D) = L_p - 20 \log (F, \text{MHz}) + 27.56$

2 Maritime mobile service

2.1 Introduction

2.1.1 Ship operations

Convention ships (which are passenger ships and cargo ships over 300 gross tonnage) carry communication equipment to comply with the requirements of Chapter IV of the International Convention for the Safety of Life at Sea (SOLAS) published by the International Maritime Organization (IMO). The system used is called the Global Maritime Distress and Safety System (GMDSS). In the GMDSS ships carry equipment, which ensures that they always have two independent radio systems available to them which will permit the transmission of a distress alert to shore.

An Emergency Position Indicating Radio Beacon (EPIRB) operating at 406 MHz (Cospas-Sarsat) or 1.6 GHz (Inmarsat) is a carriage requirement for all Convention ships and is generally employed as one means of alerting. For the second means of alerting, ships within VHF range of shore stations fitted with digital selective calling (DSC), known as A1 sea area, carry VHF equipment operating in the band 156-163 MHz which includes DSC. Ships operating within MF range of DSC shore stations (A2 sea area) carry MF radio operating in the band 1 605-3 800 kHz with DSC. Ships operating beyond MF range (A3 sea area) carry Inmarsat equipment operating at 1.5/1.6 GHz. Ships operating beyond the range of the Inmarsat geostationary satellites (70º N and S known as the A4 sea area) carry HF radio operating in the maritime mobile bands between 4 and 27.5 MHz with DSC. Communication at HF may be by radiotelephony or radiotelegraphy which is known as narrow band direct printing (NBDP). A2 and A3 ships are also required to carry duplicate equipment to mitigate against failures so most deep sea ships carry both Inmarsat and HF.

Convention ships receive safety information over a system called NAVTEX which operates at 490 and 518 kHz when in coastal areas and over a system called SafetyNet which is operated by Inmarsat at 1.5 GHz when beyond coastal areas.

For Search and Rescue purposes, Convention ships carry a number of search and rescue transponders (SART) which operate in the 9 GHz band, handheld VHF radios and passenger ships carry a radio operating on the aeronautical frequencies of 121.5 and 123.1 MHz.

Many Convention ships carry on-board communication equipment operating at 460 MHz.

Non-Convention ships (that is ships which are generally not subject to SOLAS requirements such as pleasure craft) carry radio equipment to similar standards but not necessarily the complete SOLAS fit.

2.1.2 Shore operations

Coast stations provide facilities for Maritime Rescue Coordination Centres (MRCC) to maintain DSC and aural watch. MRCCs also have associated Inmarsat Land Earth Stations and Cospas-Sarsat Mission Control Centres. MRCCs act on distress alerts by coordinating search and rescue resources (aircraft and ships) and provide safety information to ships. Inmarsat and some coast stations also provide public correspondence facilities.

2.1.3 Port operations

Ports use frequencies in the RR Appendix 18 VHF band for communicating with ships. Ports offer vessel traffic services (VTS) which often require the use of radar in the 3 GHz or 9 GHz bands and automatic identification systems (AIS) operating in the VHF band.

2.1.4 Maritime radionavigation service

Convention ships carry navigation equipment to comply with Chapter V of the SOLAS Convention. All ships are required to carry an electronic position fixing system which is typically a global navigation satellite system (GNSS) such as GPS but may be LORAN-C operating in the band 90-110 kHz. GPS may be differentially corrected using signals from radiobeacons operating in the band 285-325 kHz. All ships carry a radar operating in the 9 GHz band and larger ships additionally carry a radar operating in the 3 GHz band. All ships carry automatic identification systems (AIS) operating in the VHF band.

Non-Convention ships carry similar equipment voluntarily but the equipment may be to reduced technical standards.

2.2 Assumptions and calculations

Detailed protection criteria for maritime radio services are not listed in the relevant ITU-R Recommendations and consequently the receiver sensitivity values have been based on the International Electrotechnical Commission (IEC)/European Norm Standard EN 60945. This Standard typically lists receiver sensitivity levels as field strengths in μV/m, but in some instances it also lists levels as e.m.f.s. Where e.m.f. levels have been listed, nominal/typical antenna gain values have been assumed in order to assess the level of interference at the receiver input. Where receiver field strengths sensitivities have been listed, the interference is assessed as a field strength for comparison.

No account has been taken of near field effects, nor of feeder losses and the antenna gains are nominal and will be dependent on the particular antenna used. The UWB interference is assessed as noise-like. The bandwidths of the maritime receivers have been obtained from various standards/recommendations and in some cases channel spacing have been used. In the case of radars, typical bandwidths and noise figures have been used.

The criteria (threshold) used for interference are as follows. In the case of interference to radars, there are established ITU-R Recommendations (ITU-R M.1460) series and a value of I/N of –10 dB is used. In the case of other equipment, a protection ratio (wanted to unwanted signal) of 10 dB is used. It should be noted that in both cases these values are increased by a further 6 dB in order to cater for multi-system interference.

A free space transmission loss was assumed in the calculations and polarisation discrimination was not considered. The effect of UWB interference was assessed for two distances – 10 m for the case of UWB devices on board the ship and 300 m for the case of UWB devices on shore.

The integral aggregate model was used to determine the densities of UWB emitters allowable. A receiver antenna height of 15 m was used which is the IMO assumed height for a radar antenna. This height gives a horizon distance:

$$R = 4.63 \sqrt{15} = 18 \text{ km} \tag{34}$$

Thus the aggregate interference A (Watts per unit bandwidth)

$$A \approx 2\pi \, \rho \, \alpha \, \eta \, \ln((R/R_0) \tag{35}$$

where:

ρ: average density of UWB emitters/m^2 in the observed zone and for which values of 1, 10, 100, 1 000, 10 000, 5, 50 and 500 emitters/km^2 were used

α: $W_{eirp} (\lambda/4\pi)^2 \, g_r$

where:

W_{eirp}: average UWB device e.i.r.p. (W/unit bandwidth)

λ: wavelength at the centre of the receiver passband (m)

g_r: receiver antenna gain in the horizontal plane

η: activity factor taken as 5%

R: observed zone taken as 18 km

R_0: minimum radius of calculation taken as 300 m.

So if W_{eirp} is expressed in mW/MHz:

$$A = 8.14.10^{-3}\ \rho\ W_{eirp}\ \lambda^2\ g_r \qquad \text{mW/MHz} \qquad (36)$$

This aggregate interference *A* assumes the victim receiver receives UWB interference over a complete circle so for directional antennas is corrected for the antenna beamwidth.

2.3 Results

Tables 33 to 36 indicate the process used for determining the maximum e.i.r.p. of a UWB emitter for a maritime receiver. In addition, an indication of the maximum e.i.r.p. for the densities of UWB emitters/km^2 for maritime receiver protection is given with a nominal height separation of 15 m.

Cospas-Sarsat and Inmarsat services have not been considered as these are covered in Annex 4, § 1. Similarly GNSS has not been considered as this is covered as RNSS in Annex 4, § 2. The search and rescue portable radios operating in the maritime bands and aeronautical bands have not been considered as these are generally only used when ships are in distress in remote locations. Similarly the SART which is only used in distress situations is not considered further.

2.4 Conclusions

Three circumstances are of interest for the maritime services – the effect of UWB devices on board a ship to the ship's systems, the effect of UWB devices located on shore to the ship's systems and the effect of UWB devices to shore/port stations.

Regarding the use of UWB devices on board a ship, the most sensitive communication system is the VHF which requires a UWB e.i.r.p. limited to –75 dBm/MHz at 158 MHz. This is below the United States limit of –41.3 dBm/MHz. In the case of navigation systems, the radars operating in the band 2 900-3 100 MHz requires a limit of –82 dBm/MHz at 3 000 MHz and radars operating in the band 9 300-9 500 MHz require –72 dBm/MHz at 9 400 MHz. Based on these studies calculations these e.i.r.p. densities will be exceeded. So the use of UWB devices on board will be precluded until further study of the actual impact on ships radars has been determined.

Regarding UWB devices on shore, the e.i.r.p. limit at VHF is –45 dBm/MHz and the above limit of –72 dBm/MHz is required for an aggregate interference in the urban case of 10 000 devices/km^2. Again there does not appear to be a problem to ship communication systems. For the radar systems, the limits are –53 dBm/MHz for radars operating in the band 2 900-3 100 MHz and –43 dBm/MHz for those operating in the band 9 300-9 500 MHz. These limits reduce to –61 dBm/MHz and –51 dBm/MHz respectively for aggregate interference in the urban case, although this situation is very unlikely to be encountered by ships. There appears to be a possible problem therefore with ship radar systems, particularly those in the band 2 900-3 100 MHz, although the physical locations where this shore based interference might arise may be limited and subject to further study.

Regarding shore/port stations, the effect on communication receivers is similar to the ship case so there should not be a problem. In the case of shore based radar systems associated with vessel traffic services, these radars look out to sea and are sector blanked when scanning over the shore so they may not be as severely affected by UWB devices as the ship case.

TABLE 33

Maritime radiocommunication equipment characteristics

Equipment type	Frequency band (MHz)	Frequency used for calculation (MHz)	Bandwidth (kHz)	Receiver sensitivity	Nominal antenna gain (dB)	Minimum Rx field strength sensitivity (dBμV/m)	Minimum wanted field strength pfd at antenna (dBm/m^2/MHz)	Protection ratio 10 dB + 6 dB (multi system) (dB)	Maximum allowable UWB field strength pfd at antenna (dBm/m^2/MHz)
LORAN	0.09-0.11	0.1	20	20μV/m	0	26.02	–72.75	16	–88.75
DGNSS	0.285-0.325	0.304	0.5	5μV/m	0	13.98	–68.77	16	–84.77
NAVTEX	0.490-0.518	0.504	0.27	–	0	44.0	–36.08	16	–52.08
MF radiotelephony	1.6-3.8	2	3	25μV/m	0	27.96	–62.58	16	–78.58
HF radiotelegraphy	4-27.5	8.4	0.5	25μV/m	0	27.96	–54.79	16	–70.79
HF radiotelephony	4-27.5	8.4	3	25μV/m	0	27.96	–62.58	16	–78.58
VHF DSC	156-163	158	25	1μV e.m.f.	3	10.7	–89.04	16	–105.04
VHFradiotelephony	156-163	158	25	2μV e.m.f.	3	16.7	–83.04	16	–99.04
UHFradiotelephony	457-467	460	12.5	2μV e.m.f.	3	25.7	–71.03	16	–87.03

TABLE 34

Maritime radiocommunication equipment interference from UWB scenario

Equipment type	Maximum UWB power into receiver antenna (dBm/MHz)	Maximum allowable UWB e.i.r.p. for a single device at distances of: (dBm/MHz)		Maximum allowable UWB e.i.r.p. for receiver height of 15 m and multiple devices with 5% activity factor and at densities of: (dBm/MHz)							
		d = 10 m	*d* = 300 m	1/km²	10/km²	100/km²	1 000/km²	10 000/km²	5/km²	50/km²	500/km²
DGNSS	–35.9	–53.7	–24.2	–14.9	–24.9	–34.9	–44.9	–54.9	–21.9	–31.9	–41.9
NAVTEX	–7.6	–21.1	8.5	17.8	7.8	–2.2	–12.2	–22.2	10.8	0.8	–9.2
MF radiotelephony	–46.0	–47.6	–18.0	–8.7	–18.7	–28.7	–38.7	–48.7	–15.7	–25.7	–35.7
HF radiotelegraphy	–50.7	–39.8	–10.3	–0.9	–10.9	–20.9	–309	–40.9	–7.9	–17.9	–27.9
HF radiotelephony	–58.5	–47.6	–18.0	–8.7	–18.7	–28.7	–38.7	–48.7	–15.7	–25.7	–35.7
VHF DSC	–107.5	–74.1	–44.5	–32.1	–42.1	–52.1	–62.1	–72.1	–39.1	–49.1	–59.1
VHFradiotelephony	–101.5	–68.1	–38.5	–26.1	–36.1	–46.1	–56.1	–66.1	–33.1	–43.1	–53.1
UHFradiotelephony	–98.7	–56.0	–26.5	–14.1	–24.1	–34.1	–44.1	–54.1	–21.1	–31.1	–41.1

TABLE 35

Maritime radionavigation equipment characteristics

Equipment type	Frequency band (MHz)	Frequency used for calculation (MHz)	Bandwidth (MHz)	Receiver sensitivity	Nominal antenna gain (dB)	Nominal noise figure (dB)	Noise at Rx IF output (using kTBF) (dBm/MHz)	Protection ratio 10 dB + 6 dB (multi system) (dB)	Maximum UWB power into receiver (dBm/MHz)	Maximum UWB power into receiver antenna (dBm/MHz)
S band radar	2 900-3 100	3 000	20	–	25	5	–109	10	–119	–144
X band radar	9 300-9 500	9 400	20	–	25	5	–109	10	–119	–144
SART	9 200-9 500	9 350	20	– 80 dBW	1.5	5	–109	16	–125	–126.5

TABLE 36

Maritime radionavigation equipment interference from UWB scenario

Equipment type	Maximum UWB power into receiver antenna (dBm/MHz)	Maximum allowable UWB e.i.r.p. for a single device at distances of: (dBm/MHz)		Maximum allowable UWB e.i.r.p. for receiver height of 15 m and multiple devices with 5% activity factor and at densities of: (dBm/MHz)							
		d = 10 m	*d* = 300 m	1/km^2	10/km^2	100/km^2	1 000/km^2	10 000/km^2	5/km^2	50/km^2	500/km^2
LORAN	–10.2	–57.7	–28.2	–18.9	–28.9	–38.9	–48.9	–58.9	–25.9	–35.9	–45.9
S band radar	–144.0	–82.0	–52.5	–20.5	–30.5	–40.5	–50.5	–60.5	–27.5	–37.5	–47.5
X band radar	–144.0	–72.1	–42.6	–10.6	–20.6	–30.6	–40.6	–50.6	–17.5	–25.5	–35.5
SART	–126.5	–54.6	–25.1	–15.7	–25.7	–35.7	–45.7	–55.7	–22.7	–32.7	–42.7

3 Aeronautical service

UWB devices have the potential to cause harmful interference to aeronautical safety services. The development of provisions regulating the spectrum access for UWB devices should therefore be built up on a sound technical basis.

In order to assess under what conditions UWB is likely to cause interference to aviation systems an understanding of what is considered "harmful interference" in respect of aviation systems needs to be determined. In this regard, particular care is necessary with systems in which the output is neither aural nor visual, such as modern digital systems or systems where the output is used to operate control systems, and detection may go unnoticed for some time.

No. 1.169 of the RR defines "harmful interference" as:

"*Interference* which endangers the functioning of a *radionavigation service* or of other *safety services* or seriously degrades, obstructs, or repeatedly interrupts a *radiocommunication service* operating in accordance with Radio Regulations (CS) ."

Once the maximum tolerable interference signal power has been defined, a total tolerable aggregate protection level for all interference sources at an appropriate point (e.g. the receive antenna) within the aviation system can be defined. This aggregate protection level then has to be apportioned since a single interference system/network should not be able to claim the total aggregate protection margin. Knowing the apportioned aggregate protection level, the minimum coupling loss required between a single UWB source and the victim receiver can be calculated. Once the minimum coupling loss is known a minimum separation distance for a single UWB device and the maximum UWB density can be calculated assuming free-space path loss.

The maximum value of UWB interference signal power that still allows the receiver to meet its performance requirements needs to be derived by measurements. The results of these measurements may be specific to the UWB waveform tested. Therefore, the most threatening UWB signal characteristic needs to be determined and use for laboratory testing of aeronautical receivers. It may also be necessary to conduct field-testing on operational aircraft. Recommendation ITU-R SM.1140 may provide guidance in the development of test procedures for measuring aeronautical receiver characteristics to be used for determining the influence of emissions from UWB devices into aeronautical receivers

Having determined the maximum tolerable UWB signal level at the receiver input a value for a single UWB device can then be calculated using the following formula:

$$EIRP_{MAX} = I_{UWB\text{-}max} + L_R + L_{AF} - L_{safety} - L_{allotment} - L_{multiple} \tag{37}$$

where:

$EIRP_{MA}$: tolerable interference emission limit of a single UWB device (dB(mW/MHz))

I_{UWB_max}: maximum level of UWB interference signal power at the victim receiver antenna port that still allows the victim receiver to meet its performance requirements. To be derived by measurements when the desired signal is at the appropriate minimum required level, and the result may be specific to the UWB waveform tested (dB(mW/MHz))

L_R: insertion loss (loss between the receiver antenna and receiver input) (dB). A zero dB may be assumed if no value is available; or other obstructions based on the deployment scenario (e.g. indoor)

L_{AF}: activity factor of the UWB device (dB)

L_{safety}: aeronautical safety service margin (dB) (see also Recommendations ITU-R M.1477 and ITU-R M.1535)

$L_{allotment}$: factor to be considered if there is a potential for other than UWB interference sources at the same time, an allowance should be made for the aggregate interference (dB)

$L_{multiple}$: factor to be considered if there is a potential for more than one UWB source of interference at the same time, an allowance should be made for the aggregate interference (dB). For the determination of $L_{multiple}$ the formula given for the airborne aggregate model may be used after rearrangement:

$$L_{multiple} = 10 \log\left(\frac{\lambda^2 \cdot G_R \cdot \rho \cdot R_e}{16 \cdot \pi \cdot (R_e + h)} \cdot \ln\left(\frac{2 \cdot (R_e + h) \cdot H + h^2}{h^2}\right)\right)$$

3.1.1 Indicative methodology

3.1.1.1 Based on a required *I*/*N* ratio

Within ICAO there are no SARPs for primary radar, however ITU-R Recommendations and national databases can provide information on the noise factor, antenna gain, feeder loss and the receiver bandwidth of such systems. These figures can be combined to provide an indicative figure of the maximum tolerable value of UWB interference at the antenna port. This methodology can in principle be expanded to other systems where the relevant parameters are known.

Calculation of indicative maximum tolerable value of UWB interference

System	Receiver inherent noise factor (dBm)	Feeder loss (dB)	Antenna gain (dBi)	Required *I*/*N* (dB)	Receiver bandwidth (MHz)	Maximum tolerable value of UWB interference (dBm/MHz)
50 cm radar	A_1	B_1	C_1	D_1	E_1	$F_1 = A_1 + B_1 - C_1 + D_1 - 10 \log(E_1)$
23 cm radar	A_2	B_2	C_2	D_2	E_2	$F_2 = A_2 + B_2 - C_2 + D_2 - 10 \log(E_2)$
↓	→					

3.1.1.2 Based on the minimum wanted signal and intra-system protection limit

For a majority of systems used in aviation the ICAO Standards And Recommended Practice (SARPs) recommends a minimum wanted signal level at the receive antenna. ICAO also recommend a minimum receiver sensitivity level at the same point which is normally slightly below the recommended minimum wanted signal. In certain circumstances, a service provider can be approved to provide a minimum wanted signal within the facilities service area that is equivalent to the defined minimum receiver sensitivity. The minimum desired signal level is therefore taken as the lower value given by either the minimum wanted signal or the minimum receiver sensitivity. Combining the minimum wanted signal at the receive antenna and the required *S*/*I* gives the maximum level of interference at the receive antenna to ensure protection of the wanted signal in terms of dBm. Where systems operate autonomously figures are not available from ICAO SARPs (e.g. radio altimeters) then the information should be sourced from other ICAO documentation, ITU-R Recommendations or relevant international standards. As a last resort manufacturers data may be used, but care must be taken due to the international nature of operations.

Calculation of indicative maximum tolerable value of UWB interference

System	Receiver location (Ground/air)	Minimum received desired signal at the isotropic antenna port (dBm)	Required *S/I* (dB)	Receiver bandwidth (MHz)	Maximum tolerable value of UWB interference (dBm/MHz)
NDB	Air	A_1	B_1	C_1	$D_1 = A_1 + B_1 + 10 \log(C_1)$
VHF Comms (8.33kHz)	Ground	A_2	B_2	C_2	$D_2 = A_2 + B_2 + 10 \log(C_2)$
↓	→				

3.1.2 Interference assessment

3.1.2.1 Single interfering UWB device analysis

3.1.2.1.1 Maximum tolerable UWB emission limit

The interference level at the victim receiver is a function of the gains and losses the interference signal will incur between the source and the receiver. Maximum tolerable UWB emission limit for given separation distances/heights can be derived from equation (38):

$$P_{UWB\_tol} = P_{RX\_tol} + 32.4 + 20 \log f + 20 \log d \tag{38}$$

where:

P_{UWB_tol}: maximum tolerable UWB emission limit per reference bandwidth (dBm/MHz)

P_{RX_tol}: victim receiver total tolerable UWB interference level at isotropic antenna port per reference bandwidth (dBm/MHz)

f: frequency (MHz)

d: distance/height (km).

3.1.2.1.2 Minimum required separation distance for a given UWB emission limit

The minimum geographical separation between a single UWB device and the aeronautical receiver is derived from the required propagation loss between UWB transmitter and victim receiver:

$$L_{req} = \begin{vmatrix} eirp - P_{RX\_tol} & if & eirp > P_{cum\_tol} \\ 0 & if & eirp \le P_{cum\_tol} \end{vmatrix} \tag{39}$$

where:

L_{req}: required propagation loss (dB)

$eirp$: UWB emission limit (dBm/MHz)

P_{RX_tol}: victim receiver total tolerable UWB interference level at isotropic antenna port per reference bandwidth (dBm/MHz).

If the required propagation loss is known then equation (40) may be used to calculate the minimum required distance between a single UWB device and the victim receiver:

$$d_{min} = 10^{\frac{L_{req} - 32.4 - 20 \log f}{20}} \qquad (40)$$

where:

d_{min}: minimum required separation distance (km)

L_{req}: required propagation loss (dB)

f: frequency (MHz).

3.1.2.2 Aggregate interference analysis

In highly populated areas, aircraft in flight may be exposed to interfering signals transmitted from a large number of emitters on the ground at the same time. This leads to the issue of potential aggregate interference. For the estimation of aggregate interference power levels produced by a large number of UWB devices two methodologies (NTIA and ICAO) are currently proposed.

Both methodologies make a number of fundamental assumptions:

– that all emitters are uniformly distributed in a circular area below the victim receiver;

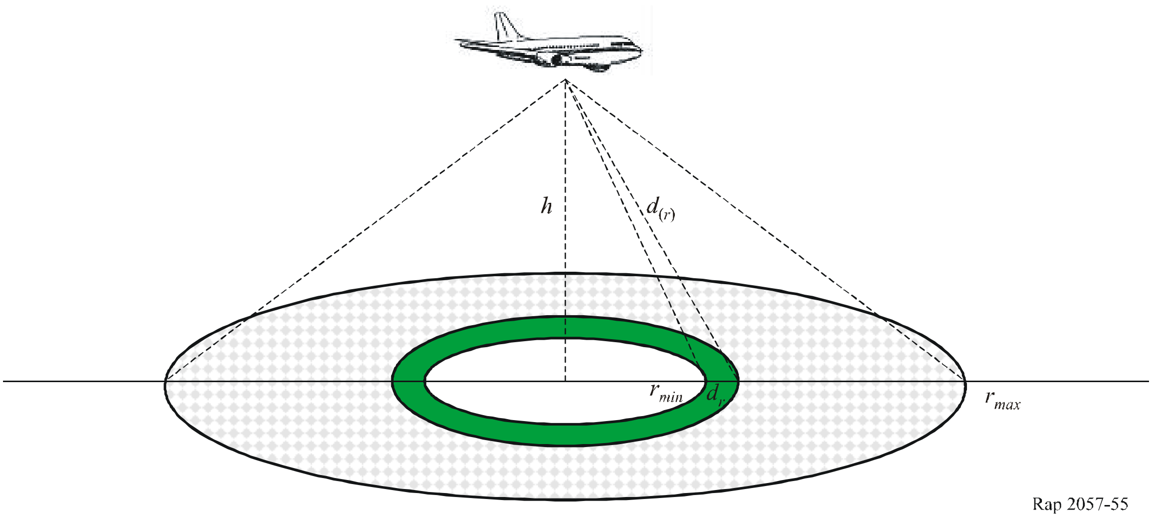
– that all emitters radiating on the same frequency, the same power levels and using isotropic antennas with omnidirectional radiation pattern;

– that free-space propagation are assumed;

– that all single emitters are statistically independent and the power contribution of all single emitters can be added arithmetically.

FIGURE 55

The cumulative methodology



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3.1.2.2.1 Airborne aggregate model

The average aggregate interference A (W/unit bandwidth) can be written as:

$$A = \frac{eirp\,\lambda^2 G_r \rho R_e}{16\pi(R_e + h)} \cdot \ln\left(\frac{2(R_e + h)H + h^2}{h^2}\right) \qquad (41)$$

where:

- A: average aggregate interference power (W/unit bandwidth)
- $eirp$: average UWB device effective isotropically radiated power (W/unit bandwidth)
- λ: wavelength (m)
- G_r: victim receiver antenna gain
- ρ: average density of UWB emitters (emitters/m^2)
- R_e: effective earth radius (m)[24]
- R: radius of the observed zone or the radio horizon (m)
- h: height of the receive antenna above the ground (m)
- H: $= R_e(1 - \cos(R/R_e))$.

3.1.2.2.2 ICAO cumulative model

$$p_{cum} = \frac{\lambda^2}{16\pi} \cdot n \cdot p_i \cdot \ln\left(\frac{r_{max}{}^2 + h^2}{r_{min}{}^2 + h^2}\right) \qquad (42)$$

where:

- p_{cum}: received cumulative interference power per reference bandwidth (W)
- a_w: aperture of an isotropic antenna (m^2)
- λ: wavelength (m)
- n: density of emitters/m^2
- p_i: isotropically radiated power from a single emitter per reference bandwidth (W)
- h: aircraft height (m)
- r_{min}: inner radius of the observed zone (m)
- r_{max}: outer radius of the observed zone (m).

A comparative analysis has shown that both models deliver similar results therefore calculations in this section have been performed using the airborne aggregate model.

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[24] Recommendation ITU-R P.310 defines *Effective radius of the Earth*: Radius of a hypothetical spherical Earth, without atmosphere, for which propagation paths are along straight lines, the heights and ground distances being the same as for the actual Earth in an atmosphere with a constant vertical gradient of refractivity.

NOTE 1 – The concept of effective radius of the Earth implies that the angles with the horizontal planes made at all points by the transmission paths are not too large.

NOTE 2 – For an atmosphere having a standard refractivity gradient, the effective radius of the Earth is about 4/3 that of the actual radius, which corresponds to approximately 8 500 km.

3.1.2.2.3 Calculation of maximum tolerable UWB emitter density

Equation (43) can be used to calculate the UWB emitter density ρ_{max} that will generate an aggregate interference power level equal to the victim receiver's total tolerable interference level P_{RX_tol} at its isotropic antenna port.

$$\rho_{max} = \frac{P_{RX\_tol} \cdot 16\pi \cdot (R_e + h)}{eirp\,\lambda^2\, G_r\, R_e \ln\left(\frac{2(R_e + h)H + h^2}{h^2}\right)} \tag{43}$$

3.1.2.2.4 Calculation of maximum UWB single device emission limit

The maximum UWB single device emission limit for given receiver height, *h*, and UWB emitter density, ρ, can be derived when solving equation (44) for the effective isotropically radiated power *eirp*.

$$eirp_{max} = \frac{P_{RX\_tol} \cdot 16\pi \cdot (R_e + h)}{\rho\,\lambda^2\, G_r\, R_e \ln\left(\frac{2(R_e + h)H + h^2}{h^2}\right)} \tag{44}$$

3.2 Results

3.2.1 Specific studies

3.2.1.1 Instrument landing system – Localizer (ILS LLZ)

Application: Instrument landing system – Localizer

The instrument landing system (ILS) is one of the ICAO standard precision approach and landing systems. It provides precision guidance to an aircraft during the final stages of the approach. The signals can either be interpreted by the pilot from the instruments or be input directly into the autopilot and flight management system. ILS performance is divided into three categories depending on the reliability, integrity and quality of guidance, with Category III having the strictest requirements. An ILS comprises the following elements:

– the localizer, operating in the frequency band from 108 to 112 MHz, providing azimuth guidance to a typical maximum range of 46.3 km (25 nm) from the runway threshold;

– the glide path, operating in the frequency band from 328.6 to 335.4 MHz, providing elevation guidance to a typical maximum range of 18.5 km (10 nm) from the runway threshold;

– the marker beacons operating on the frequency of 75 MHz, providing position information at specific distances from the runway threshold.

Frequency band:

108-117.975 MHz.

Protection requirements:

Total tolerable interference level at isotropic antenna port.

Parameter	Value	Unit	Remarks
Minimum pfd limit within ILS LLZ service area	–114	dBW/m²	ICAO Annex 10
Received power at isotropic antenna port	–116.3	dBW	Reference frequency: 110 MHz $P_R = PFD + A_{eff}$ $A_{eff} = 10 \log \left(\frac{\lambda^2}{4\pi} \right)$
S/*I*	46	dB	RTCA DO-233 interference type 1
Aeronautical safety factor	6	dB	
Single-to-multiple interference factor	10	dB	If there is a potential for other than interference sources at the same time, an allowance should be made for the aggregate interference
Total tolerable interference level at isotropic antenna port per IF bandwidth	–178.3	dB(W/40 kHz)	Receiver IF bandwidth 40 kHz
Bandwidth correction factor	14	dB	$BWCF = 10 \log \left(\frac{B_{IF}}{B_{\mathrm{Re}f}} \right)$ assumed ILS LLZ B_{IF} = 40 kHz
Total tolerable UWB interference level at isotropic antenna port per reference bandwidth	–164.3	dB(W/MHz)	Reference bandwidth 1 MHz

Interference scenarios and methodology

UWB characteristics

Parameter	Value	Unit	Remarks
United States indoor emission limit	–42.5	dBm/MHz	110 MHz
United States outdoor emission limit	–42.5	dBm/MHz	110 MHz
Slope mask indoor emission limit	–177.4	dBm/MHz	110 MHz
Slope mask outdoor emission limit	–187.4	dBm/MHz	110 MHz
Activity factor	100	%	

Methodology for single UWB transmitter

The methodology as described in Recommendation ITU-R SM.1757, Annex 2, § 2.2.1. has been used. The propagation loss between transmitting and receiving antennas has been derived from free-space propagation.

Methodology for multiple UWB transmitters

For the calculation of the cumulative interference power generated by multiple UWB devices the airborne aggregate model, as given in Recommendation ITU-R SM.1757, Annex 2, § 2.3 has been used.

Results of theoretical impact studies

Single interfering UWB device analysis:

Tolerable UWB emission limit for different victim receiver heights.

Tolerable UWB emission limit for a single device at 110 MHz (dBm/MHz)				
Rx height 70 ft (21 m)	**Rx height 100 ft (30 m)**	**Rx height 1 000 ft (305 m)**	**Rx height 3 000 ft (915 m)**	**Rx height 6 000 ft (1 829 m)**
–94.6	–91.5	–71.4	–61.8	–55.8

Required separation distances for given UWB emission limits

UWB United States indoor emission limit	United States limit –42.5 dBm/MHz at 110 MHz
Required separation distance (m)	8 484

UWB United States outdoor emission limit	United States limit –42.5 dBm/MHz at 110 MHz
Required separation distance (m)	8 484

UWB slope indoor emission limit	Slope mask –177.4 dBm/MHz at 110 MHz
Required separation distance (m)	0

UWB slope outdoor emission limit	Slope mask –187.4 dBm/MHz at 110 MHz
Required separation distance (m)	0

Aggregate interference analysis:

Maximum tolerable UWB emitter density for given UWB single device emission limits and victim receiver heights.

UWB single device emission limit	Tolerable UWB emitter density/km^2				
	Rx height 70 ft (21 m)	Rx height 100 ft (30 m)	Rx height 1 000 ft (305 m)	Rx height 3 000 ft (915 m)	Rx height 6 000 ft (1 829 m)
United States in-door at 110 MHz –42.5 dBm/MHz	0	0	0	0	0
United States out-door at 110 MHz –42.5 dBm/MHz	0	0	0	0	0
Slope in-door at 110 MHz –177.4 dBm/MHz	1.01×10^{10}	1.04×10^{10}	1.26×10^{10}	1.4×10^{10}	1.51×10^{10}
Slope out-door at 110 MHz –187.4 dBm/MHz	1.01×10^{11}	1.04×10^{11}	1.26×10^{11}	1.4×10^{11}	1.51×10^{11}

Maximum UWB single device emission limit for given emitter density and victim receiver height.

Emitter density (emitters/km^2)	Tolerable UWB emission limit for a single device at 110 MHz (dBm/MHz)				
	Rx height 70 ft (21 m)	Rx height 100 ft (30 m)	Rx height 1 000 ft (305 m)	Rx height 3 000 ft (915 m)	Rx height 6 000 ft (1 829 m)
1	–77.3	–77.2	–76.4	–75.9	–75.6
10	–87.3	–87.2	–86.4	–85.9	–85.6
100	–97.3	–97.2	–96.4	–95.9	–95.6
1 000	–107.3	–107.2	–106.4	–105.9	–105.6
10 000	–117.3	–117.2	–116.4	–115.9	–115.6
100 000	–127.3	–127.2	–126.4	–125.9	–125.6
1 000 000	–137.3	–137.2	–136.4	–135.9	–135.6

3.2.1.2 Application: Distance measuring equipment (DME)

DME is the ICAO standard system for the determination of the distance between an aircraft and a ground-based DME beacon within radio LoS, using pulse techniques and time measurement. DME/N is the standard system used for en-route and terminal navigation. It can be co-located with VHF omnidirectional radio range (VOR) enabling the aircraft's position to be determined through a measurement of its bearing and the distance relative to the VOR/DME. Alternatively, the aircraft's position can be determined through measurement of the distances from three or more DMEs. DME/P is a precision version of DME with enhanced precision measurement capability which is used in conjunction with MLS to provide accurate distance to touch down.

Frequency band:

960-1 215 MHz.

Protection requirements:

Total tolerable interference level at isotropic antenna port.

Parameter	Value	Unit	Remarks
DME interference threshold at antenna port	–129	dBW	This value is based on a –129 dBW CW interference threshold specified for international DME systems used by civil aviation. Measurement has demonstrated that an noise-like RNSS signal spread over 1 MHz would have the same effect as a CW signal on DME performance. The applicability of this value to UWB signals should be verified by measurements
Antenna gain towards interference source	0	dB	The difference in antenna gain towards the interference signal
Single-to-multiple interference factor	10	dB	If there is a potential for other than interference sources at the same time, an allowance should be made for the aggregate interference. Since UWB is not considered as a radio service a 10% allowance is made.
Aeronautical safety factor	6	dB	
Total tolerable UWB interference level at isotropic antenna port	–145	dB(W/MHz)	

Interference scenarios and methodology

UWB characteristics

Parameter	Value	Unit	Remarks
United States indoor emission limit	–75.3	dBm/MHz	960-1 215 MHz
United States outdoor emission limit	–75.3	dBm/MHz	960-1 215 MHz
Slope mask indoor emission limit	–95.6	dBm/MHz	960 MHz
	–90.4	dBm/MHz	1 100 MHz
	–86.7	dBm/MHz	1 215 MHz
Slope mask outdoor emission limit	–105.6	dBm/MHz	960 MHz
	–100.4	dBm/MHz	1 100 MHz
	–96.7	dBm/MHz	1 215 MHz
Activity factor	100	%	

Methodology for single UWB transmitter

The methodology as described in Recommendation ITU-R SM.1757, Annex 2, § 2.2.1 has been used. The propagation loss between transmitting and receiving antennas has been derived from free-space propagation.

Methodology for multiple UWB transmitters

For the calculation of the cumulative interference power generated by multiple UWB devices the airborne aggregate model, as given in Recommendation ITU-R SM.1757, Annex 2, § 2.3 has been used.

Results of theoretical impact studies

Single interfering UWB device analysis:

Tolerable UWB emission limit for different victim receiver heights.

Tolerable UWB emission limit for a single device at 1100 MHz, dBm/MHz				
Rx height 70 ft (21 m)	**Rx height 100 ft (30 m)**	**Rx height 1 000 ft (305 m)**	**Rx height 10 000 ft (3 048 m)**	**Rx height 45 000 ft (13 716 m)**
–15.3	–12.3	–12.1	–12.1	1

Required separation distances for given UWB emission limits

UWB United States indoor emission limit	**United States limit –15.3 dBm/MHz at 960 MHz**	**United States limit –15.3 dBm/MHz at 1100 MHz**	**United States limit –75.3 dBm/MHz at 1 215 MHz**
Required separation distance (m)	24	21	19

UWB United States outdoor emission limit	**United States limit –75.3 dBm/MHz at 960 MHz**	**United States limit –75.3 dBm/MHz at 1 100 MHz**	**United States limit –75.3 dBm/MHz at 1 215 MHz**
Required separation distance (m)	24	21	19

UWB slope mask indoor emission limit	**Slope mask –95.6 dBm/MHz at 960 MHz**	**Slope mask –90.4 dBm/MHz at 1 100 MHz**	**Slope mask –86.7 dBm/MHz at 1 215 MHz**
Required separation distance (m)	0.2	0.3	0.5

UWB slope mask outdoor emission limit	**Slope mask –105.6 dBm/MHz at 960 MHz**	**Slope mask –100.4 dBm/MHz at 1 100 MHz**	**Slope mask –96.7 dBm/MHz at 1 215 MHz**
Required separation distance (m)	0.06	0.1	0.2

Aggregate interference analysis:

Maximum tolerable UWB emitter density for given UWB single device emission limits and victim receiver heights.

UWB single device emission limit	Tolerable UWB emitter density/km^2				
	Rx height 70 ft (21 m)	**Rx height 100 ft (30 m)**	**Rx height 1 000 ft (305 m)**	**Rx height 10 000 ft (3 048 m)**	**Rx height 45 000 ft (13 716 m)**
United States in-door at 960 MHz –75.3 dBm/MHz	4 000	4 100	5 000	6 300	7 700
United States in-door at 1100 MHz –75.3 dBm/MHz	5 300	5 400	6 600	8 300	10 100
United States in-door at 1215 MHz –75.3 dBm/MHz	6 400	6 600	8 000	10 200	12 400
United States out-door at 960 MHz –75.3 dBm/MHz	4 000	4 100	5 000	6 300	7 700
United States out-door at 1 100 MHz –75.3 dBm/MHz	5 300	5 400	6 600	8 300	10 100
United States out-door at 1 215 MHz –75.3 dBm/MHz	6 400	6 600	8 000	10 200	12 400
Slope in-door at 960 MHz –95.6 dBm/MHz	434 400	446 100	540 800	685 300	831 000
Slope in-door at 1 100 MHz –90.4 dBm/MHz	172 200	176 900	214 400	271 700	329 400
Slope in-door at 1 215 MHz –86.7 dBm/MHz	89 600	92 000	111 600	141 400	171 400
Slope out-door at 960 MHz –105.6 dBm/MHz	4 344 500	4 461 500	5 408 600	6 853 900	8 310 000
Slope out-door at 1 100 MHz –100.4 dBm/MHz	1 722 600	1 769 000	2 144 500	2 717 600	3 294 900
Slope out-door at 1 215 MHz –96.7 dBm/MHz	559 600	574 700	696 700	882 900	1 070 500

Maximum UWB single device emission limit for given emitter density and victim receiver height.

Emitter density (emitters/km^2)	Tolerable UWB emission limit for a single device at 1 100 MHz, dBm/MHz				
	Rx height 70 ft (21 m)	**Rx height 100 ft (30 m)**	**Rx height 1 000 ft (305 m)**	**Rx height 10 000 ft (3 048 m)**	**Rx height 45 000 ft (13 716 m)**
1	–38.0	–37.9	–37.1	–36.1	–35.2
10	–48.0	–47.9	–47.1	–46.1	–45.2
100	–58.0	–57.9	–57.1	–56.1	–55.2
1 000	–68.0	–67.9	–67.1	–66.1	–65.2
10 000	–78.0	–77.9	–77.1	–76.1	–75.2
100 000	–88.0	–87.9	–87.1	–86.1	–85.2
1 000 000	–98.0	–97.9	–97.1	–96.1	–95.2

3.2.2 Studies using the indicative methodology

3.2.2.1 Calculations based on the minimum wanted signal and intra-system protect limit

Indicative maximum tolerable value of UWB interference

System	Frequency band	Receiver location	Minimum desired signal at the isotropic antenna port (µV/m)	(dBm)	Required *S/I* (dBm)	Typical Receiver bandwidth (MHz)	Maximum tolerable value of UWB interference (dB/MHz)
NDB	190-535 kHz	Airborne	70	–35	15	0.006	**–27.8**
HF Comms	2.85-22 MHz	Ground			15	0.003	
		Airborne			15	0.003	
Marker beacon	74.8-75.2 MHz	Airborne	1 500	–51	20	0.022	**–54.4**
ILS Localizer	108-112 MHz	Airborne	40	–86	20	0.05	**–93.0**
VOR	108-117.975 MHz	Airborne	90	–79	20	0.05	**–-86.0**
GBAS	108-117.975 MHz	Airborne	136	–76	26	0.014	**–83.5**
VHF Comms, VDL Mode 4	108-137 MHz	Ground	35	–89	20	0.006	**–86.8**
		Airborne	75	–82	20	0.00556	**–79.5**
VHF Comms, VDL Mode 2&3	117.975-137 MHz	Ground	20	–94	20	0.008	**–93.0**
		Airborne	75	–82	20	0.016	**–84.0**
VHF Comms, 8.33 kHz AM	117.975-137 MHz	Ground	20	–94	20	0.0056	**–91.5**
		Airborne	30	–90	20	0.0056	**–87.5**
VHF Comms, 25 kHz AM	117.975-137 MHz	Ground	20	–94	20	0.016	**–96.0**
		Airborne	30	–90	20	0.016	**–92.0**
ILS Glidepath	328.6-335.4 MHz	Airborne	400	–76	20	0.15	**–87.8**
DME/TACAN	960-1 215 MHz	Ground	–103(dB(W/m^2))	–96	8	6	**–111.8**
		Airborne	–89(dB(W/m^2))	–82	8	6	**–97.8**
Secondary surveillance radar	1 030 MHz	Airborne	–82(dB(W/m^2))	–74	12	9	**–95.5**
	1 090 MHz	Ground	–111(dB(W/m^2))	–103	12	5.5	**–122.4**
Radio altimeters	4 200-4 400 MHz	Airborne		–93.5	6	30	**–114.3**
MLS	5 030-5 150 MHz	Airborne	–89.5(dB(W/m^2))	–95	25	0.15	**–111.8**
Weather radar	5 350-5 470 MHz	Airborne					
Doppler radar	8 750-8 850 MHz	Airborne					

Indicative total tolerable interference level at isotropic antenna port

System	Frequency band	Receiver location	Maximum tolerable value of UWB interference (dBm/MHz)	Antenna gain difference (dB)	Aeronautical safety factor (dB)	Multiple Interference source factor (dB)	Total tolerable interference level at isotropic antenna port (dBm/MHz)
NDB	190-535 kHz	Airborne	**–27.8**	0	6	6	**–39.8**
HF Comms	2.85-22 MHz	Ground		0	6	6	
		Airborne		0	6	6	
Marker beacon	74.8-75.2 MHz	Airborne	**–54.4**	0	6	6	**–66.4**
ILS Localizer	108-112 MHz	Airborne	**–93.0**	0	6	6	**–105.0**
VOR	108-117.975 MHz	Airborne	**–86.0**	0	6	6	**–98.0**
GBAS	108-117.975 MHz	Airborne	**–83.5**	0	6	6	**–95.5**
VHF Comms, VDL Mode 4	108-137 MHz	Ground	**–86.8**	0	6	6	**–98.8**
		Airborne	**–79.5**	0	6	6	**–91.5**
VHF Comms, VDL Mode 2&3	117.975-137 MHz	Ground	**–93.0**	0	6	6	**–105.0**
		Airborne	**–84.0**	0	6	6	**–96.0**
VHF Comms, 8.33 kHz AM	117.975-137 MHz	Ground	**–91.5**	0	6	6	**–103.5**
		Airborne	**–87.5**	0	6	6	**–99.5**
VHF Comms, 25 kHz AM	117.975-137 MHz	Ground	**–96.0**	0	6	6	**–108.0**
		Airborne	**–92.0**	0	6	6	**–104.0**
ILS Glidepath	328.6-335.4 MHz	Airborne	–**87.8**	0	6	6	**–99.8**
DME/ TACAN	940-1 215 MHz	Ground	–**111.8**	0	6	6	**–123.8**
		Airborne	–**97.8**	0	6	6	**–109.8**
Secondary surveillance radar	1 030 MHz	Airborne	–**95.5**	0	6	6	**–107.5**
	1 090 MHz	Ground	**–122.4**	**0**	**6**	**6**	**–134.4**
Radio altimeters	4 200-4 400 MHz	Airborne	**–114.3**	**0**	**6**	**6**	**–126.3**
MLS	5 030-5 150 MHz	Airborne	**–111.8**	**0**	**6**	**6**	**–123.8**
Weather radar	5 350-5 470 MHz	Airborne					
Doppler radar	8 750-8 850 MHz	Airborne					

Maximum acceptable UWB e.i.r.p. density

System	Frequency band (MHz)	Mid band (MHz)	Receiver location	Total tolerable interference level at isotropic antenna port (1) (dBm/MHz)	Assumed minimum separation distance (m)	Required single UWB PSD limit to ensure given protection distance(1) (dBm/MHz)	Density of UWB transmitters (/km²)(1) Assumptions: – An activity factor indoor and outdoor of 5% is applied to the density values given below – Percentage outdoor 20% – Building attenuation: <0.4 GHz 5 dB; 0.4-2.6 GHz 9dB; >1.6 GHz 10 dB							
								10	**100**	**1000**	**10 000**			
							Required UWB e.i.r.p. limit (dBm/MHz)							
NDB	0.190-0.535	0.39	Airborne	**–39.8**	300	–26.0		–24.5	–34.5	–44.5	–54.5			
			Ground											
HF Comms	2.85-22	12.43	Airborne		300									
Marker beacon	74.8-75.2	75.00	Airborne	**–66.4**	100	–16.5		-5.8	-15.8	-25.8	-35.8			
ILS Localizer	108-112	110.00	Airborne	**–105.0**	50	–57.8		-41.3	-51.3	-61.3	-71.3			
VOR	108-117.975	112.99	Airborne	**–98.0**	100	–44.5		-33.8	-43.8	-53.8	-63.8			
GBAS	108-117.975	112.99	Airborne	**–95.5**	30	–52.5		-31.7	-41.7	-51.7	-61.7			
VHF Comms,			Ground	**–98.8**	30	–55.1		-34.3	-44.3	-54.3	-64.3			
VDL Mode 4	108-137	122.50	Airborne	**–91.5**	300	–27.8		-26.2	-36.2	-46.2	-56.2			
VHF Comms,			Ground	**–105**	30	–60.9		-40.2	-50.2	-60.2	-70.2			
VDL Mode 2&3	117.975-137	127.49	Airborne	**–96**	300	–31.9		-30.4	-40.4	-50.4	-60.4			
VHF Comms,			Ground	**–103.5**	30	–59.4		-38.7	-48.7	-58.7	-68.7			
8.33 kHz AM	117.975-137	127.49	Airborne	**–99.5**	100	–45.0		-34.3	-44.3	-54.3	-64.3			
VHF Comms,			Ground	**–108.0**	30	–63.9		-43.2	-53.2	-63.2	-73.2			
25 kHz AM	117.975-137	127.49	Airborne	**–104.0**	100	–49.5		-38.8	-48.8	-58.8	-68.8			
ILS Glidepath	328.6-335.4	332.00	Airborne	**–99.8**	50	–43.0		-26.5	-36.5	-46.5	-56.5			

System	**Frequency band (MHz)**	**Mid band (MHz)**	**Receiver location**	**Total tolerable interference level at isotropic antenna port (1) (dBm/MHz)**	**Assumed minimum separation distance (m)**	**Required single UWB PSD limit to ensure given protection distance(1) (dBm/MHz)**	**Density of UWB transmitters (/km²)(1)** **Assumptions:** – **An activity factor indoor and outdoor of 5% is applied to the density values given below** – **Percentage outdoor 20%** – **Building attenuation: <0.4 GHz 5 dB; 0.4-2.6 GHz 9dB; >1.6 GHz 10 dB**							
								10	**100**	**1000**	**10 000**			
							Required UWB e.i.r.p. limit (dBm/MHz)							
DME/ TACAN	960-1 215	1 077.50	Ground	**–123.8**	5	–76.8		-39.2	-49.2	-59.2	-69.2			
			Airborne	**–109.8**	100	–36.8		-24.3	-34.3	-44.3	-54.3			
Secondary surveillance radar	1 030	1 030.00	Airborne	**–107.5**	100	–34.8		-22.4	-32.4	-42.4	-52.4			
	1 090	1 090.00	Ground	**–134.4**	30	–71.7		TBD	TBD	TBD	TBD			
Radio altimeters	4 200-4 400	4 300.00	Airborne	**–126.3**	50	–47.3		-28.7	-38.7	-48.7	-58.7			
MLS	5 030-5 150	5 090.00	Airborne	**–123.8**	50	–43.3		–43.2	-34.7	-44.7	-54.7			
Weather radar	5 350-5 470	5 410.00	Airborne		300									
Doppler radar	8 750-8 850	8 800.00	Airborne		300									

(1) Values calculated here are based on the intra system *D*/*U* ratio and are provided as an indicative value.

TBO: To be decided.

3.2.2.2 Calculations based on the *I*/*N* of the receiver

Indicative maximum tolerable value of UWB interference

System	Frequency band	Receiver location	Receiver inherent noise factor (dBm)	Feeder loss (dB)	Antenna gain (dBi)	Required *I*/*N* (dBm)	Receiver bandwidth (MHz)	Maximum tolerable value of UWB interference (dBm/MHz)
50 cm radar	590-598 MHz	Ground	–107.2	3	28	–6	3	**–143.0**
23 cm radar	1 215-1 400 MHz	Ground	–113.6	2	38.9	–6	0.69	**–154.9**
10 cm radar	2 700- 3 300 MHz	Ground	–111.1	2	34.3	–10	1.2	**–154.2**
3 cm radar	9 000-9 500 MHz	Ground	–102.0	3	38	–6	10	**–153.0**

Indicative total tolerable interference level at isotropic antenna port

System	Frequency band	Receiver location	Maximum tolerable value of UWB interference (dBm/MHz)	Antenna gain difference (dB)	Aeronautical safety factor (dB)	Multiple interference source factor (dB)	Total tolerable interference level at isotropic antenna port (dBm/MHz)
50 cm radar	590-598 MHz	Ground	**–143.0**	0	6	6	**–155.0**
23 cm radar	1 215-1 400 MHz	Ground	**–154.9**	0	6	6	**–166.9**
10 cm radar	2 700-3 300 MHz	Ground	**–154.2**	0	6	6	**–166.2**
3 cm radar	9 000-9 500 MHz	Ground	**–153.0**	0	6	6	**–165.0**

Maximum acceptable UWB PSD

System	Frequency band (MHz)	Mid Band (MHz)	Receiver location	Total tolerable interference level at isotropic antenna port(1) (dBm/MHz)	Assumed minimum separation distance (m)	Required single UWB PSD limit to ensure given protection distance(1) (dBm/MHz)	Density of UWB transmitters (/km²)(1) Assumptions: – An activity factor indoor and outdoor of 5% is applied to the density values given below – Percentage outdoor 20% Building attenuation: <0.4 GHz 5 dB; 0.4-2.6 GHz 9 dB; >1.6 GHz 10 dB							
								10	100	1 000	10 000			
							Required UWB PSD limit (dBm/MHz)							
50 cm radar	590-598	594	Ground	**–155.0**	400	–75.1		TBD	TBD	TBD	TBD			
23 cm radar	1 215-1 400	1 307	Ground	**–166.9**	400	–80.3		TBD	TBD	TBD	TBD			
10 cm radar	2 700- 3 300	3 000	Ground	**–166.2**	170	–79.9		TBD	TBD	TBD	TBD			
3 cm radar	9 000-9 500	9 250	Ground	**–165.0**	20	–87.2		TBD	TBD	TBD	TBD			

(1) Values are calculated here are based on the system *I*/*N* ratio and are provided as an indicative value.

4 IMT-2000 and systems beyond IMT-2000

4.1 Introduction

Various administrations and international organizations are studying devices that use UWB technology, which may occupy up to several gigahertz of bandwidth. The spectrum used by these devices may overlap completely or partially with the bands used by land mobile, maritime mobile, aeronautical mobile and radiodetermination services. To help address the conditions for a safe introduction and implementation of devices using UWB technology, Radiocommunication SG 1 has adopted Question ITU-R 227/1, on the impact between devices using UWB technology and radiocommunication services, and Question ITU-R 226/1, about spectrum management framework related to the introduction of devices using UWB technology. It should be noted that the frequency range for the operation of UWB is currently an open issue.

In addressing Question ITU-R 227/1, this Reportt provides information on the impact of devices using UWB technology on IMT-2000 systems. It is expected that the results of the studies should provide guidance on the measures to ensure limitations on interference to IMT-2000 systems.

A study by one Administration assessing the "Compatibility between devices using UWB transmission and both IMT-2000 and land mobile devices operating in the 1 750-1 780/1 840-1 870 and 1 850-1 910/1 930-1 990 MHz frequency bands" is presented in Annex 1, § 1.6 of this Report. The study is based on a conservative approach that accounts for parameters, inherent to the operation of a mobile station.

4.2 Scope

This section is structured in the following main parts:

– *Assumed UWB technical characteristics and expected usage*

  This part describes the assumptions made regarding the characteristics of the devices using UWB technology used for the purpose of assessing the impact of devices using UWB technology, including UWB emission limits, expected usage, densities, and traffic scenarios.

– *Victim receiver characteristics and deployment scenarios*

  This part establishes the different types of scenarios (rural, suburban, urban, indoor e.g. business areas and conference centres), the technical characteristics of IMT-2000 victim receivers (mobile, base stations) in terms of antenna type, propagation conditions, etc.

– *Interference scenarios*

  This part establishes the different types of interference scenarios involving IMT-2000 systems in different environments and scenarios, and UWB transmitter densities, usage and traffic statistics.

– *Methodologies for interference assessment*

  This part establishes the methodologies used to model UWB interference (single source, multiple sources) on IMT-2000 user devices, base stations and networks, and the tolerable degradation in terms of performance, coverage and capacity (protection criteria).

– *Studies and results*

  This part covers the studies and results and subsequent conclusions on the impact of devices using UWB technology. Taking into account are the identified scenarios, tolerable UWB interference levels in terms of power spectral density, required isolation distance, etc. One administration carried out a series of laboratory and field measurements on the impact of impulse and multi-band OFDM UWB interference on the performance of an IMT-DS handset. Up to 44 different types of impulse UWB signals were considered. The results of this measurement-based study are presented in Annex 7, § 2 to this Report.

4.3 Assumed UWB technical characteristics and usage

4.3.1 UWB usage scenarios

Systems using UWB technology may provide a very wide range of applications, enabling any type of deployment scenario, including those where devices using UWB technology could operate close to victim IMT-2000 terminals. For example, UWB devices and the IMT-2000 victim receivers may be integrated or connected to the same laptop. Hence some studies have considered the assessment of the interference created by a single device using UWB technology into a single IMT-2000 terminal.

In the absence of clear guidance on forecasted typical UWB deployment schemes, some studies have envisaged an assessment of the aggregate impact of devices using UWB technology on a IMT-2000 deployed network, and considered different densities of devices using UWB technology as spread over IMT-2000 networks. UWB populations were designed assuming each UWB device transmitting 100% of the time, at maximum power, notably in the scenarios involving victim IMT-2000 base stations. Potential co-location of the two systems, as well as the impact of duty cycles have been considered in some of the studies involving IMT-2000 terminals.

One study focused specifically on the assessment of UWB localized interference impact into IMT-2000 mobile stations. This study provided detailed UWB application and market studies in the aim to bring out representative and realistic simulation theatres, together with a wish to more accurately model the likely UWB interference effects. Information was gathered from a variety of sources including the literature, IEEE 802.15.3 and 3a[25] specifications, ETSI System Reference Documents[26], and material from several manufacturers and regulatory bodies within the field. In summary, the market survey showed that typical mass market applications of UWB have the following characteristics: they are short range (less than 10 m) with a wireless need (mobile or aesthetics), they are probably battery driven devices operating upon bursts of data in the order of 100 Mbit/s or greater, and they are only used a few times per day. Lower data rate applications with otherwise similar characteristics will find that incumbent, wireless LANs, Bluetooth and other technologies will represent a significant barrier to market entry for devices using UWB technology.

Principal applications and hot spots

From the market survey, several *general* application groups were identified:

– Medical applications
– Consumer communications applications
– Automotive applications
– Consumer and industrial construction applications
– Ground penetrating radar (GPR) systems
– Industrial liquid level gauges

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[25] The IEEE 802.15 working group has the remit to determine WPAN standards. Working group 3a of IEEE 802.15 is investigating WPAN at data rates of greater than 110 Mbit/s at ranges of less than 10 m. Its goal is to specify a communications system that can transmit data at a rate of at least 110 Mbit/s over a distance of 10 m and up to 400 Mbit/s over shorter distances. The applications identified by IEEE 802.15.3a largely agree with those found through independent research, although IEEE 802.15.3a market views are confined more to download type applications as opposed to streaming applications.

[26] ETSI TR 101 982, TR 102 263, TR 102 347, TR 101 994-1, TR 101 994-2.

– Data communications systems
– Wireless high-speed networking.

Mindful of points raised by the contributors to the survey and the advantages and disadvantages of the technology, the following *principal* UWB application groups have been identified:

– Consumer communications applications
– Data communications systems
– Wireless high-speed networking.

The remaining application groups are regarded as niche markets for the foreseeable future.

Furthermore, these application groups have been identified as predominantly indoor systems. This is well supported by independent research, where 88% of the UWB market is expected to be indoor applications. In light of this, the office and the home were identified as the two principal hot spots. In particular, general office and high tech conference rooms, as well as the home PC cluster and the home theatre were identified as UWB hot spots with the following applications:

Office

General Office:

– PC to laser printers
– PC to PDAs for file downloads (plus calendar/email synchronization)
– PC to wireless monitor (with compression)
– PC to scanner
– PC to external hard drive for drive backups
– Wireless Universal Serial Bus (USB) in general for high rate applications.

High Tech Conference Room:

– PC or Digital Video Player (DVP) to wireless video projection
– PC to PC wireless peer-to-peer file sharing.

Home

PC Cluster:

– PC to laser printer
– PC to MP3 players (flash based) for file downloads
– PC to PDAs for file downloads (including calendar/email synchronization)
– PC to digital camera downloads
– PC to wireless monitor (with compression)
– PC to scanner
  – PC to external hard drive for drive backups
  – PC or DVD Recorder to digital video camera for download (e.g. ‘Firewire^{TM}, IEEE 1 394 replacement).

Home Theatre

– Hi-Fi/CD player to speakers (surround sound with seven channels) streaming
– DVD player to wireless video projector for home theatre streaming
– PC or DVD player to personal video player/recorder movie downloads
– Set-top digital TV box to flat screen TVs streaming (multi-channel)

– Games console to TV screen streaming.

Among these hot spot scenarios, the most problematic is called “power office user environment”, derived from the general office scheme.

4.3.2 UWB channel propagation models

One parameter of great importance to the studies is the model assumed for the UWB propagation characteristics in the IMT-2000 frequency bands. Different propagation models were used in the studies, depending on the various scenarios and environments under consideration. In scenarios involving small separation distances between devices using UWB technology and IMT-2000 terminals (less than 1 or 2 m), the free-space loss model was mostly used.

4.3.3 UWB interference modelling

All the studies have considered that the pulse repetition rate (PRR) from a UWB device will typically be much more rapid than the chip/bit rate of the victim system, and considered subsequently that the interference created by devices using UWB technology would be of continuous, permanent Gaussian noise type.

Average/peak emission UWB PSD levels

It is noted that one administration’s rules allow peak emission of 0 dBm/50 MHz at the centre frequency. Converting this to a peak level on an IMT-2000 band may lead to a UWB peak level of –27 dBm/MHz. In this case, the peak-to-average ratio (PAR) of UWB can be (–27.0 to –51.3) 24.3 dB. Evaluating the effects this high PAR may have on IMT-2000 receivers, some studies indicate that the UWB waveform is clearly irregular, so that some peakness may be assumed, and suggested a conservative value of +6 dB “peak-to-average ratio” to be added to the UWB power spectral density derived from the studies. Another analysis underlines that the peak power limits provided in the above-mentioned administration’s rules would limit the peak power for systems using UWB technology with a PRF lower than 500 kHz. Attached to this Report were plots of the BER vs. SNR for a generic system with a bandwidth of 3.5 MHz (comparable to the widest-band IMT-2000 system) and 7/8 convolutional code with a constraint length 7 in the presence of UWB interference. The plots show that the impact of white Gaussian noise (WGN) interference (representative of high PRF UWB systems) and a considered 500 kHz pulsed UWB waveform with the same average interference power is approximately the same. This suggests that the peak emissions of UWB are not expected to add degradation to the performance the widest band IMT-2000 systems. The averaged UWB PSD emissions modelled as WGN can be used when analysing the IMT-2000 performance.

At any place in this Report, the UWB e.i.r.p. (dBm/MHz) at the relevant receiver frequencies is assumed to be represented by WGN.

UWB activity

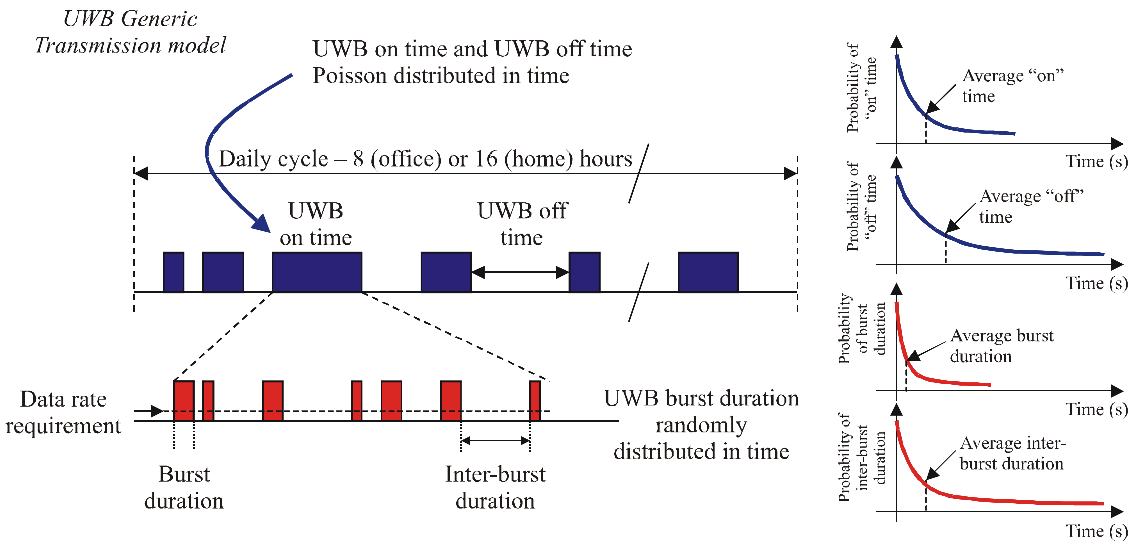
A temporal UWB activity model has been developed to be used in Monte-Carlo simulations in hot spot indoor scenarios. Various devices using UWB technology were simulated, including wireless monitors, PDAs, HDDs, a printer and a scanner.

The characteristics that measure UWB activity or *usage* in the model are *“the percentage of link rate when active”* and *“the percentage of daily usage”*. For each application, these figures were revealed by the market survey (see § 4.3.1 in this Annex). Figure 56 illustrates the temporal behaviour for the general UWB transmission case.

The *percentage of link rate when active* is measured by the ratio of these burst durations to burst arrival periods. The beginning of a transaction is called "UWB on-time"; the end of the transaction is the "UWB off-time". The ratio of *average "on" time* to *average "off" time* plus *average "on" time* is the percentage of daily usage, or duty cycle[27].

FIGURE 56

Generic UWB temporal transmission model for a device using UWB technology



Application data rate (Mbit/s) = (100 or 250 Mbit/s) × (% of link rate when active or UWB "on")

$$\% \text{ of link rate (when active)} = \frac{\sum(\text{burst periods})}{(\text{UWB on time})}$$

$$\% \text{ daily usage} = \frac{(\text{UWB on time})}{(\text{UWB on time} + \text{UWB off time})}$$

Overall activity (%) = (% of link rate when active) × (% daily usage)

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Whilst only a limited number of applications were modelled (see § 4.7.1.1.2 of this Annex), within a single scenario, separate, not reported, analysis showed that even with large numbers (many tens) of UWB transmission devices within a relatively small, 5 m × 4 m area, it was found to be quite uncommon for more than one or two devices to be transmitting at the same time. This is largely due to the fact that many devices using UWB technology are used very rarely, for example, digital camera downloads, PDA data exchange, scanners, printers etc. Such devices are used for a minute or two, at most a few times per day. For devices using UWB technology that are active for longer periods, such as wireless monitors, set-top TV boxes, and potentially wireless keyboards etc. we found that data transmissions occur in bursts (of 100 or 250 Mbit/s) lasting a few milliseconds (long enough to transfer the required data) and inter-burst periods of tens of milliseconds. Such UWB transmissions have an effective low activity factor, typically <10%, and hence it is uncommon for many UWB transmissions to be active at the same specific time.

[27] In many ways, the temporal activity model described above follows similar transmission burst metrics to the ETSI Web model as used in many traffic-engineering models for IP networks.

UWB power control capability

There are discussions ongoing about the option to use transmit power control in devices using UWB technology. For example, the specification group IEEE 802.15.03a[28] has begun considering to include a power control option into the emerging IEEE 802.15.03a standard. Due to the lack of reliable information on power control to be provided by finalized standards, so far this facility has rarely been modelled when evaluating UWB interference. Mitigating effects using UWB power control would be expected to enhance the protection of radiocommunication services and could impact the maximum permissible UWB PSD levels to a limited extent. If power control is taken into account when assessing the impact of devices using UWB technology, some consideration may be appropriate as to how such devices with power control would be assured by means of regulations.

4.4 Victim IMT-2000 receiver characteristics and deployment scenarios

4.4.1 IMT-2000 overview

The impact of devices using UWB technology studies involving UWB devices and victim terrestrial IMT-2000 systems should encompass all of the frequency bands identified for terrestrial IMT-2000, which are the following:

806-960 MHz, 1 710-1 885 MHz, 1 885-2 025 MHz, 2 110-2 170 MHz, 2 500-2 690 MHz

IMT-2000 is a set of five family members, whose most detailed characteristics can be found in Recommendation ITU-R M.2039.

Some further mobile radio systems behave similarly with respect to UWB interference. UWB interference will add to the receiver internal noise floor $N_{receiver}$, which impacts the link budget (coverage) and the capacity of these systems. The sensitivity of the IMT-2000 receiver degrades by a factor that is equal to the increase in UWB interference I_{UWB}.

Both ratios, $(I_{UWB} + N_{receiver})/N_{receiver}$ and $I_{UWB}/N_{receiver}$ are independent of the considered bandwidth.

Therefore, I_{UWB} and $N_{receiver}$ may be specified with respect to any arbitrary bandwidth. A generic reference bandwidth of 1 MHz was chosen.

Figure 57 depicts the relation between the UWB interference increase and the UWB interference-to-noise ratio, both in dB.

[28] An IEEE working group considering standards for wireless personal area networks of WPAN with data rates of greater than 100 Mbit/s.

FIGURE 57

Interference increase versus UWB *I*/*N* ratio

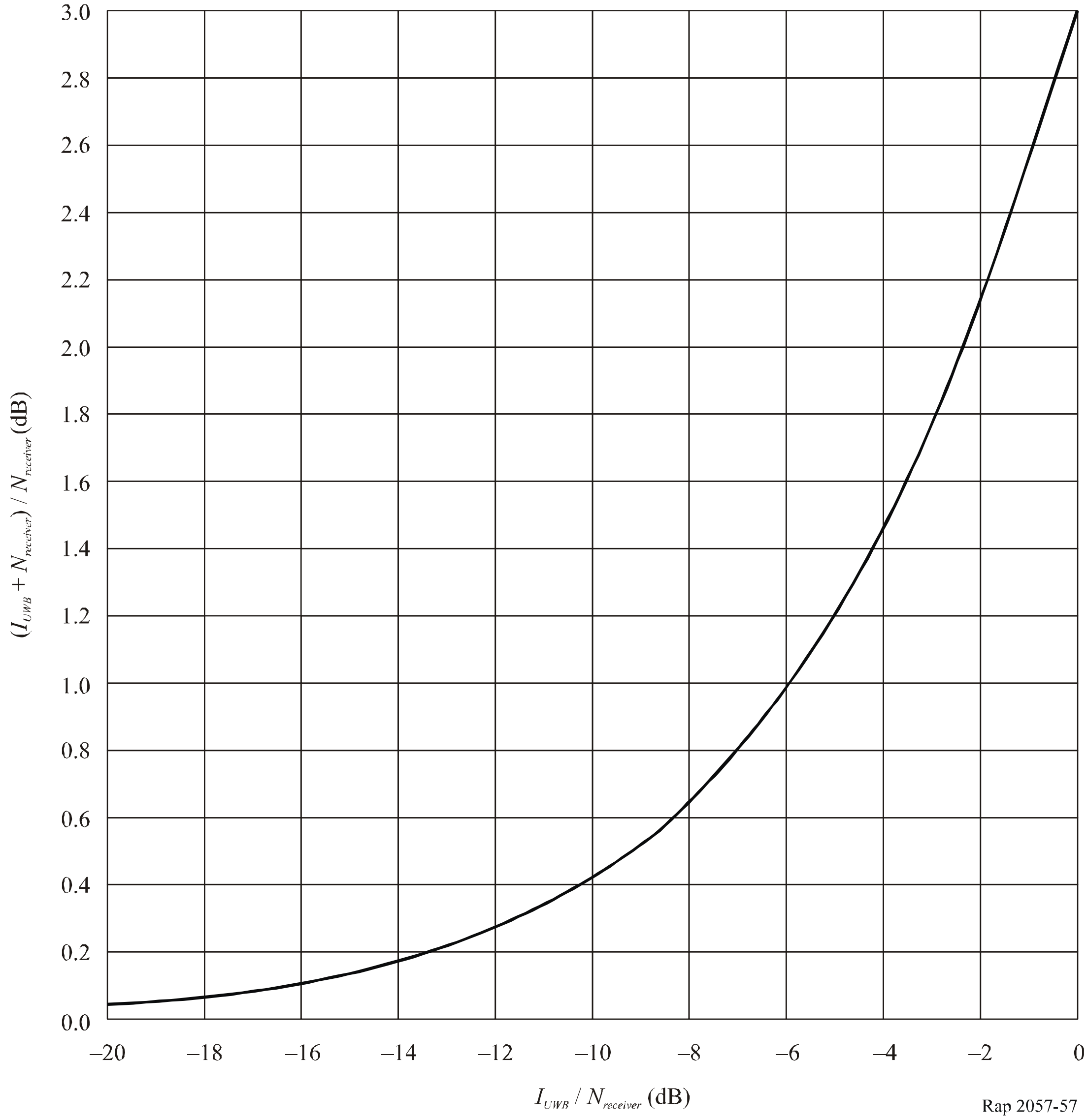


Figure 57 illustrates the following:

If $I_{UWB} << N_{receiver}$, there will be insignificant impact on the victim IMT-2000 system.

$I_{UWB} \geq N_{receiver}$, there will be severe impact on the victim IMT-2000 system.

A fundamental difference in the effect of UWB interference in the uplink and downlink performance is the following. UWB interference into a particular BS affects the uplink of *all* MSs connected to this BS. In contrast, UWB interference into MSs may be different for each MS, depending on the MS individual local environment of UWB transmitters. A certain *I*/*N* ratio for a BS is therefore considered to be more critical than the same *I*/*N* ratio perceived by a single MS.

In Table 37, I_{UWB} /N_{th} values used in previous ITU-R studies are summarized. The reference noise N_{th} for all I_{UWB} /N_{th} values is the thermal noise plus the receiver noise figure.

TABLE 37

I/N_{th} (dB)	Reference	Comment
–6	Report ITU-R M.2039	Criterion used with regard to IMT-2000 mobile and base stations, in the case of scenarios involving different IMT-2000 networks or when a limited number of IMT-2000 cells are affected by another type of co-primary service or system
–10	Report ITU-R M. 2039	Criterion used with regard to IMT-2000 mobile and base stations, in the case of scenarios involving co-primary satellite systems (e.g. BSS (Sound)) interfering into IMT-2000 networks

Conformance to value I_{UWB}/N_{th} = –10 dB in the case of interference from BSS (Sound) into IMT-2000 networks (MS and BS), excludes any exceeding allowance, because only a small safety margin is necessary to take into account deviations between predicted and actual satellite interference. Since UWB interference is less predictable in terms of densities and activity factors, it was felt important to further analyse this I_{UWB} N_{th} criterion.

Therefore, part of the UWB impact study results involving IMT-2000 stations contained in these Sections also addresses the relevant I_{UWB} $/N_{\text{th}}$ criteria for mobile and base stations (see § 4.4.2 and § 4.4.3).

High-speed downlink packet access (HSDPA) is an expected downlink variation with regard to IMT-DS and IMT-TC, where a larger percentage of the total downlink T*x* power may be allocated to a single user at a time. In comparison with the above-mentioned IMT-2000 technologies, HSDPA may be more susceptible to interference created by lower densities of devices using UWB technology.

The generic principles used in the UWB impact studies deal with two major principles: the assessment of levels of interference into IMT-2000 receivers, and an evaluation of the potential impact of UWB transmissions into an IMT-2000 network.

When addressing the assessment of the level of interference created by devices using UWB technology into IMT-2000 receivers, the approaches are basically deterministic, relying on link budget calculations: calculations present results for isolated UWB – IMT-2000 links, or in selected typical scenarios involving devices using UWB technology and IMT-2000 (mobile) stations deployments.

When evaluating the potential impact from devices using UWB technology into IMT-2000 networks, the approaches focus mainly on addressing capacity/coverage losses[29], throughput or quality of service degradation, or increase in the outage:

– Some deterministic approaches link the potential impact into IMT-2000 stations basically to a constant and ubiquitous UWB interference power over a whole IMT-2000 network.
– Another simulation driven approach uses a link level simulator to investigate the impact of burst-like UWB localized interference close to an IMT-2000 mobile station, upon the IMT-2000 power control technology. The effect is measured in terms of QoS degradation.
– Statistical approaches simulate UWB and IMT-2000 networks, and focus on the effect of distributions of UWB transmitting devices spread over an IMT-2000 network, assuming different UWB densities, varying transmit power levels, etc.

[29] It is noted that coverage loss is of particular concern for IMT-2000 systems when addressing lightly loaded cells, as in rural areas. It is expected that capacity losses would be more critical when addressing heavily loaded cells as in urban and dense urban scenarios. A combination of both aspects may also be considered.

– Another probabilistic approach addresses a cumulative effect of devices using UWB technology into an IMT-2000 base station, aggregates the contributions of UWB transmitters randomly and uniformly distributed around this victim base station (with a spherical area free of devices using UWB technology in the close vicinity of this base station) and derives an equivalent single UWB interferer situated at the calculated equivalent distance from the base station (see § 4.5.2.2 and § 4.6.2.2).

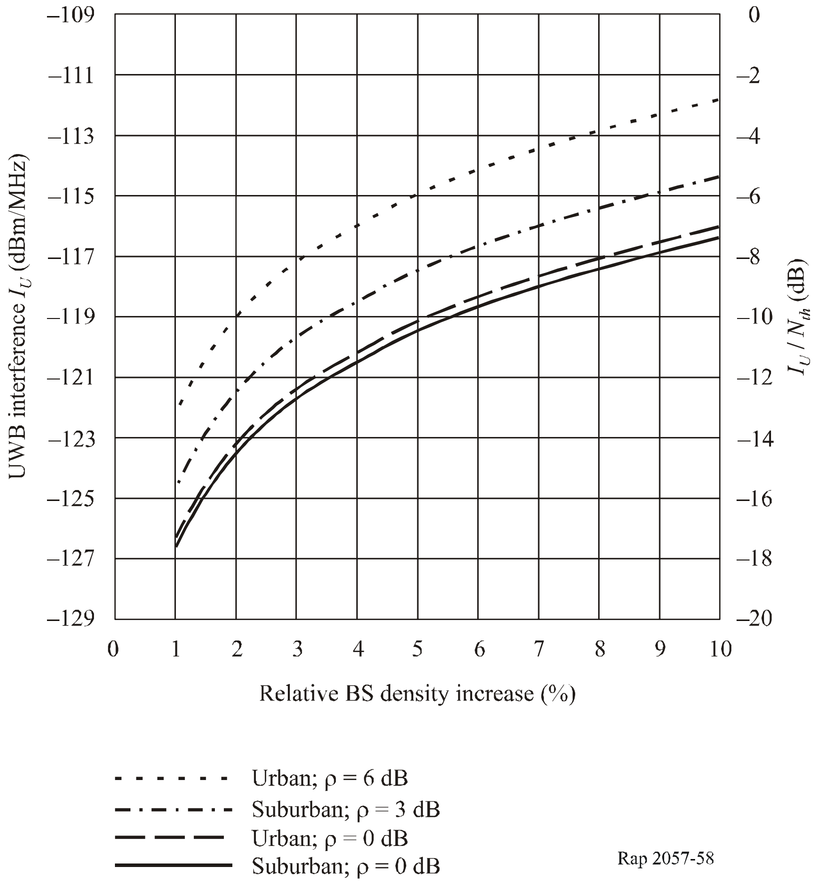
4.4.2 Base stations

Detailed values of the main characteristics of IMT-2000 BS can be found in the Report ITU-R M.2039. Some of them, such as the minimum coupling loss can be found in other relevant 3GPP specifications, mainly 3GPP TR 25.942 v6.0.0: cell type, cell radius, service type, deployment, antenna height, antenna gain, reference pattern, antenna tilt, receiver noise figure, receiver thermal noise level, feeder loss, MCL and power control.

Figure 58 shows which increase in IMT-2000 BS density is required in order to compensate for a given level of UWB interference at the base station. From the tolerable UWB interference I_{UWB} on the left y-axis the corresponding protection ratio I_{UWB}/N_{th} for a noise figure of 5 dB has been derived and can be read from the figure using the right y-axis.

FIGURE 58

Impact of UWB interference on BS density



ρ is the cell maximum noise rise, typically 6 dB in highly loaded (75%) cells, 3 dB in medium loaded (50%) cells, and close to 0 dB for cells of close to zero load.

The two main deployment specific parameters influencing the required I_{UWB}/N_{th} ratio are the load of IMT-2000 cells and the propagation conditions. The load has the main influence whereas the effect of the particular propagation model selected is minor and almost negligible, as can be seen in Fig. 58. For this reason, the results that can be read from this figure for propagation conditions in suburban areas are almost identical to those in rural areas. The major relevant difference between both area classes is that the traffic load in suburban areas is expected to be about 50% of the maximum cell capacity while in rural areas the traffic load will be very small, which is approximated by the zero-load case in Fig. 58.

An increase of no more than 1% in relative base station density is considered to be a maximum burden on IMT-2000 systems. Therefore, the following I_{UWB}/N_{th} ratios are to be used as references when assessing interference from devices using UWB technology into IMT-2000 base stations, see Table 38.

TABLE 38

IMT-2000 base station protection criteria

Area class	Urban areas	Suburban areas	Rural areas
Load	75%	50%	Close to 0
Tolerable interference (dBm/MHz)	–122	–124.5	–126.5
I_{UWB}/N_{th} ratio (dB)	–13	–15.5	–17.5

These I_{UWB}/N_{th} ratios assume that interference at the corresponding value is tolerable concurrently in each cell. In reality, UWB interference will vary in time and between cells. The I_{UWB}/N_{th} criteria in Table 38 are understood as being relevant for long-term protection criteria and may be exceeded only for a small percentage of time or cells.

4.4.3 Mobile station (user terminals)

The main characteristics of IMT-2000 mobile stations can be found in the Report ITU-R M.2039: deployment, antenna height, antenna gain, reference pattern, antenna tilt, receiver noise figure, receiver thermal noise level, feeder loss, and power control.

IMT-2000 protection criterion for mobile stations

The study results contained in § 4.7.1.1.2 (Table 42) show that a UWB PSD interference level at the mobile of –115 dBm/MHz creates no noticeable impact on the performance of the considered IMT-2000 mobile station.

4.4.4 IMT-2000 environment and scenarios

As IMT-2000 systems are generating intra- and inter-cell interference, the relative impact of additional UWB interference may differ according to the IMT-2000 deployment scenarios under consideration and IMT-2000 family member. The rise in system noise can be considered in the methodologies focusing on the degradation of the S/N on single links, or sets/distributions of links over an assumed deployed network.

For IMT-2000 CDMA Direct Spread and IMT-2000 CDMA TDD, the following cell load factors and noise rise can be used (source: 3GPP TR 25.942 v5.0.1):

– rural deployment scenario: load factor 0.2 (system noise rise *NR* 1 dB);
– suburban deployment scenario: load factor 0.5 (system noise rise *NR* 3 dB);
– urban, indoor deployment scenario, e.g. business areas and conference centres: load factor 0.75 (system noise rise *NR* 6 dB).

4.4.5 Propagation conditions

Propagation conditions experienced by IMT-2000 stations in the IMT-2000 bands may be of use together with methodologies focusing on the degradation of the *S*/*N* on single links or sets/distributions of single links over an assumed deployed network due to UWB interference (see § 4.6). Different propagation models were used in the studies, depending on the various scenarios and environments under consideration.

4.5 Interference scenarios

4.5.1 Scenarios involving victim IMT-2000 mobile station receivers

4.5.1.1 Single interferer into a single mobile station

In these scenarios, a single UWB device interferer is located in the vicinity of an IMT-2000 mobile station.

One purely deterministic approach aims to establish the relationship between a minimum separation distance and an assumed level of UWB interfering power in the IMT-2000 receiving band, or to determine a maximum tolerable interfering power in the IMT-2000 receiving band assuming a given separation distance. The minimum separation distance is determined using the assumed propagation models, depending on the deployment scenario under consideration together with a criterion expressed in terms of maximum I_{UWB} or I_{UWB}/N_{th}.

Another, simulation-driven approach focuses on modelling the localized interference into an IMT-2000 mobile station, including the effect on IMT-2000 power control, to investigate the effect of burst-like UWB interference. Results and metrics include QoS (BLER measure) degradation and IMT-2000 base station transmit power increase associated with the given coupling loss assumptions between the UWB devices and the IMT-2000 mobile station.

4.5.1.2 Multiple interferers into multiple mobile stations

The scenarios involving multiple UWB interferers into multiple mobile stations provide information on the distance at which the effect of the UWB interference into single IMT-2000 station is deemed unacceptable.

One type of approach aims to assess the systemic impact of multiple UWB interference upon the IMT-2000 downlink channel(s) over an IMT-2000 cell and wider IMT-2000 network. The impact can be interpreted in a number of ways, including cell range or cell area coverage reduction, or cell or network capacity reduction (or reduction in Grade of Service). In the case of HSDPA, the impact is assessed in terms of throughput reduction. It can be noticed that the scenarios considered in the multiple interferers into multiple mobile stations investigations assume that each IMT-2000 mobile station in the network under consideration is impacted by the same level of UWB interference.

4.5.2 Scenarios involving victim IMT-2000 base station receivers

4.5.2.1 Single interferer into a single base station

In the same spirit as the scenario involving a single UWB interferer into a single IMT-2000 mobile station, this scenario gives information on the minimum separation distance (or maximum acceptable UWB interfering power in the IMT-2000 receiving band) needed between a base station and a UWB device. The interference criterion can be expressed in terms of a tolerable interference margin (I_{UWB}/N_{th}). Equivalently, the results of such a scenario analysis can also be expressed in terms of IMT-2000 cell range or cell coverage area reduction, or IMT-2000 cell capacity reduction.

4.5.2.2 Multiple interferers into a single base station

This scenario focuses on the aggregate effect of devices using UWB technology into single IMT-2000 base stations (including suburban, urban outdoor and urban indoors environments). Devices using UWB technology are assumed to be distributed in an area of virtually infinite extent around the IMT-2000 outdoor macro base station, beyond an exclusion zone (sphere) around this station. The individual UWB contributions to the interference received at the base station are added together and the resulting total interference power is then virtually placed on one single device using UWB technology, placed at a certain distance and transmitting a typical power level of E_{UWB}. It is expected that the effect of aggregation could be minimal when considering pico- or indoor micro-cells, where the impact of the closest UWB interferer to the base station may be almost as large as the aggregated interference.

The effect of interference is then derived here in terms of coverage or capacity loss in the cell under consideration, following the principles of the first type of scenario described in this section.

4.5.3 Scenarios involving IMT-2000 (including base stations and mobile stations) and UWB networks

Two studies analysed scenarios involving IMT-2000 and UWB networks, both using Monte-Carlo models.

A first study focussed on analysing the effect of UWB interference across an IMT-2000 network, and employed a Monte-Carlo model to calculate the power levels across a system of cells which is used by a distribution of mobile users using different services. The Monte-Carlo aspect of this model was used to randomize the IMT-2000 users' positions, services, locations (in/outdoor or vehicular), vehicular speeds, floor-levels within buildings and also account for stochastic fading between the IMT-2000 transmitter and receiver. It is also used to randomize the location of devices using UWB technology and the amount of fading in the paths between these devices to IMT-2000 receivers.

Simulation results can show variations in dropped calls within the IMT-2000 network, which may be attributed to a too-high localized interference caused by devices using UWB technology in close vicinity of IMT-2000 mobile stations, or to a too-high level of interference caused directly to base stations by UWB devices interfering transmission, or to a too-high level of internal interference caused by increased individual IMT-2000 mobile stations transmit power in response to local UWB interference.

A second analysis is based on a market and service survey on UWB, and used a Monte-Carlo model to simulate realistic hot spot scenarios involving IMT-2000 and UWB networks. The Monte Carlo aspects of the model offers randomization of IMT-2000 users' positions in an office, suffering interference from a number of power-controlled UWB clusters. Graphical results of the levels of interference experienced at the IMT-2000 mobile stations are provided.

4.6 Methodologies for interference assessment

4.6.1 Scenarios involving victim IMT-2000 mobile station receivers

4.6.1.1 Single interferer into a single mobile station

4.6.1.1.1 Deterministic methodology

This deterministic methodology is based on a link budget calculation, assuming inherently that the I_{UWB} interference is Gaussian noise in the receiver bandwidth with a constant power level.

The link budget used in the calculation of minimum separation distances is basically as follows when IMT-2000 mobile stations are involved:

$$I_{UWB} = PSD_{UWB} - L(d) + G_{IMT\text{-}2000} - FL_{IMT\text{-}2000} \quad (45)$$

where either PSD_{UWB} or d can be determined depending on the input parameters used with this methodology, among which the criterion to determine the maximum level of UWB interference power, I_{UWB}max. This can expressed in terms of:

a) an absolute value I_{UWB}max (dBm/MHz);

b) (I_{UWB}/N_{th})max (dB), where N_{th} is the IMT-2000 mobile receiver noise. The thermal noise at the receiver includes the noise figure of the receiver.

– *Input parameters*:

PSD_{UWB}: maximum emission level in the IMT-2000 band under study (dBm/MHz)

d: separation distance (m)

$L(d)$: path-loss (dB) between the device using UWB technology and the IMT-2000 receiver which varies with d

$G_{IMT\text{-}2000}$: antenna gain (dBi)

$FL_{IMT\text{-}2000}$: local losses at the IMT-2000 receiver (body-losses at the mobile station, (dB))

N_{th}: thermal noise at the receiver includes the noise figure of the receiver, calculated as follows: $N_{th} = NF + N_0$*log10(B) (dBm/MHz)

B: reference bandwidth (1 MHz)

NF: noise figure of the receiver (dB)

N_0: thermal noise density of the receiver (–174 dBm/Hz).

– *Criterion*:

I_{UWB} max, or (I_{UWB}/N_{th})max.

– *Output results*:

PSD_{UWB}max: maximum emission level in the IMT-2000 band under study (dBm/MHz)

or:

d_{min}: minimum separation distance (m).

4.6.1.1.2 Link level simulation

This method investigates the impact of UWB interference upon a IMT-2000 mobile stations under certain conditions (characterized by the interference environment of the mobile under consideration). The simulations involve a series of UWB applications and IMT-2000 services. A link level simulator was developed to investigate the impact of burst-like UWB interference upon the IMT-2000 power control technology: the effect of separation distance between the device using UWB technology and the IMT-2000 mobile station upon QoS (BLER) is investigated.

More precisely, the simulator assesses the impact of UWB upon DCH (dedicated data channels), which represents the most common form of IMT-2000 service transport, through modelling of the IMT-2000 fast power control (FPC) and outer loop power control (OLPC).

For each IMT-2000 service the effect of separation distance is investigated by varying the coupling loss between UWB devices and the IMT-2000 mobile station. The simulations also involve varying UWB applications in terms of burst durations and duty cycles and the UWB link budget.

– *Input parameters*:

1 UWB

For each type of applications: transmit power (power control implemented or not), activity factors (% link activity, % daily usage, burst duration), data rates, ...

2 IMT-2000 mobile stations

– Service category: circuit switched voice, packet data (data rates, required E_b/N_0, interleaving/TTI, BLER requirement, and maximum power).

– Environment

There are many characteristics or factors of the propagation environment that affect the impact of UWB interference; they are:

– The range between IMT-2000 mobile stations and base station: The total noise power experienced by a mobile station in a network cell includes thermal noise (which includes the mobile station noise figure), intra-cell interference and inter-cell interference, *I*o; this intra-system interference becomes less as we move away from the base stations. Noise power drops to a minimum of around –100 dBm in rural areas, but we could expect some indoor areas (especially those locations that exhibit high penetration losses) in the urban areas at similar *I*o levels. The lower the *I*o level, the more impact a particular UWB interference source has. Detailed analysis of cell range for a number of services, for static and mobile cases with appropriate fading margins shows that the range is only marginally different for each service.

– The propagation environment, i.e. urban, rural and suburban and the nature of the multi-path channel(s): includes propagation models, fading margins, and an orthogonality factor. In an urban cell, the downlink orthogonality is better than rural or suburban cells and, consequently, there is less intra-cell interference. An environment, i.e. indoor, may be regarded as quasi-static, meaning little or no movement of the IMT-2000 receiver and principal reflectors. This is known as a slow faded environment, having significantly different fading parameters compared with the outdoor, mobile environment. There is no requirement for a Rayleigh fading margin in the quasi-static case; instead we will need to consider a shadow-fading margin and a slow-fading margin. The analysis shows that the slow-fading component dominates, giving a net fading margin of 13 dB, under worst-case conditions[30].

– The level of isolation between adjacent cells in the network, and the loading conditions of the network: careful analysis of the joint and individual effects of cell loading and isolation is required. Good cell isolation refers to the fact that little inter-cell interference is propagated from one cell to another. A light cell loading would refer to little intra-cell interference. Both metrics can be expressed through *G* factors and/or noise rise (see also § 4.6.1.2.1).

– Simulator: FPC and OLPC mechanisms

  – Criteria:

QoS (BLER) degradation

  – Output results:

QoS via BLER results and complementary metrics showing the degradation sensitivity factors within the IMT-2000 power control loops.

4.6.1.2 Multiple interferers into multiple mobile stations

4.6.1.2.1 "*G*" factor method

This deterministic methodology is based on a link budget calculation, assuming inherently that the I_{UWB} interference is of Gaussian noise-like type, with a constant power level. The *G* factor method allows the impact of UWB interference to be assessed over the whole network, which is achieved by

[30] This is a reasonable assumption, given the prior part understanding of an indoor propagation environment. However, further analysis of the UWB, indoor propagation channel may require that these assumptions be reviewed.

"attaching" to any victim mobile station, a UWB source of interference (device). The interfering power is calculated using the link budget calculations as in the scenarios involving a single UWB interferer into a single victim mobile station: I_{UWB}max is supposed to be experienced at any IMT-2000 mobile station, so that the UWB interference is experienced as a global increase of the total noise at the receiving IMT-2000 mobile stations.

I_{UWB}max can be converted into a degradation of the "geometry value", G, which can then be converted back into the system performance degradation in terms of throughput degradation. A criterion in terms of maximum throughput degradation will help determining I_{UWB}max.

The "geometry factor" G relates to the distance of the mobile station from the serving cell site and is defined as the ratio of own cell received power to inter-cell interference plus noise. Intra-cell channels are separated by orthogonal channel codes. Hence, the G factor is defined by:

$$G = \frac{I_{intra}}{N_{th} + I_{inter}} \tag{46}$$

where:

Input parameters:

N_{th}: thermal noise power (dBm/MHz, see § 4.6.1.1.1)

I_{intra}: intra-cell power received from the serving cell (dBm/MHz)

I_{inter}: inter-cell interference (dBm/MHz).

G_{Nth} is the parameter to introduce the other cell interference to the calculations. It shows therefore the overall network loading and/or cell isolation:

$$G_{Nth} = \frac{N_{th}}{N_{th} + I_{inter}} \tag{46a}$$

G_{Nth} = 0 dB corresponds to an isolated cell.

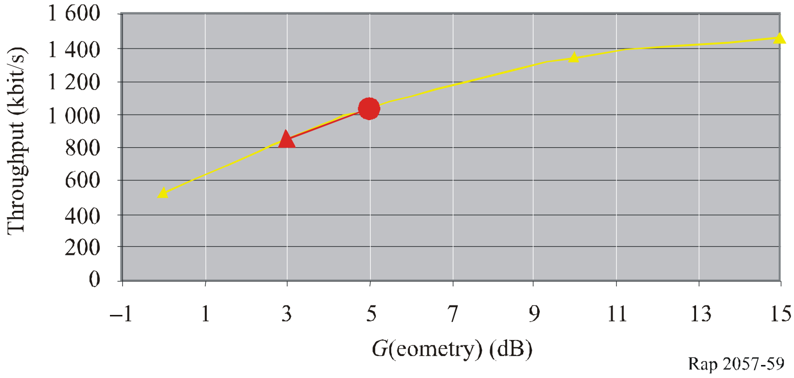
Considering the average geometry of mobile stations at a certain distance from the serving cell site, the average geometry decreases as the distance increases. Additional interference from UWB transmitter, I_{UWB}, changes the geometry point that MS experiences as:

$$G_{New} = \frac{I_{intra}}{N_{th} + I_{inter} + I_{UWB}} \tag{46b}$$

A degradation of the "geometry factor" from G to G_{New} causes an increase in required TX power and degradation in link (and cell) performance and throughput. Figure 59 illustrates an example of the HSDPA downlink performance in terms of throughput degradation expressed as the function of the geometry factor. The overall reduction in cell throughput depends also on the scheduling principle employed for HSDPA and the actual geometry distribution of the HSDPA users. Basically, a criterion in terms of maximum degradation of the throughput (x%) would help finding the corresponding "geometry factor" G degradation, and equations (46a) and (46b) will help defining I_{UWB}max.

FIGURE 59

HSPDA throughput (example)



– *Input parameters*:

Throughput graph vs. "geometry factor" degradation G (depends on lots of factors, not detailed in the study).

The "geometry factor" G at a certain distance from the serving cell base station depends on I_{intra}, I_{inter} and N_{th}.

G_{Nth} at the same distance from the serving base station will provide I_{inter}.

– *Criterion*:

Maximum throughput loss (percentage)

– *Output results*:

I_{UWB}max (dBm/MHz), the maximum UWB interference power experienced at all IMT-2000 mobile stations: obtained by reading the throughput graph vs. "geometry factor" degradation, and by using equations (46a) and (46b), assuming I_{intra} and I_{inter} unchanged for example.

4.6.1.2.2 Cell capacity, cell range and coverage reduction methods

This section considers cell range reduction and cell capacity reduction based on UWB interference levels experienced equally and uniformly at all IMT-2000 mobile stations in the IMT-2000 network. These methods were used in the context of IMT-DS systems and may remain valid for the other types of CDMA systems in the IMT-2000 family of standards.

a) Cell capacity reduction = 100*(1 – CellLoad/CellLoad$_0$) %

where:

CellLoad$_0$: (numerical, between 0 and 1) is the maximum cell load without UWB interference: with a maximum noise rise NR of 6 dB (typical), CellLoad$_0$ = 1 – 10^(–NR/10).

CellLoad: (numerical, between 0 and 1) is the maximum cell load with UWB interference, taking into account the network limitation of a total noise allowed in the system: $N_{totmax} = N_{th} + NR$. The interference "consumed" by UWB interference is considered as no more available to system internal noise, thus reducing the maximum cell load calculated as a function of the noise rise due to system internal noise (I_{intra} and I_{inter}):

$NR_{internal}$ = 10 log10(10^(N_{totmax})/10) –10^(I_{UWB}/10)) – N_{th} dB

and CellLoad = 1 – 10^(–$NR_{internal}$/10).

This calculation assumes that the cell range remain constant.

– *Input parameters*:

N_{th}: IMT-2000 mobile station thermal noise (dBm/MHz)

NR: maximum noise rise, or equivalently initial cell load factor CellLoad_0 (dB).

– *Criterion*

Maximum capacity cell reduction allowance (%)

– *Output result*:

I_{UWB}max (dBm/MHz), the maximum UWB interference power experienced at all IMT-2000 mobile stations.

b) Cell range reduction = 100*(1 – Δ*R*) %

The impact of UWB interference is to decrease the range of a cell. This is a degradation in the propagation loss available in the link budget, Δ*L*, which can be calculated as:

$$\Delta L = 10 \log_{10}(1 + 10^{(I_{UWB}/N)/10}) \qquad \text{dB} \qquad (47)$$

where the total noise N is dependent upon the thermal noise N_{th}, and the noise generated by CDMA system (intra-cell and inter-cell) interference N_{sys}, as follows

$$N = N_{th} + N_{sys} \qquad \text{dBm/MHz} \qquad (48)$$

This loss in propagation margin *L*, can be converted into a loss of range *R*, using the IMT-2000 propagation model, expressed as:

$$L = const + \beta \log_{10} R \qquad \text{dB} \qquad (49)$$

Hence the change in range Δ*R*, for a given degradation in the propagation loss is:

$$\Delta R = 10^{-\Delta L/\beta} \qquad \text{(numerical, between 0 and 1)} \qquad (50)$$

where *R* is the cell range (m) obtained with the propagation model associated with the IMT-2000 channel propagation model, hence with/without UWB interference. Variation in the cell range Δ*R* is obtained.

This calculation assumes that the cell capacity remains constant.

– *Input parameters*:

IMT-2000 channel propagation model.

Cell load factor or noise rise.

– *Criterion*:

Maximum cell range reduction (%).

– *Output result*:

I_{UWB}max (dBm/MHz), the maximum UWB interference power (experienced at all IMT-2000 mobile stations)

c) Cell coverage reduction = 100*(1 – Δ*A*) (%), using the same principles as above again

Δ*A* is the change in coverage area, with the same notations as above. Δ*A* is proportional to the square of the change in range, thus:

$$\Delta A = (10^{-\Delta L/\beta})^2 \qquad \text{(numerical, between 0 and 1)} \qquad (51)$$

This calculation assumes that the cell capacity remains constant.

– *Input parameters*:

IMT-2000 channel propagation model.

Cell load factor or noise rise.

– *Criterion*:

Maximum cell coverage reduction (%)

– *Output result*:

I_{UWB}max (dBm/MHz), the maximum UWB interference power (experienced at all IMT-2000 mobile stations).

4.6.2 Scenarios involving victim IMT-2000 base station receivers

4.6.2.1 Single interferer into a single base station

The link budget used in the calculation of minimum separation distances is basically as follows:

$$I_{UWB} = PSD_{UWB} - L(d) + G_{IMT\text{-}2000}(\theta_{BS,UWB}) - FL_{IMT\text{-}2000} \quad (52)$$

where either PSD_{UWB} or d can be determined depending on the input parameters used with this methodology, among which the criterion to determine the maximum level of UWB interference power, I_{UWB}max. This can be expressed in terms of:

a) an absolute value I_{UWB}max (dBm/MHz);

b) (I_{UWB}/N_{th})max (dB), where N_{th} is the IMT-2000 mobile receiver noise. The thermal noise at the receiver includes the noise figure of the receiver;

c) with the same equations as in § 4.6.1.2.2a), express the linkage between I_{UWB} and cell capacity reduction (%);

d) with the same equations as in § 4.6.1.2.2b), express the linkage between I_{UWB} and cell range reduction (%);

e) with the same equations as in § 4.6.1.2.2c), express the linkage between I_{UWB} and cell coverage reduction (%).

– *Input parameters*:

PSD_{UWB}: maximum emission levels in the IMT-2000 band under study (dBm/MHz)

d: separation distance (m)

$L(d)$: path-loss (dB) between the device using UWB technology and the IMT-2000 base station which varies with d

$G_{IMT\text{-}2000}$ $(\theta_{BS,UWB})$: IMT-2000 BS antenna gain (dBi), in the direction of the UWB transmitter: $\theta_{BS,UWB}$ is the off-axis angle between the IMT-2000 base station and the UWB device transmitter. It will depend on the respective antenna heights of the IMT-2000 BS and the UWB device, on the distance between them and on the IMT-2000 base station antenna pattern (vertical and horizontal/azimuthal). The UWB device antenna is assumed to be omni-directional.

$FL_{IMT\text{-}2000}$: feeder losses at the IMT-2000 receiver (dB), cable losses at the base station)

N_{th}: thermal noise at the receiver includes the noise figure of the receiver, calculated as follows: $N_{th} = NF + N_0$*log10(B) (dBm/MHz)

B: reference bandwidth (1 MHz)

NF: receiver noise figure (dB)

N_0: receiver thermal noise density (–174 dBm/Hz).

– *Additional input parameter*:

Load factor[31] – when using methods c), d) and e), numerical between 0 and 1. The load factor is representative of the assumed load of the cells for the scenario under consideration (see § 4.4.4) and is necessary to evaluate the noise rise:

$$NR = -10 \log(1 - \text{Load factor}) \qquad \text{dB} \qquad (53)$$

The IMT-2000 propagation model is needed when using the method in d) and e).

– *Criterion*:

With methods a) and b): I_{UWB}max or (I_{UWB}/N_{th})max; the other methods c), d), and e) allow converting criteria expressed in cell coverage, capacity or range reduction (%), back into (I_{UWB})max.

– *Output results*:

PSD_{UWB}max: maximum emission level in the IMT-2000 band under study (dBm/MHz)

or:

d_{min}: minimum separation distance (m).

4.6.2.2 Multiple interferers into a single base station

The methodology developed in this section provides a probabilistic assessment of the aggregate interference produced by distributions of UWB users into a victim base station.

An IMT-2000 base station is surrounded by UWB transmitters which are randomly and uniformly distributed in the horizontal and vertical planes, leaving a spherical area of a radius R_{min} around the BS antenna free of UWB transmitters. This accounts for special locations like masts on roofs in which the macro BS antennas are mounted with respect to worst-case locations where UWB transmitter operation is expected to be practicable.

A cumulative path gain from all UWB transmitters distributed around the base station is assessed by calculation on sets of simulations of devices using UWB technology random distributions. The cumulative path gain is the sum of the gains of all individual paths from the considered BS to UWB transmitters, aggregated virtually on a single UWB transmitter with a propagation path of the same path gain. The cumulative path gain depends on the specific spatial distribution of UWB transmitters, which is random, and therefore requires a number of simulations to determine stable cumulative distribution function (CDF) curves. The maximum UWB transmit power can then be determined by:

$$PSD_{UWB}\text{max} = I_{UWB}\text{max} - G_{Rx} + FL_{Rx} + (\text{x\% quantile of the effective path loss}) \ \text{dBm/MHz} \qquad (54)$$

where PSD_{UWB} can be determined depending on the input parameters used with this methodology, among which the criterion to determine the maximum level of UWB interference power, I_{UWB}max. This can be expressed in terms of:

a) an absolute value $I_{UWB\text{max}}$ (dBm/MHz);

b) (I_{UWB}/N_{th})max (dB), where N_{th} is the IMT-2000 mobile receiver noise. The thermal noise at the receiver includes the noise figure of the receiver;

c) with the same equations as in § 4.6.1.2.2a), express the linkage between I_{UWB} and cell capacity reduction (%);

d) with the same equations as in § 4.6.1.2.2b), express the linkage between I_{UWB} and cell range reduction (%);

[31] The noise rise NR is derived from the load factor as: $NR = -10*\log(1 - \text{Load factor})$, which is representative of the assumed load of the cells for the scenario under consideration (see § 4.4).

e) with the same equations as in § 4.6.1.2.2c), express the linkage between I_{UWB} and cell coverage reduction (%).

– *Input parameters*:

Base station characteristics: G_{Rx} (dBi), FL_{Rx} (dB), BS antenna pattern (vertical/horizontal), tilt angle (°), antenna height (m).

UWB channel propagation model.

UWB distribution parameters to operate simulations and determine the cumulative path loss CDF graphs: UWB user density (users/km^2), activity factor(s) (%), transmit power variations (power control implemented or not, etc.), R_{min} (exclusion zone, m), device heights (m).

– *Additional input parameters*:

As required by the methodology used to derive I_{UWB}max (b), c), d) and e)).

– *Criterion*:

Prob($I_{UWB} > I_{UWB}$max) = x%.

– *Output results*[32]:

PSD_{UWB}max maximum emission limits in the IMT-2000 band under study (dBm/MHz).

4.6.3 Scenarios involving IMT-2000 and UWB networks (Monte-Carlo simulations)

In order to analyse the effect of UWB interference across an IMT-2000 network, Monte-Carlo models were used to calculate the power levels across a system of cells which is used by a distribution of mobile users using different services. The Monte-Carlo aspect of the model is used to randomize the IMT-2000 users' positions, services, locations (in/outdoor or vehicular), vehicular speeds, floor-levels within buildings, and also accounts for stochastic fading between the IMT-2000 transmitter and receiver. It is also used to randomize the location of devices using UWB technology and accordingly their power when power control is simulated, and the amount of fading in the paths between these devices to IMT-2000 receivers.

The Monte-Carlo test-bed simulation generates the transmit power, interference levels, and link-success probability for a given number of users at an instant in time. The model effectively captures a "snapshot" of the power levels in the system and the number of links which can be successfully carried in light of these power levels.

Devices using UWB technology are characterized by their number density, their location classification (whether or not the device is outdoors, indoors or in-vehicular), and the power spectral density in the IMT-2000 band.

For the simulations, the input parameters need to describe the technical characteristics and the behaviour of IMT-2000 or UWB networks in the environment under consideration. Correlation between IMT-2000 and UWB distributions can also be considered through Monte-Carlo simulations. Simulations will help producing informative intermediate figures and results.

– *Input parameters*:

1 IMT-2000 distributions (depending on environment types under consideration: rural, suburban, urban): thermal noise, base station characteristics (*P*max/typical, antenna pattern, MCL, *FL*, *NF*), mobile station characteristics (*P*max/typical, antenna gain, *NF*, Body loss, activity factor), orthogonality factors, power control and soft handover implementation, cell load factor, channel propagation models.

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[32] Intermediate result: cumulative path loss CDF graphs obtained by series of simulations.

2 UWB distributions: UWB transmitter characteristics and interference modelling (AWGN/others), channel propagation models, network type and corresponding power variation schemes (UWB users may be organized in master-slave networks, or exchange information from user to user, power control may be implemented or not), UWB users density and location distribution, activity factors (and % of link rate, % of daily usage)

3 Possibly, correlation schemes linking together UWB and IMT-2000 distributions, which may be expressed in different ways.

– *Criterion*:

For example: maximum degradation in outage, detailed interference levels received at IMT-2000 mobile stations.

– *Output results*:

Graphs presenting the criterion magnitude in presence of UWB networks. Additional graphs aiming to understand the main underlying phenomenon/a conducting to the criterion graphs may be useful to perform sensitivity analyses.

4.7 Studies and results

4.7.1 Scenarios involving victim IMT-2000 mobile station receivers

4.7.1.1 Single interferer into a single mobile station

4.7.1.1.1 Deterministic approach

This scenario was addressed in all the input documents. The initial parameters used in these studies were not aligned, but it was agreed to present the results with a single set of parameters.

Frequency bands: 1 710-1 885 MHz, 1 885-2 025 MHz, 2 110-2 170 MHz, 2 500-2 690 MHz

Technologies: CDMA-2000 (1X and 3X), TD-CDMA, W-CDMA, TD-SCDMA, DECT, UWC-136 TDMA

Methodology: as described in § 4.6.1.1b).

– *Input parameters*:

d_{min} = 0.2 and 1 m.

UWB channel propagation model: free-space loss

$G_{IMT\text{-}2000}$ = 0 dBi (mobile station)

$FL_{IMT\text{-}2000}$ = 0 dBi

Mobile station thermal noise levels including a receiver noise figure of 9 dB:

TABLE 39

Mobile station thermal noise levels including a receiver noise figure of 9 dB

Technology	N_{th} (dBm/MHz)
CDMA-2000 1X	–105
CDMA-2000 3X	–105
TD-CDMA	–105

W-CDMA	–105
TD-SCDMA	–105
DECT	–101
UWC-136 TDMA	–104
UWC-136 EDGE	–105

– *Criterion*:

(I_{UWB}/N_{th})max = –6 dB

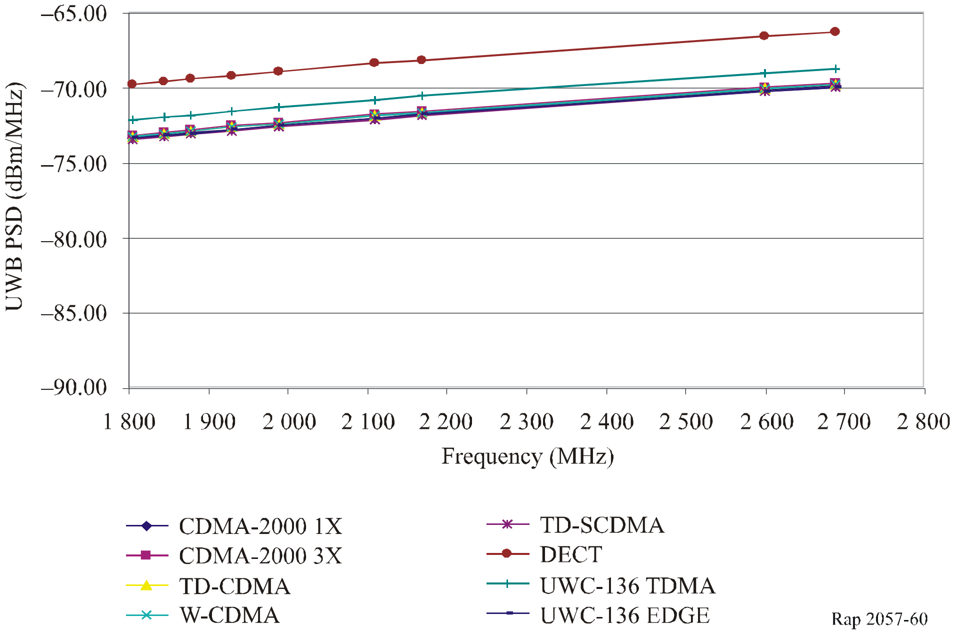
– *Output results:*

UWB PSD: the graphs[33] in Figs. 60 and 61 present the maximum UWB emissions levels associated with a minimum separation distance of 0.2 m and 1 m, in the frequency range encompassing all the frequency bands under consideration.

It is noted that the calculation and measurement based results for CDMA PCS networks operating in the 1 900 MHz band agree well with the results found in this band in Fig. 60 for IMT-2000 systems based on CDMA technology.

FIGURE 60

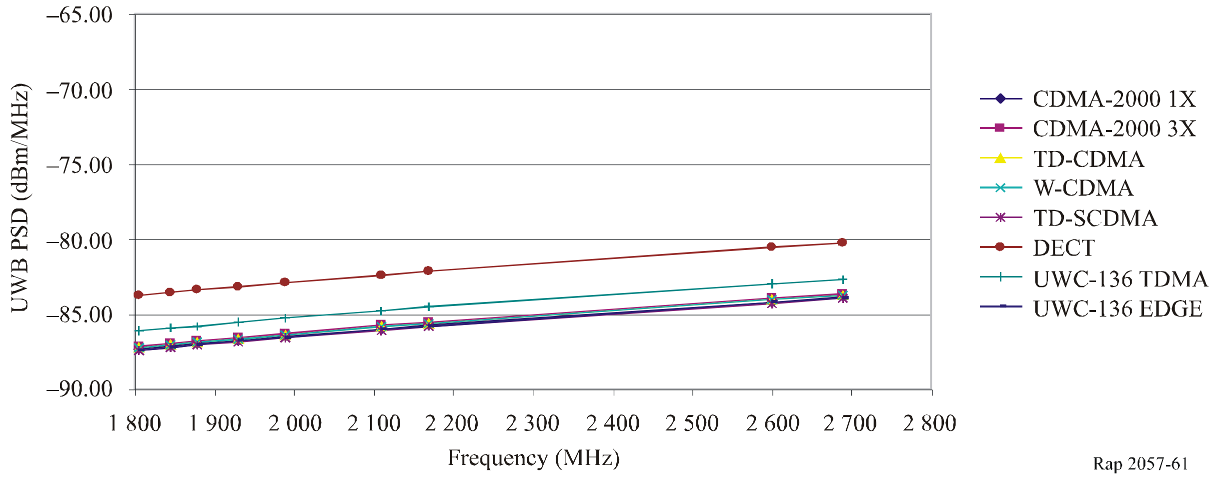
Maximum average UWB emission @ 1 m



[33] The curves for CDMA-2000 1X, CDMA-2000 3X, W-CDMA, TD-CDMA and TD-SCDMA are identical (superimposed on the graphs).

FIGURE 61

Maximum average UWB emission @ 0.2 m



4.7.1.1.2 Link level simulation

Frequency band: 2 110-2 170 GHz

Technologies: IMT-DS

Methodology: as described in § 4.6.1.1.2.

– *Input parameters*:

1 Devices using UWB technology.

Varying UWB applications: three different UWB applications, namely: wireless monitor, digital TV set-top box (three channels) and digital camera download. The characteristics of the UWB applications in terms of burst durations and duty cycles and the UWB link budget, along with detailed discussion of the various parameters, are detailed hereafter:

TABLE 40

UWB applications and usage parameters for office "power user" environment

Device and usage scenarios	Data rate (Mbit/s)	Percent burst duty cycle
PC – wireless monitor (with compression)	250	4
PC – digital camera (download)	250	96
Digital TV set-top box 3 channels	100	30

An UWB market study showed that UWB was designed to deliver data rates greater than 100 Mbit/s for WPAN applications. With one exception (PC-Monitor), the net UWB data rate is greater than 100 Mbit/s. Applications that require less net data rate than 100 Mbit/s (for example, wireless monitors) still feature in the market survey as key applications. In order to monitor these applications, we deduced that UWB could support such applications by delivering short intermittent *bursts* of data at the proposed 250 Mbit/s such that a net throughput of, for example, 10 Mbit/s for a wireless monitor could be supported. Furthermore, the transmission *bursts* were deemed to occur at typical refresh rates of video appliances, in this case 50 Hz.

$$PSD_{UWB} = -65 \text{ dBm/MHz} \quad (55)$$

UWB channel propagation model: For each IMT-2000 service, the effect of the separation distance is investigated by varying the coupling loss between the UWB devices and the IMT-2000 mobile station. The coupling loss is varied from 40 dB to 10 dB in 10 dB decrements, where 40 dB coupling loss is representative of a 1 m separation distance between device using UWB technology and IMT-2000 terminal. A 10 dB coupling loss is representative of a worst-case condition where a device using UWB technology may be next to a IMT-2000 terminal.

2 IMT-2000 environment and services

The investigation assumes the worst-case propagation environment, namely: *an indoor terminal at the edge of an urban cell in a lightly loaded network*. Lightly loaded networks present the worst-case scenario rather than the fully or nearly fully loaded cells, because the ratio of UWB interference to absolute downlink intra- and inter-cell interference *I*o is higher than in a fully loaded network where the base stations are transmitting at or near to their full powers. Hence, the UWB interference will make a much smaller contribution to the total interference seen at the victim terminal than if the network of base stations were less loaded.

It should however be noted that the effect of propagation environment upon UWB interference (cell load and isolation levels) is quasi negligible. The impact of UWB interference is assessed in DCHs, representing the most common form of UMTS service transport, which utilizes fast power control (FPC, at 1 500 Hz) and outer loop power control (OLPC, at 100 Hz). The following representative set of IMT-2000/UMTS services were selected: Voice 12.2 kbit/s, CS144, and PS384 physical channels:

TABLE 41

UMTS Service parameters				
UMTS Service	Voice 12.2	CS 144	PS 384	
IMT-2000 service E_b/N_0 (Static channel)	4.4	7.0	–1.0	dB
BLER target	1.00%	0.10%	10.0%	
Interleaving or TTI	20	40	80	ms
IMT-2000 service rate	12.2	144	384	kbit/s
IMT-2000 maximum average DPCH power	37.0	37.0	37.0	dBm (in 3.84 MHz)
IMT-2000 Downlink environment				
IMT-2000 environment	Hata urban			
IMT-2000 multi-path model	Pedestrian A			
IMT-2000 BS height	20 m			
IMT-2000 MS height	1.5 m			
IMT-2000 actual distance	0.70	0.70	0.70	km
IMT-2000 Downlink link budget parameters				
IMT-2000 DL antenna gain	16.0	16.0	16.0	dBi
IMT-2000 DL feeder losses	2.0	2.0	2.0	dB
IMT-2000 DL e.i.r.p.	33.3	40.8	40.1	dBm (in 3.84 MHz)

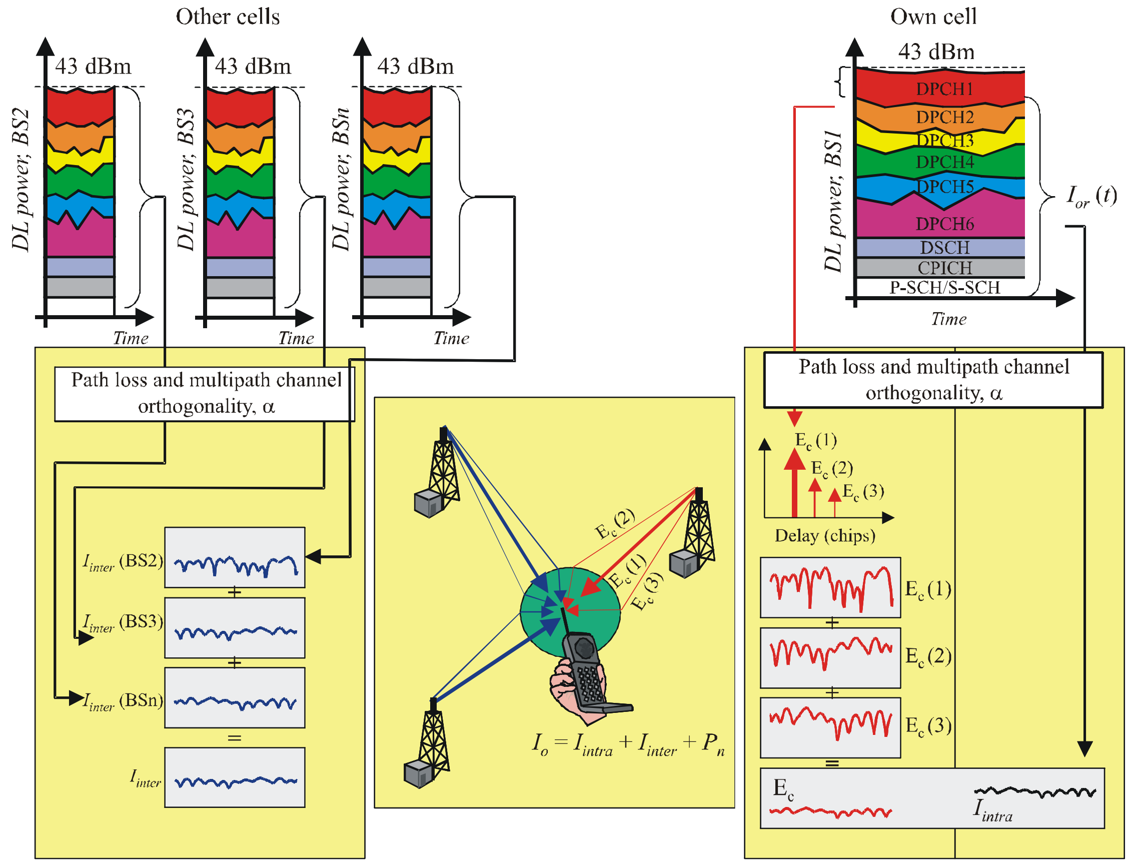
IMT-2000 DL path loss	132.8	132.8	132.8	dB
IMT-2000 DL SHO gain	3.0	3.0	0.0	dB
IMT-2000 DL in-building penetration	10.0	10.0	10.0	dB
IMT-2000 DL head penetration loss	3.0	0.0	0.0	dB
IMT-2000 DL spatial fade margin	13.0	10.0	10.0	dB
IMT-2000 DL DPCH Rx power (RF)	–122.5	–109.0	–112.7	dBm (in 3.84 MHz)
IMT-2000 thermal noise floor	–108.2	–108.2	–108.2	dBm (in 3.84 MHz)
IMT-2000 terminal *NF*	5.0	5.0	5.0	dB
IMT-2000 terminal noise floor	–103.2	–103.2	–103.2	dBm (in 3.84 MHz)
IMT-2000 DL orthogonality factor	0.90	0.90	0.90	
IMT-2000 *G*pn factor	–1.0	–1.0	–1.0	dB
IMT-2000 *Ior* (All other PHY channels)	37.0	37.0	37.0	dBm (in 3.84 MHz)
IMT-2000 I_{intra}	–104.8	–101.8	–101.8	dBm (in 3.84 MHz)
IMT-2000 I_{inter}	–109.0	–109.0	–109.0	dBm (in 3.84 MHz)
IMT-2000 *G* factor	–2.6	0.4	0.4	DB
IMT-2000 total *I*o (RF)	–100.3	–99.0	–99.0	dBm (in 3.84 MHz)
IMT-2000 *I*o component at baseband	–101.9	–101.7	–101.7	dBm (in 3.84 MHz)
IMT-2000 DL DPCH process gain	25.0	14.3	10.0	dB
IMT-2000 DL Rx E_b/N_0	4.4	7.0	–1.0	dB

3 Link level simulator: fast and outer loop power control

Figure 62 depicts a generic test scenario for the link level simulator, which is used here for explanation purposes. A wanted signal, represented by DPCH1, is transmitted from the "own cell" base station cell. The received signal of DPCH1 undergoes multi-path scattering that has a certain delay profile. When the mobile moves, a number of independently Rayleigh-fading replicas of the signal exist and are effectively combined at the UMTS Rake diversity receiver. The more dispersive the radio channel, the more independently fading signal replicas there are, and ultimately the combined resultant signal (after Rake processing) has reduced fading statistics. The wanted received fading signal after Rake processing is shown in red as *E*c in Fig. 62. The "own cell" also supports other traffic and signalling channels for other users in the cell, and these channels may be fluctuating in transmitted power due to their own independent power control mechanisms. Total power less wanted channel power, and less path loss from the "own cell" is intra-cell interference received at the UMTS terminal. This intra-cell interference will also undergo the same multi-path channel as the wanted signal.

FIGURE 62

Generic test set-up for IMT-2000 CDMA direct spread link level FPC/OLPC simulator



Rap 2057-62

Inter-cell interference comes from all other cells within the network that will carry different levels of traffic and, hence, downlink power levels; and it comes from different locations within the network. Inter-cell interference is modelled as a variable Geometry Factor (see also § 4.6.2.1 for the definition of *G* factors). Cell edge conditions result in *G* ~ –3 dB and close to the cell centre *G* ~ +20 dB. The total inter-cell interference will also fade due to the multi-path channel, but to a lesser extent than intra-cell interference. This is because inter-cell interference is made up of a number of independent "other cell" cells, which sum together producing a diverse like (less variable) interference. The inter-cell interference shows partial correlation with the intra-cell interference. Partial correlation is due to the fact some local scatterers around the UMTS terminal will exist for intra- and inter-cell interference.

The mobile terminal undergoes motion at various cell positions and, hence, varying intra- and inter-cell interference conditions. The FPC and OLPC algorithms respond to the received *S*/*R*, and ultimately aim to maintain a target BLER for the UMTS service. The target BLER results in a target E_b/N_0 for the environmental conditions.

The model captures the variation in DPCH over time, typically 20 s, in the following manner. The wanted DPCH signal power, the inter-cell interference power, the intra-cell interference power, and the resulting E_b/N_0 are measured every 1/1500th s (DPCH slot interval). Data transported on the downlink DPCH in each slot interval has its BER estimated using a model of E_b/N_0 vs. BER. The BER model was a simple QPSK waterfall curve using ½ rate convolution coding. If the resulting E_b/N_0 for that slot was below the target E_b/N_0 set by the OLPC loop, then the FPC algorithm would instruct the downlink DPCH to power up by +1 dB on the next transmission slot. Similarly, if the actual E_b/N_0 was greater than the target E_b/N_0, then the FPC algorithm would instruct the downlink DPCH to power down by 1 dB on the next DPCH slot. BLER was determined at each block TTI (corresponding to the IMT-2000 CDMA Direct Spread service interleaving period) by the averaging of all slot BERs as part of the current TTI. If the BLER was worse than the required BLER for the IMT-2000 CDMA Direct Spread service, then the OLPC algorithm would adjust its OLPC E_b/N_0 target upwards. Similarly, if the BLER was better than the required BLER, the target E_b/N_0 would be adjusted downward.

– *Criterion*:

No criterion expressed.

– *Output results*:

TABLE 42

Summary of BLER/QoS impact, resulting OLPC E_b/N_0, and resulting DL transmit power rise for voice, CS144, and PS384 IMT-2000 CDMA direct spread services which experience UWB monitor, UWB set-top box, and UWB digital camera interference at various coupling losses

	UWB wireless monitor	**UWB set-top box (3 channels)**	**UWB digital camera**		**UWB wireless monitor**	**UWB set-top box (3 channels)**	**UWB digital camera**		**UWB wireless monitor**	**UWB set-top box (3 channels)**	**UWB digital camera**		**UWB wireless monitor**	**UWB set-top box (3 channels)**	**UWB digital camera**
	BLER (%)				**Resulting OLPC E_b/N_0 (dB)**				**Resulting downlink Tx power rise (dB)**				**QoS**		
Coupling loss = 50 dB															
Voice 12.2	1.0	1.0	1.0		4.5	4.5	4.5		0.5	0.5	0.5		A	A	A
CS144	0.1	0.1	0.1		7.0	7.0	7.0		0.5	0.5	0.5		A	A	A
PS384	10	10	10		–0.7	–0.7	–0.7		0.5	0.5	0.5		A	A	A
Coupling loss = 40 dB															
Voice 12.2	1.0	1.0	1.0		5.8	6.6	5.2		1.7	3.8	4.8		B	B	B
CS144	0.1	0.1	0.1		9.8	11.0	9.7		3.1	4.3	5.4		B	B	B
PS384	10	10	10		–0.7	–0.1	–0.5		0.6	2.5	4.3		A	A	A
Coupling loss = 30 dB															
Voice 12.2	1.0	1.0	1.7		12.7	14.3	7.5		8.6	13.1	14.9		B	B	B
CS144	5.9	69	96		N/A	N/A	N/A		N/A	N/A	N/A		C	C	C
PS384	10	10	94		0.3	3.4	N/A		1.6	6.6	N/A		A	A	C
Coupling loss = 20 dB															
Voice 12.2	9.5	76	96		N/A	N/A	N/A		N/A	N/A	N/A		C	C	C
CS144	25	90	97		N/A	N/A	N/A		N/A	N/A	N/A		C	C	C
PS384	10	78	97		0.8	N/A	N/A		2.1	N/A	N/A		A	C	C
Coupling loss = 10 dB															

Voice 12.2	43	97	99		N/A	N/A	N/A		N/A	N/A	N/A		C	C	C
CS144	26	90	97		N/A	N/A	N/A		N/A	N/A	N/A		C	C	C
PS384	10	93	99		1.0	N/A	N/A		2.3	N/A	N/A		A	C	C

N/A: Not available.

QoS code key:

A: No measurable impact on QoS.

B: Transient QoS degradation (when UWB becomes active) and persistent QoS degradation (during UWB activity).

C: IMT-2000 DS service failure.

Table 42 summarizes all results from the QoS impact analysis using the link level simulator. It can be seen that at 40 dB coupling loss, all services can be maintained at the cell edge with some transient loss in QoS for circuit switched services. Table 42 summarizes that at 50 dB coupling loss, all services in fact do not exhibit any measurable QoS loss in terms of transient QoS, and therefore presents the isolation required for no discernable impact upon a range of IMT-2000 CDMA Direct Spread services.

4.7.1.2 Multiple interferers into multiple mobile stations

4.7.1.2.1 Capacity or range reduction evaluations

Frequency band: 2 110-2 170 GHz

Technologies: IMT-DS

Methodology: as described in § 4.6.1.2.2, a) and b).

– *Input parameters*:

PSD_{UWB} = –64.7 dBm/MHz

G_{Rx} = 0 dBi (IMT-2000 mobile stations)

FL_{Rx} = 0 dB (IMT-2000 mobile stations)

UWB channel propagation model: free-space loss.

– *Additional input parameters, needed with § 4.6.1.2.2, a) and b), b) and c)*

NR = 6 dB (suburban areas), or cell load factor 0.75

N_{th} = –110 dBm/MHz (including 4 dB for IMT-2000 base station noise factor)

IMT-2000 channel propagation model: COST 231, outdoor quasi open area, h_1 (IMT-2000 BS antenna height) 30 m and h_2 (IMT-2000 MS antenna height) 1.5 m.

– *Criterion*:

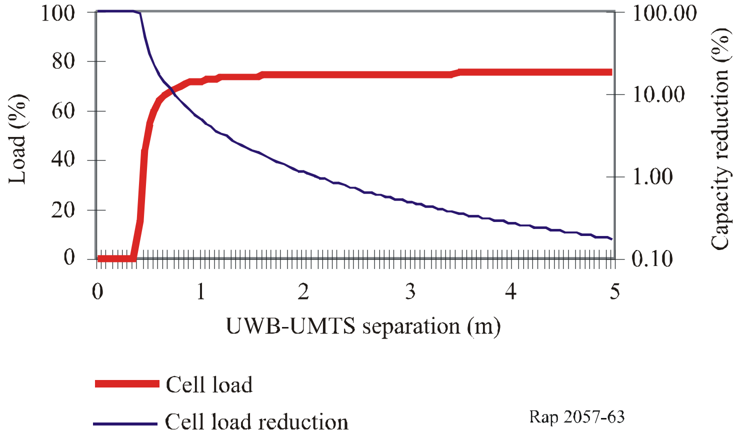
No criterion expressed.

– *Output results*:

a) Plot distance vs. capacity reduction

FIGURE 63

Load at the IMT-2000 handset when the devices using UWB technology are different distances away (left-hand axis) and the associated capacity reduction (right-hand axis)

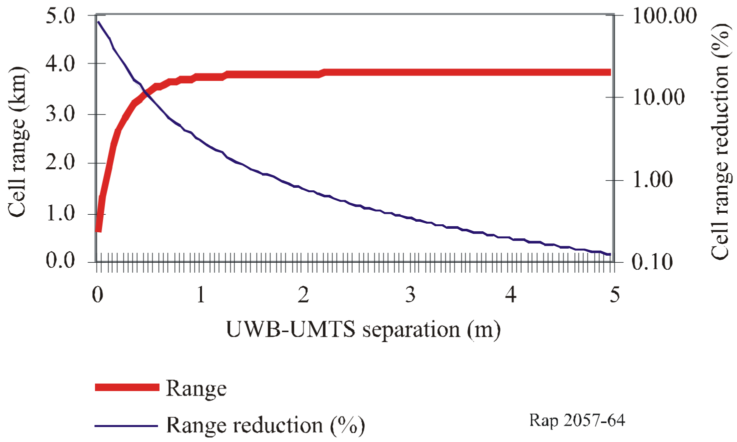


The mobile terminal is completely swamped by the device using UWB technology when it is within 0.5 m. At 1 m, the amount of intra-cell interference which can be tolerated by the IMT-2000 receiver is reduced by 10% of the value which appears when there is no device using UWB technology. This figure falls to 1% when the device using UWB technology is around 2 m away.

b) Plot distance vs. cell range reduction

FIGURE 64

Range of an IMT-2000 handset when the device using UWB technology is at different distances away (left-hand axis) and the associated range reduction (right-hand axis)



4.7.1.2.2 Throughput degradation evaluation

Frequency band: 2 GHz

Technology: HSDPA

Methodology: as described in § 4.6.1.2.1 ("Geometry factor")

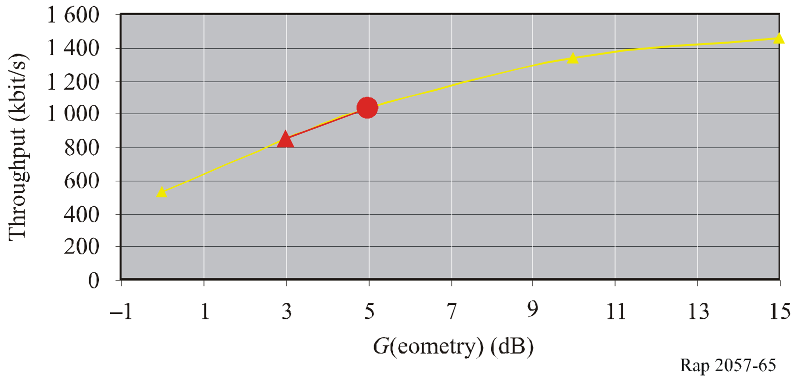
– *Input parameters*:

G factor = 5 dB

Throughput graph: example in Fig. 65.

FIGURE 65

HSPDA throughput (example)



– *Criterion*:

1% throughput loss.

– *Output results*:

I_{UWB}max, assuming this level of UWB interference is experienced at all IMT-2000 mobile stations in the cell/network. Two values of G_{Nth} are varied: 0 dB which stands for no inter-cell interference (isolated cell, or very low loaded network), and –5 dB where a high level of inter-cell interference is experienced (heavily loaded network).

Throughput (kbit/s)	G	Criterion 1% (kbit/s)	G_{new}	I_{UWB}max with G_{Nth} = 0 (dBm/MHz)	I_{UWB}max with G_{Nth} = –5 (dBm/MHz)
≈ 1 035	5	≈ 1 025	≈ 4.9	≈ –122	≈ –117

I_{UWB}max can then be used in conjunction with methods in § 4.6.1.1 to determine the corresponding maximum PSD for UWB transmitters in the HSDPA band.

NOTE 1 – There is a relationship between G and G_{Nth}, and the base to mobile station distance: when the distance from the serving cell increases, G decreases and G_{Nth} increases, one can assume that when G/G_{Nth} >1 then handover occurs, so that there may be a definition domain for G. Clarification would be beneficial on the relationship between G and G_{Nth}, as well as on the method used to derive the throughput vs. geometry G graphs.

4.7.2 Scenarios involving victim IMT-2000 base station receivers

4.7.2.1 Single UWB interferer into a single base station

Frequency band: 2 110-2 170 GHz

Technologies: IMT-DS

Methodology: as described in § 4.6.2.1 c) and d).

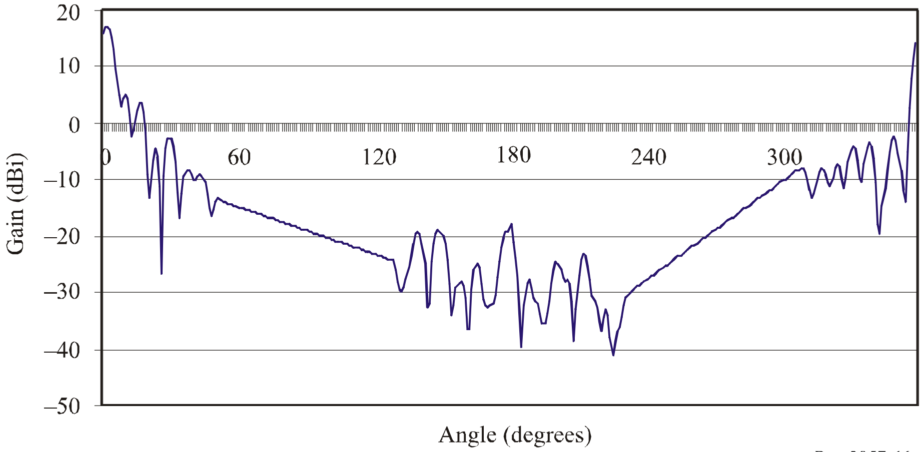
– *Input parameters*:

PSD_{UWB} = –64.7 dBm/MHz

G_{Rx} = 18 dBi, 2.5° down-tilted, elevation pattern in Fig. 66 (valid in 360° horizontal plane):

FIGURE 66

Elevation pattern of a typical/IMT-2000 antenna



FL_{Rx} = 0 dBi

h_{UWB} = 1.5 m (UWB devices)

h_{BS} = 30 m (IMT-2000 base station antenna)

UWB channel propagation model: free-space loss.

– *Additional input parameters (needed with § 4.6.2.1 c) and d))*

NR = 3 dB (suburban areas), or cell load factor 0.5

N_{th} = –110 dBm/MHz (including IMT-2000 base station noise factor 4 dB).

IMT-2000 channel propagation model: COST 231, outdoor quasi-open area, h_1 (IMT-2000 BS antenna height) 30 m, and h_2 (IMT-2000 mobile stations) 1.5 m.

– *Criterion*:

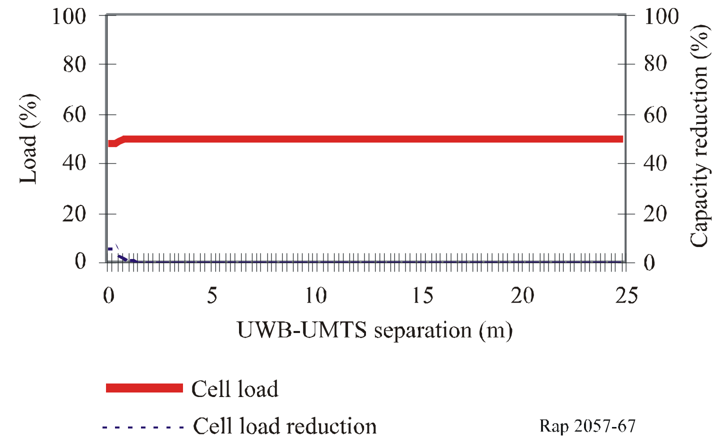
No criterion expressed.

– *Output results*:

Methodology § 4.6.2.1 c) plot distance vs. capacity reduction.

FIGURE 67

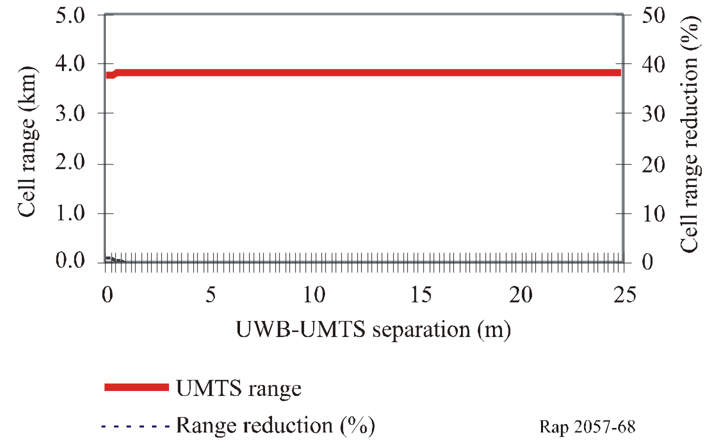
Load at the IMT-2000 base station when the devices using UWB technology are different horizontal distances away (left-hand axis) and the associated capacity reduction (right-hand axis)



Methodology § 4.6.2.1 d) plot distance vs. cell range reduction.

FIGURE 68

Range of a base station when the device using UWB technology is at different horizontal distances away (left-hand axis) and the associated range reduction (right-hand axis)



Because of its lower noise figure, the base station is more sensitive than the mobile station. However, because of the minimum coupling loss and its antenna pattern, the base station would be much less affected by the device using UWB technology in this study.

4.7.2.2 Multiple UWB interferers into a single base station

Frequency: 2.1 GHz

Technology: IMT-DS

Methodology: as described in § 4.6.2.2

– *Input parameters*:

  – IMT-2000 BS stations:

  G_{Rx} = 18 dBi

Vertical antenna pattern: modelled with Recommendation ITU-R 1336-1, k = 0.7.

Horizontal antenna pattern: 65° sector, modelled with the vertical pattern within the 65° main beam and no emissions outside the horizontal main beam.

BS antenna down-tilt: 4° (urban areas), 1.3° (suburban areas).

FL_{Rx} = 0 dB

h_{BS} = 35 m (BS antenna height)

– UWB characteristics:

h_{UWB} = for indoors: randomly distributed height between 0 m and 30 m UWB channel propagation model (outside the 10 m radius spherical exclusion zone around the IMT-2000 base station).

Hata based models with 10 dB additional attenuation due to building penetration losses (indoor scenario) are used. The resulting path loss equations for locations larger than 10 m away from the IMT-2000 base station are recalled in the following table per environment:

TABLE 43

Propagation models used from IMT-2000 base station to terminals and devices using UWB technology

	Scenario		
Parameter	**Suburban**	**Urban outdoor**	**Urban indoor**
Path gain (dB) vs. Distance, d (m)	–17.8–35.0 log(d)	UWB: –15.3–37.6 log(d) MS: –25.3–37.6 log(d)	–25.3–37.6 log(d)
Shadowing σ (dB)	6	10	12

In the urban indoor scenario, the path gain according to the Hata model increases with the UWB device height in addition to the equation given in the table.

– UWB users distribution[34]:

UWB user density: varied from 10 to 100 000 users/km^2 (in the indoor case, the user density decreases linearly to 0 when height of the UWB increases: no devices would be located at 30 m; in the outdoor case, the devices using UWB technology are all located at height 0 m).

Activity factor: 100%

UWB transmit power variations: no variations (devices using UWB technology transmit at max power, any time).

R_{min} (spherical exclusion zone): 10 m, taken into account as a corresponding MCL of 58.5 dB assuming free-space loss propagation model in the first 10 m, together with the max IMT-2000 base station antenna gain: $MCL = L_{FSL}(10\text{ m}) + \max G_{IMT\text{-}2000BS}$.

– Additional input parameters (to derive Fig. 69).

N_{th} = –109 dBm/MHz

34 Although the distribution is supposed to be infinite around that base station, there is a need to bound the definition domain for simulation purposes. In this regard, the UWB users were spread over a circular zone of maximum 1 500 m around the base station (this was shown as not truncating the results).

Antenna base station pattern (as above)

NR: 3 dB (suburban), 6 dB (urban)

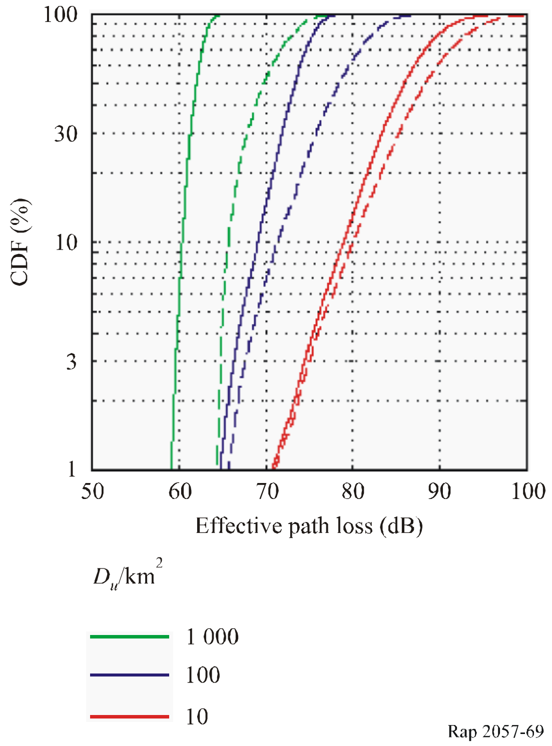
IMT-2000 channel propagation model: as the UWB propagation channel above.

– *Simulation "intermediate" results: effective path loss CDF graphs*

The solid curves are the CDFs of the effective path loss. For comparison, the dashed curves represent the CDFs of the minimum path loss of each considered random UWB population. By comparing the solid and dashed curve of the same UWB density (D_U), the effect of aggregation becomes visible.

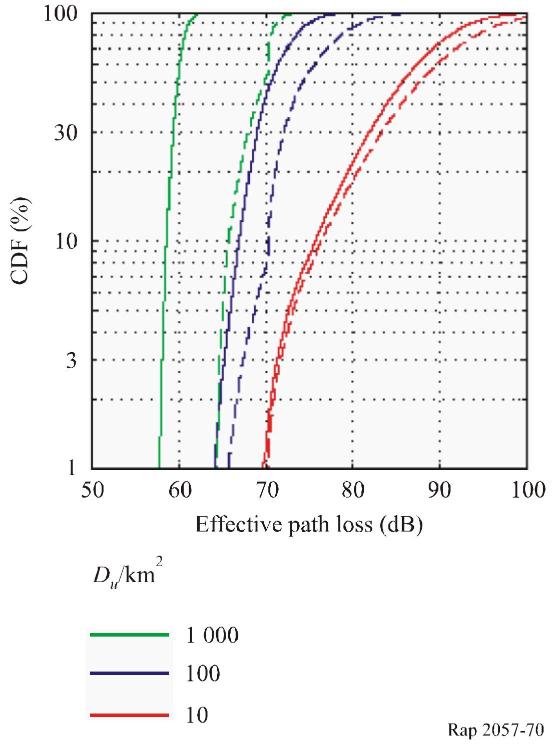
Suburban scenario:

FIGURE 69



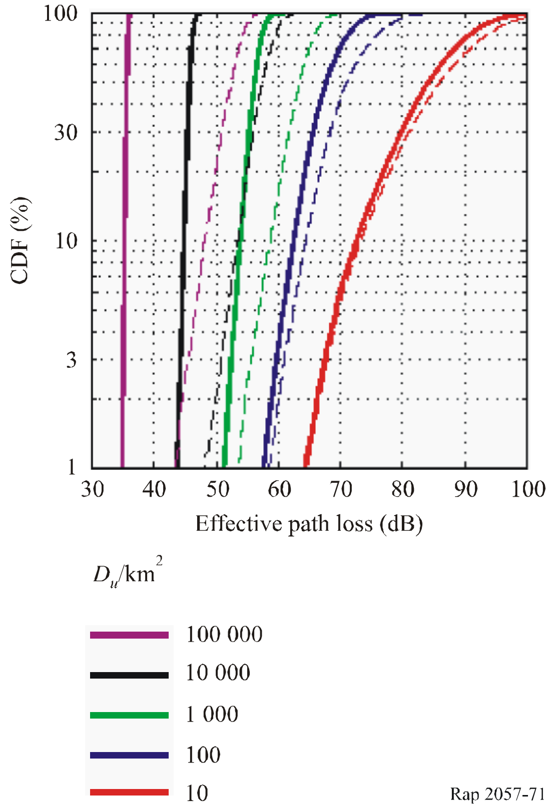
Urban outdoor scenario:

FIGURE 70



Urban indoor scenario:

FIGURE 71



Higher UWB transmitter densities of 10 000 and 100 000 per km^2 are additionally considered in the urban indoor scenario. A density of 10 000 units/km^2 corresponds with 1 UWB transmitter per square area of 10 m edge length. 100 000 units/km^2 can be interpreted as one UWB transmitter per square footprint of 10 m edge length on each building floor in a hot spot area with an average of 10 storeys per building.

– *Criterion*:

Expressed in terms of: $Prob(I_{UWB} > I_{UWB}\max) = 1\%$, where $I_{UWB}\max$ is the tolerable interference that requires 1% base station density, taken from Table 38.

– *Output results*[35]:

TABLE 44

Overview of maximum UWB PSD per transmitter for 1% probability of exceeding I_{UWB}max at CDMA network base station

Scenario	UWB transmitters/km^2					
	10	**100**	**1 000**	**10 000**	**100 000**	
Suburban	**–53.9**	**–59.8**	–65.3	-	-	PSD_{UWB}max (dBm/MHz)
Urban/UWB outdoor	–52.4	**–57.9**	**–64.3**	-	-	
Urban/UWB indoor	–57.5	**–64.2**	**–70.8**	**–78.2**	**–87.0**	

4.7.3 Results of the Monte-Carlo analysis

4.7.3.1 First study results

Frequency: 2 GHz

Technology: IMT-DS

Methodology: as described in § 4.6.3

– *Input parameters*:

1 IMT-2000 stations, distribution characteristics and complementary specifications (handover, power control[36]):

Antenna heights

TABLE 45

Variable	MS value	BTS value
Antenna height (m): Urban		15
Antenna height (m): Suburban		15
Antenna height (m): Rural	1.5	20

[35] Intermediate result: Cumulative path loss CDF graphs obtained by series of simulations.

[36] See the “services” section hereafter to capture the way power control is taken into account in this Monte-Carlo simulation deriving statistics based on snapshots: basically the effect of power control is expressed in the variations of E_b/N_0 requirements at the mobile stations which are flagged to be in movement and/or making voice calls or data transmissions.

Antenna height (m): Micro-cell		6
Antenna height (m): Indoor		1.5 (from floor)

Antenna patterns

TABLE 46

Variable	MS value	BTS value	Notes
Antenna pattern	Omni	Antenna pattern	Assuming $G(\theta,\varphi) = G(\theta) + G(\varphi)$ for the 2D BTS pattern, as is standard practice
Antenna gain at transmitter (dBi): Macro	0	17	BTS value refers to typical bore-sight gain (which varies with pre-set tilt and manufacturer). 2D antenna patterns are used in the simulation using those from a well-known manufacturer
Antenna gain at transmitter (dBi): Micro	0	5	
Antenna azimuth and elevation 3 dB-beamwidth: Macro	Modelled as an ideal omni pattern	65° (azimuth) and 2-5° (elevation)	BTS outdoor antennas will typically have pre-set electrical tilts of 2-6°; the values of beamwidth will be set by the pattern. Indoor antennas will be omni with no tilt

IMT-DS transmitters

TABLE 47

Variable	MS value	BTS value
Maximum transmit power (dBm): Macro	21	43
Maximum transmit power (dBm): Micro	21	33
Maximum transmit power/TCH (dBm): Macro	Not available	30
Maximum transmit power/TCH (dBm): Micro	Not available	20
Local losses (dB)	3	2

IMT-DS receiver

TABLE 48

Variable	MS value	BTS value	Notes
Receiver noise figure (dB)	9	4	The values of 9 dB and 5 dB for the system noise figure were taken from 3GPP TR 25.942 V5.1.0. The 5 dB noise figure was modified by the LNA gain at the BTS, given that we understand incorporation of an LNA will be standard practice amongst the IMT-2000 operators
Maximum loading (%): Urban	90%	50%	

Variable	MS value	BTS value	Notes
Maximum loading (%): Suburban		50%	Maximum cell-load values are used to determine whether or not the next arriving call will be admitted to the system. When the cell-load is high, further increases in traffic can reduce the cell radius by a relatively large fraction compared to when there is less traffic. Therefore, in rural areas, where cells are deployed for coverage rather than capacity, operators will set lower values to avoid this effect causing coverage holes. The maximum load, L, is related to the maximum noise rise in dB, NR, via the equation $NR = -10 \log10(1 - L)$.
Maximum loading (%): Rural		50%	
Maximum loading (%): Indoor		50%	

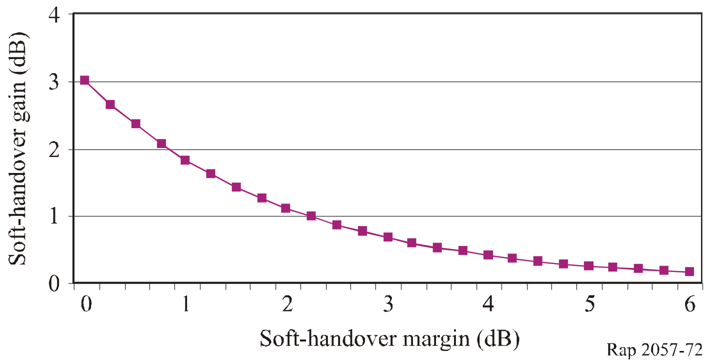
Soft(er) handover

Soft-handover links are deemed to be those where the difference in link powers between two servers is less than the soft-handover window. If this is the case, a soft-handover gain reduces the powers on uplink and downlink. Of course, both base station cells now serve on the downlink, so the penalty for the gain is an increased use of downlink resources.

TABLE 49

Variable	MS value	BTS value	Notes
SHO Window (dB)	3	3	The delta in powers between the path to the first and second best servers
SHO Gain (dB)	Function in form of graph (Fig. 67)	Function in form of graph below (Fig. 67)	The SHO gain has been simplified and will be expressed as an exponential function of the power delta between paths to two serving cells. Values have been based on those given in "Radio Network Planning and Optimization for IMT-2000" by Laiho, Wacker and Novosad, Wiley Press p. 70 – which, in turn, have been fitted to results from 3GPP channel model 4 with antenna diversity. The values are in qualitative agreement with the values from 3GPP TR 25.942 V5.1.0. where a fixed 2 dB gain was assumed for diversity i.e. about the average over the SHO window between 0 dB and 3 dB

FIGURE 72



Cell sizes and configuration

TABLE 50

Type	**Cell-size**	**Cell-type**
Urban cell	500	Tri-sectored
Suburban (m)	1 500	Tri-sectored
Rural (m)	4 000	Tri-sectored

Path loss models

A stochastic break-point model is deployed with a LoS and NLoS component. The point where the path switches from LoS to NLoS will be determined stochastically using a mean-path length.

Mean path-loss

$d <= \lambda$, Free-space model ($n = 2$ where n is the power attenuation factor) => LoS

$d > \lambda$, Cost-231 model ($n = 3.5$ for outdoor or indoor model as applicable) => NLoS

λ is a stochastic path-length which marks the point of the first obstacle.

The same path-loss models are used for IMT-2000 and UWB.

Variance on path loss

For each link, the path loss is calculated as $PL = PL_o(d) + \nu(rn)$ where $PL_o(d)$ is the deterministic mean value for a given distance (given by Cost 231 etc.) and $\nu(rn)$ is the random variance, selected randomly from a log-normal distribution (outdoor) or Rayleigh distribution (indoor). Rayleigh margins were not superimposed on top of the log-normal values but we assume that variations with speed are subsumed in E_b/N_0 figures.

TABLE 51

Environment	**Path-loss standard deviation, σ (dB)**
Urban	6.0
Suburban	7.0
Rural (flat/mountainous)	8.0

Penetration losses

Depending on the position of the IMT-2000 CDMA Direct Spread device user and the device using UWB technology, there will be different associated penetration losses.

TABLE 52

UWB device	IMT-2000 direct spread device	Penetration loss (dB)	Notes
Outdoor	Outdoor	0	
Outdoor	In-building	10	
Outdoor	In-car	8	
In-building	In-building	0	LoS
In-building	In-building	10	Non-LoS

Orthogonality

An orthogonality factor of zero corresponds to perfectly orthogonal users while "1" corresponds to the same effect as inter-cell interference.

According to 3GPP TR 25.942 V5.1.0:

TABLE 53

Cell type	Factor
Own-cell interference: Macro	0.4
Own-cell interference: Micro	0.06
Other-cell interference	1

Services

E_b/N_0

E_b/N_0 for uplink/downlink for stationary mobiles have been taken from 3GPP TR 25.942 V5.1.0 with values for voice and data services. The book "Radio network planning and optimization", by Laiho, Wacker, Novosad, was used as a basis for understanding the effects of changing data rate, speed, and the effect of packet services. This contains methods to derive values, essentially using a theoretical 3GPP channel model. The effects of speed via the effects of power-control are included in those values.

Uplink E_b/N_0: 3GPP

TABLE 54

Service	Cell-type	E_b/N_0
Voice	Macro (Vehicular)	6.1
Voice	Micro	3.3
144 kbit/s CSD	Macro (Vehicular)	3.1
144 kbit/s CSD	Micro	2.4

Uplink E_b/N_0:

TABLE 55

Service	**Speed (km/h)**	**UL E_b/N_0 (dB)**
Voice: 12.2 kbit/s (20 ms interleaving)	3	4
	20	4.5
	120	5
64 kbit/s CS data (40 ms interleaving)	3	2
128 kbit/s CS data (40 ms interleaving)	3	1.5
384 kbit/s CS data (40 ms interleaving)	3	1
64 kbit/s, PS data (10 ms interleaving)	3	2
	120	3.3
128 kbit/s, PS data (10 ms interleaving)	3	1.5
	120	3
384 kbit/s, PS data (10 ms interleaving)	3	1
	120	2

Downlink: 3GPP

TABLE 56

Service	**Cell-type**	**E_b/N_0**
Voice	Macro (Vehicular)	7.9
Voice	Micro	6.1
144 kbit/s CSD	Macro (Vehicular)	2.5
144 kbit/s CSD	Micro	1.9

Downlink:

TABLE 57

Service	**Speed (km/h)**	**DL E_b/N_0 (dB)**
Voice: 12.2 kbit/s (20 ms interleaving)	3	6.5
	20	6
	120	6.5
64 kbit/s CS data (40 ms interleaving, BLER = 1%)	3	5
128 kbit/s CS data (40 ms interleaving, BLER = 1%)	3	5
384 kbit/s CS data (40 ms interleaving, BLER = 1%)	3	5
64 kbit/s, PS data (10 ms interleaving, BLER = 10%)	3	5.5
	120	5
128 kbit/s, PS data (10 ms interleaving)	3	5

	120	4.5
384 kbit/s, PS data (10 ms interleaving)	3	4.5
	120	4

Activity factors

Activity factors are effectively the duty cycles of the call. All activity factors are "1" following 3GPP TR 25.942 V5.1.0.

TABLE 58

Data rate	UL activity factor	DL activity factor
12.2 kbit/s (voice)	1	1
64 kbit/s	1	1
144 kbit/s	1	1
384 kbit/s	1	1

Relative take up of services

As default case for monitoring the relative success of different call-types, we assumed the following probabilities:

60% for voice calls, 30% for 32 kbit/s data calls, and 10% for 64 kbit/s data calls. Simulations with 144 kbit/s data were carried out; however, few links could be simultaneously connected using such high data rates and, therefore, the effects of UWB were statistically negligible.

2 UWB distribution characteristics:

– UWB users density: varied from 100 units/km^2 to 10 000 units/km^2

– UWB maximum power and variations: no power variation, all devices using UWB technology are transmitting at a given transmit power

– Activity factor: 100%

– UWB channel propagation model: the UWB propagation model is the same as the one used for IMT-2000 channels.

3 Correlation assumptions: varied from IMT-2000 and UWB independent distributions to correlated distributions (location correlation, together with a variation of the fraction of correlated devices).

– *Criterion*:

No criterion expressed.

– *Output results*:

Urban deployment

In this scenario, devices using UWB technology are uncorrelated with each other and uncorrelated with the IMT-2000 handsets. There is assumed to be a mean-free line-of-sight path of 10 m between the devices using UWB technology and the IMT-2000 handsets.

The IMT-2000 CDMA Direct Spread users are assumed to be located either indoors, outdoor pedestrian, or vehicular. The relative probability of a user being in each of these locations is 0.4:0.4:0.2.

All of the devices using UWB technology are assumed to be indoors. Penetration losses are not applied to paths between mobiles and devices using UWB technology which are LoS. The user density of IMT-2000 users is specified in only two dimensions (i.e. across a flat Earth) but these devices may be on different levels of a building. This is especially the case in urban areas with dense populations and built-up areas. To account for the effect of a 3D distribution of IMT-2000 users, and therefore the probability that IMT-2000 and devices using UWB technology are at different heights and separated by floors, both the IMT-2000 users and devices using UWB technology are characterized as being either:

– outdoors;

– indoors; or

– in-car.

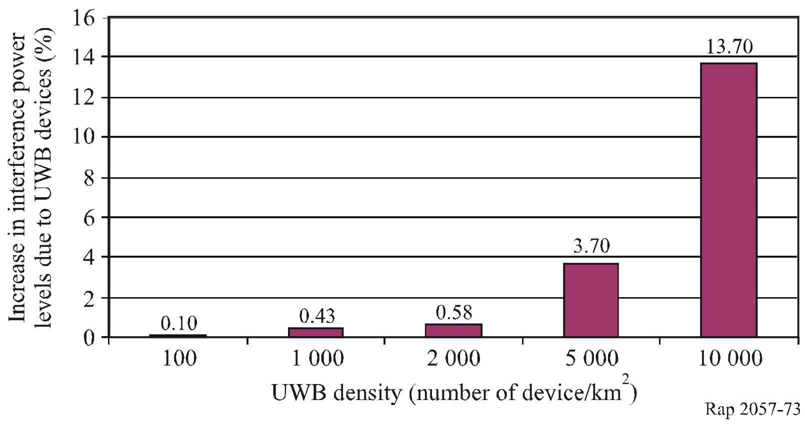
Buildings are characterized as having an average number of floors on which there are likely to be UWB users. Paths between in-building IMT-2000 devices and in-building devices using UWB technology on different floors are then susceptible to extra in-building penetration loss. However, LoS paths are not.

When there are no UWB users, this configuration gives rise to a call success probability of 90% for the voice calls[37] and around 80% for the data calls, which have a lower processing gain and therefore a worse receiver sensitivity and a smaller coverage area. The number of calls leads to cells in the central area reaching close to the maximum load value of 50% and mobiles to the maximum load value of 90%; therefore, this scenario reflects a network configuration which is loaded close to capacity.

Figure 73 shows the average power rise in the mobile stations, expressed as a percentage increase over the case where there are no devices using UWB technology. The results are presented for different values of UWB device densities, and for a UWB e.i.r.p. density of –70 dBm/MHz (1×10^{-7} mW/MHz).

FIGURE 73

Variation on receiver interference power due to devices using UWB technology



The graph shows a super linear increase in the average interference power.

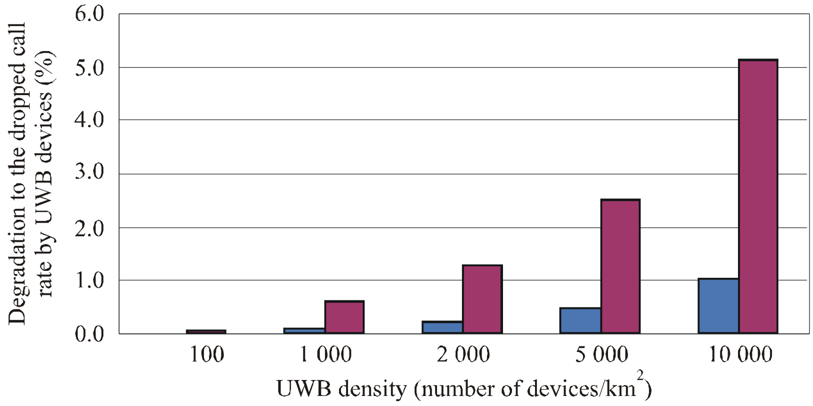
---

[37] A coverage probability of 90% for voice calls has been assumed.

The impact on the call quality are shown in Fig. 74. Two values of PSD are plotted, –70 dBm/MHz and –60 dBm/MHz.

FIGURE 74

Variation on call success probability due to different UWB densities



PSD = 1×10^{-7}	0	0.085%	0.204%	0.483%	1.010%
PSD = 1×10^{-6}	0.041%	0.600%	1.250%	2.500%	5.127%

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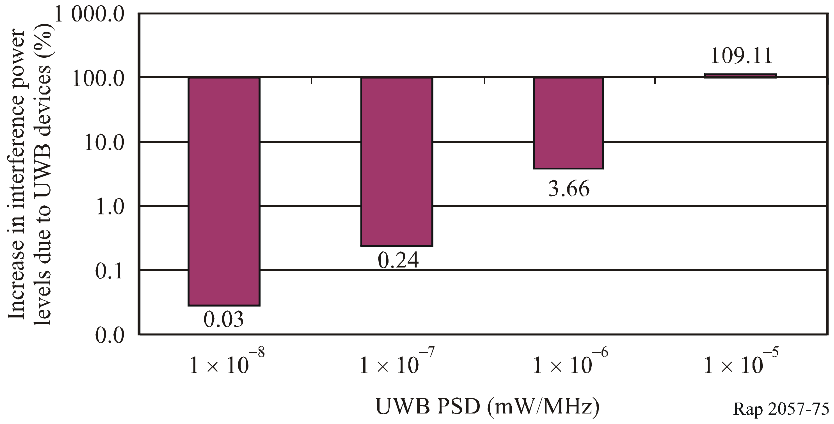
For the e.i.r.p. density = –70 dBm/MHz case, with 10 000 units/km^2, the call degradation has reached 1%. This figure is highly significant at over 5% when the e.i.r.p. density is –60 dBm/MHz.

The effect of UWB e.i.r.p. density

In this investigation, the e.i.r.p. density is varied from –80 dBm/MHz to –50 dBm/MHz to see the effect on IMT-2000 characteristics. Because the effect of UWB interference causing a noise rise at the mobile handset is, by far, the main cause for dropped calls, the increase in mobile interference power is firstly plotted in Fig. 75 as a function of the UWB device e.i.r.p. density for a fixed UWB density of 1 000 units/km^2.

FIGURE 75

Increase in mobile interference power with UWB e.i.r.p. density



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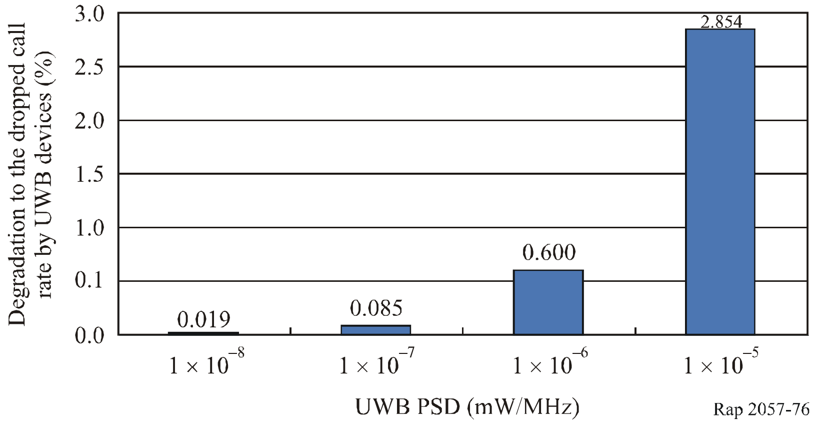
The graph shows a result that may be intuitively expected. As the e.i.r.p. density is increased by an order of magnitude, then so are the interference levels at the mobile station (within the errors resulting from the statistical nature of Monte-Carlo simulations.) The effect on dropped call probability is shown in Fig. 76 for the same configuration.

FIGURE 76

Dropped call rate variation with UWB e.i.r.p. density when the UWB device density was fixed at 1 000 units/km²

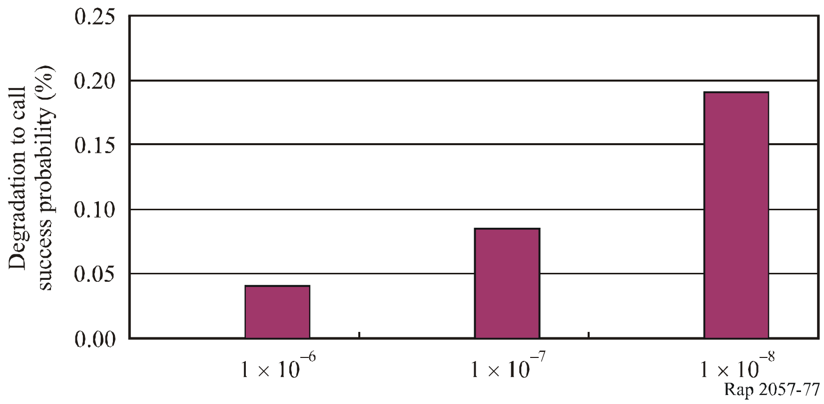


The graph indicates a super-linear rise in the percentage of successful calls. The steep increase in both interference power in Fig. 75 and in dropped call rates in Fig. 76 with increasing e.i.r.p. density, is attributed to the nature of IMT-2000. An incremental change in interference leads to a matching increase in transmit powers. This raises interference in all other handsets causing, in turn, further increases in transmit power and so on, until the transmit and received powers are balanced.

A further interesting question to answer is the effect of e.i.r.p. density when the aggregated power from the devices using UWB technology is fixed i.e. for a constant device density multiplied by e.i.r.p. density (power generated/MHz/km^2). The results from this comparison are shown in Fig. 77 where the dropped call rate degradation is plotted for 100 devices using UWB technology with a e.i.r.p. density of –60 dBm/MHz, 1 000 devices using UWB technology with a e.i.r.p. density of –70 dBm/MHz and 10 000 devices using UWB technology with a e.i.r.p. density of –80 dBm/MHz, such that there is a constant e.i.r.p. density per unit area of –40 dBm/MHz/km^2.

FIGURE 77

Dropped call rate for a fixed transmitted UWB power per unit land area



The results show that the IMT-2000 performance does not scale with a constant amount of transmitted power generated per km^2. Instead, it is sensitive to both the device density and the e.i.r.p. density independently. The greatest effects on IMT-2000 occur when the device density is high. This is attributed to the fact that an increased UWB number leads to a greater probability that the IMT-2000 device is within a few m, whereupon it can cause significant degradation to the receiver sensitivity.

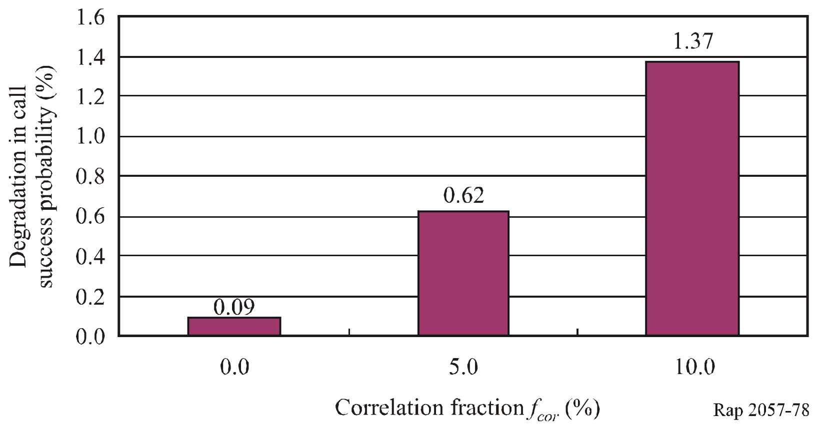
Effect of correlation between IMT-2000 handsets and devices using UWB technology in urban cells

The effect of changing the fraction of correlated devices using UWB technology was also investigated. For these calculations, the correlation length between devices using UWB technology and the IMT-2000 handsets was kept constant at 10 m while the fraction of correlated devices using UWB technology 0, 5% and 10%. For example, if a fraction of 10% devices using UWB technology is correlated to IMT-2000 handsets with a correlation length of 10 m, this means that 10% of the devices using UWB technology will be located less than 10 m from an IMT-2000 handset.

The corresponding call success degradations were 0.09%, 0.62% and 1.37%, showing that correlation factors can have a significant effect. The UWB device density is 1 000 units/km^2, with an e.i.r.p. density of –70 dBm/MHz.

FIGURE 78

The effect of correlation fraction for a length correlation value of 10 m

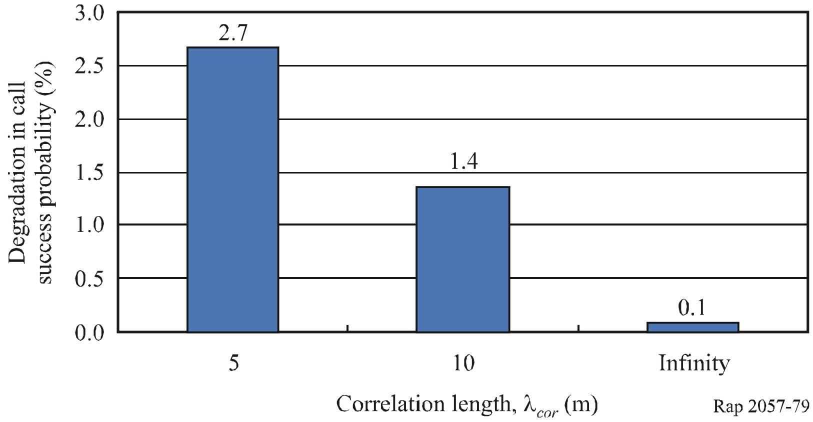


The effect of the correlation distance

The effect of changing the UWB correlation length between devices using UWB technology and the IMT-2000 handsets is shown in Fig. 79. For these calculations, the fraction of correlated devices was kept constant 10% while results are plotted for length correlation of 5 m, 10 m and ∞ (which is the random distribution case studied earlier). The value of the fraction of correlated devices was chosen to reflect half of the indoor devices using UWB technology being in the same place. The UWB device density is 1 000 units/km^2 with an e.i.r.p. density of –70 dBm/MHz.

FIGURE 79

The effect of correlation length, from 5 m to infinity



The effect of correlation clearly has a very significant effect on the call success probability. If we assume that 10% of devices using UWB technology are correlated with an IMT-2000 handset, then the results can have severe effects on the overall network capacity.

Effect of the IMT-2000 environment (rural environment)

As areas become increasingly rural, the chance of interference is reduced, largely because of the reduced likelihood of devices using UWB technology and IMT-2000 devices being in close proximity by virtue of their lower number densities. Simulations of a rural area where there were 1 000 devices using UWB technology per km^2 transmitting with a e.i.r.p. density of –70 dBm/MHz showed a 0.06% reduction in successful calls compared to the urban case which was 0.085%. In rural areas, however, it was argued that the likely UWB density would be closer to 100 units/km^2 giving rise to negligible changes in the IMT-2000 performance in the macro-scale model (in the absence of clustering effects).

4.7.3.2 Second study results

Frequency: 2 GHz

Technology: IMT-2000 CDMA direct spread

Methodology: as described in § 4.6.3.

The model runs a number of consecutive simulations. Each simulation represents one half second of real-time, and is made up of one thousand snapshots. The model positions the IMT-2000 devices randomly for each snapshot. Also for each snapshot, the UWB "on" and "off" status is varied according to its associated application. In other words the IMT-2000 *spatial positioning* and UWB *activity* is varied from snapshot to snapshot to reflect real life. In effect, the IMT-2000 handsets are allowed to "move" around over time, and the temporal correlation of usage and the spatial correlation between fixed devices using UWB technology and mobile IMT-2000 handsets is allowed to vary between being highly correlated and totally uncorrelated.

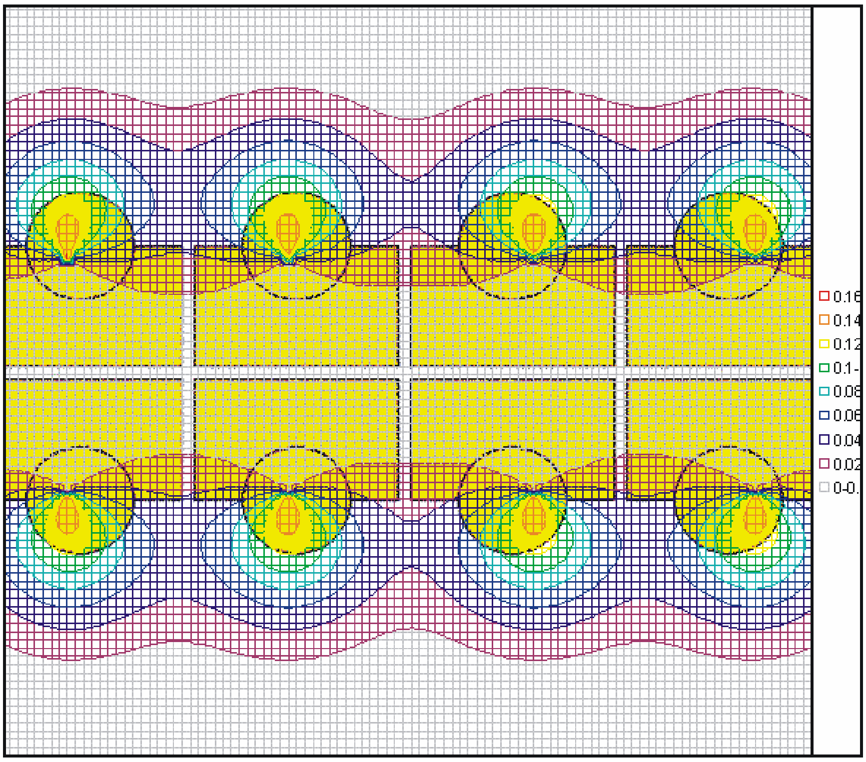
– *Input parameters*:

1 IMT-2000 mobile stations mobility

Study results imply that interference would be aggravated by applications where the UWB/IMT-2000 temporal and spatial characteristics are highly correlated. But no such applications were discovered in the market research. There was, therefore, no need to ensure that devices using UWB technology and IMT-2000 handset occupied any particular position with respect to one another at any given instant in time. Thus positions of the IMT-2000 devices, from snapshot to snapshot, were chosen from the spatial PDF shown in Fig. 80. The reasoning behind this contrived PDF is that the IMT-2000 devices are most likely to be used and laid down next to the user of the desk, and rarely in the centre of the desk cluster. Furthermore, it is less likely that the IMT-2000 devices will be used away from the desk.

FIGURE 80

Spatial PDF for positional deployment of IMT-2000 Handsets in office environment



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2 UWB applications and usage parameters

TABLE 59

UWB applications and usage parameters for office "Power User" environment

Device and usage scenarios	Data rate (Mbit/s)	% of link rate (when active or "on")	Daily usage	Average UWB "on" time (s)	Average UWB "off"' time (s)	Daily usage based on 8-hour day (%)	Overall activity (%)
PC – laser printer Mode: PC Tx	100	100	~ 2 GB bytes of files per day ~ 2 min/day "on air"	120	28 680	0.42	0.42
PC – PDA (File downloads) Mode: Tx and Rx	100	100	2x daily @ 100 MB bytes each ~ 1 min total (max)	30	14 385	0.21	0.21

TABLE 59 (*end*)

Device and usage scenarios	Data rate (Mbit/s)	% of link rate (when active or "on")	Daily usage	Average UWB "on" time (s)	Average UWB "off"' time (s)	Daily usage based on 8-hour day (%)	Overall activity (%)
PC-wireless monitor (with compression) Mode: PC Tx	10 (250 × 4%)	4	8 h/day	28 800	0	100	4
PC – scanner Mode: scanner Tx	250	100	~ 2 GB bytes of files per day ~ 2 min/day "on air"	120	28 680	0.42	0.42
PC-external HDD (remote back-up) Mode: Tx and Rx	250	100	2 x daily @ 2 GB bytes each ~ 2 min each (max)	120	14 340	0.83	0.83
PC-digital camera (download) Mode: camera Tx	100	100	1 x daily @ 200 MB bytes each ~ 1 min total	60	28 740	0.21	0.21

An application will be used throughout the day, perhaps many times. Each time a UWB application is used (and hence a device using UWB technology is transmitting), a series of UWB burst transmissions will occur to transfer the required data. The *percentage of link rate when active* is measured by the ratio of these burst durations to the burst arrival periods. A clear understanding of likely UWB burst periods is not available, and market research has done little to establish agreed figures. In the absence of this data, a one second burst period was chosen as a worst-case scenario. The burst arrival periods are drawn as random numbers from a Poisson PDF, the limits of which are the beginning and end of the transaction. The beginning of a transaction is called "UWB on-time"; the end of the transaction is the "UWB off-time". The temporal characterization of the devices using UWB technology in the simulation is achieved by drawing random transaction on-times and off-times from a Poisson PDF, the mean value of which is given in the UWB interference characteristics, namely *average "on" time* and *average "off" time.* The ratio of *average "on" time* to *average "off" time* plus *average "on" time* is the percentage of daily usage, or duty cycle[38].

e.i.r.p. density$_{UWB}$

The modelling process simulates the joint effect, due to UWB transmission activity *and* IMT-2000 mobility, on the interference experienced by several IMT-2000 receivers.

[38] In many ways, the temporal activity model described above follows similar transmission burst metrics to the ETSI Web Model as used in many traffic-engineering models for IP networks.

A number of devices using UWB technology and IMT-2000 handsets were deployed in a notional 6 m x 4 m office, see Fig. 81. Beyond 6-7 m radial distance, the UWB interference to the handset, even when aggregated from a large number of devices using UWB technology, is insignificant. The model, therefore, only considers a 6 m x 4 m area. There are 19 devices using UWB technology deployed in the model (shown as red, blue or green squares). The devices using UWB technology are placed upon a cluster of eight desks/workstations in likely positions according to their application. There are seven PCs that communicate to a variety of PC peripheral devices via UWB. The peripherals include four wireless monitors, two PDAs, two HDDs, a printer and a scanner. The clusters are master – slave structured and power control is implemented with a maximum e.i.r.p. density of –65 dBm/MHz.

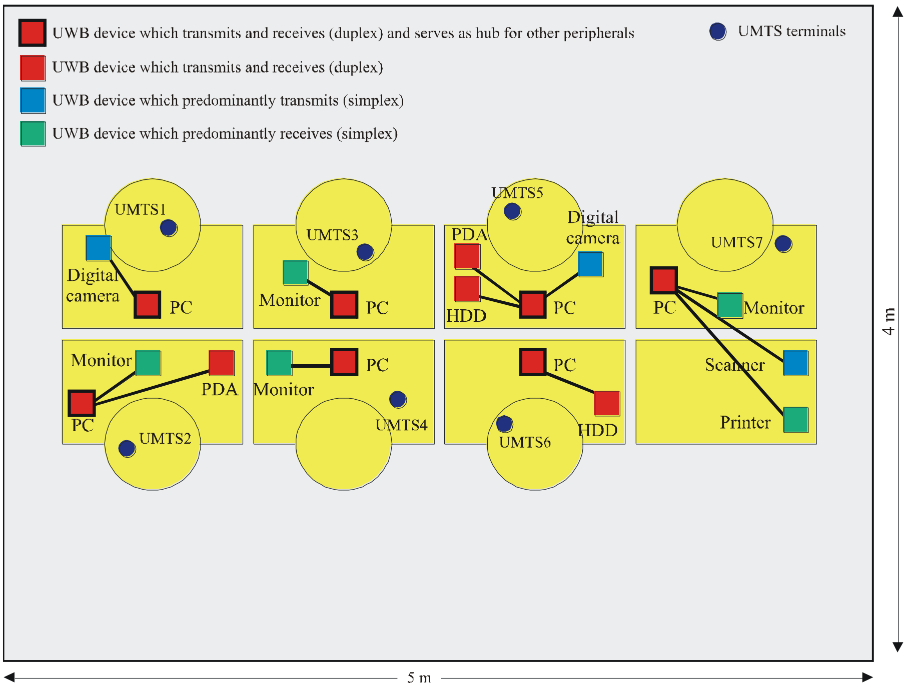
The following link budget elements were used in the study:

TABLE 60

UWB centre frequency	4 000 MHz
UWB bandwidth	1 800 MHz
UWB link path loss @ 6 m	60.0 dB
UWB noise power	–81.4 dBm
UWB processing gain	8.6 dB
UWB noise power per bit	–90.0 dBm
UWB noise figure	6.6 dB
UWB total noise power per bit	–83.4 dBm
UWB E_b/N_0	4.0 dB
UWB implementation loss	2.5 dB
UWB link fade margin	6.0 dB
UWB sensitivity (static)	–76.9 dBm
UWB sensitivity (dynamic)	–70.9 dBm
UWB Tx power total	–10.9 dBm
UWB emission limits	
UWB e.i.r.p. density @ 2.1 GHz	–65 dBm/MHz

FIGURE 81

Power office user environment, showing UWB and IMT-2000 device, placement and application



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UWB propagation channel: free-space loss.

– *Criterion expressed*:

No criterion was expressed

– *Output results*:

– Typical power office user scenario.

Six hot spot scenarios were identified in the market survey phase of the work. As it represents the worst-case environment for UWB interference to IMT-2000 mobile stations, the office “Power User” model scenario was investigated.

FIGURE 82

Activity and distribution of UWB and IMT-2000 devices in a typical power office user scenario

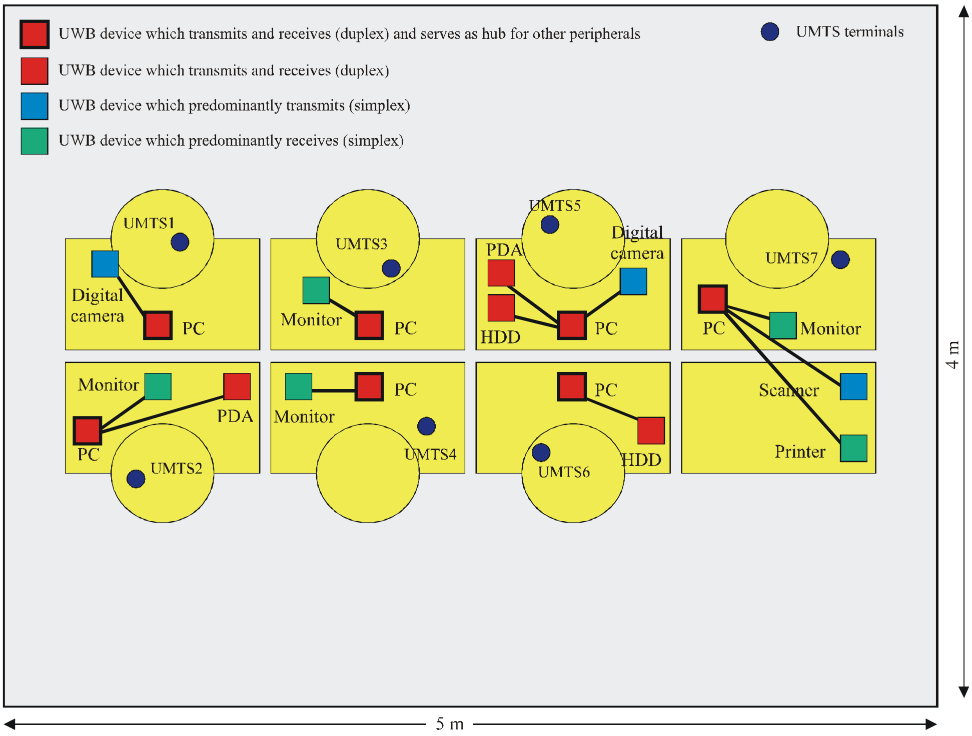

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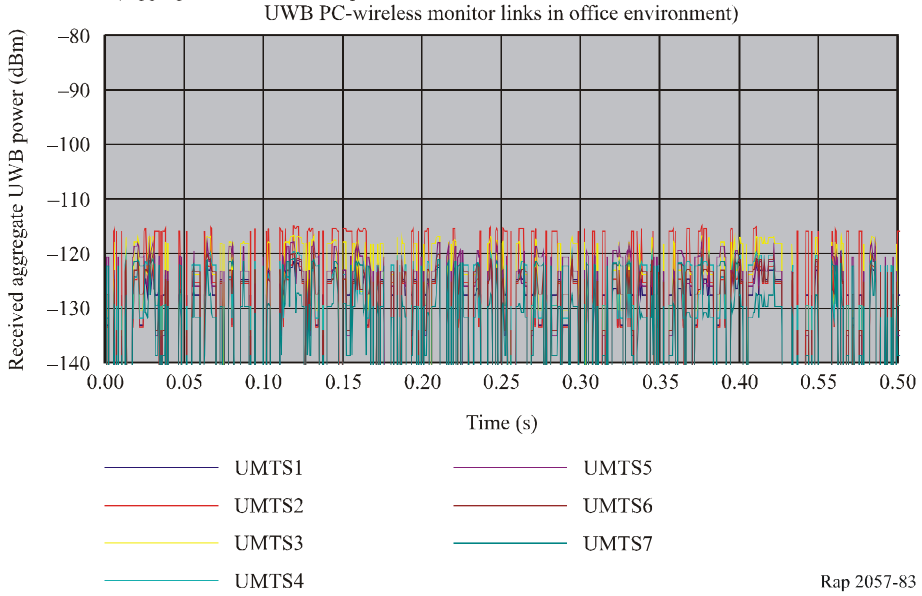
FIGURE 83

Aggregate UWB interference at the IMT-2000 handsets

(Aggregate UWB interface power received at 7 UMTS terminals over 0.5 s interval from 4 UWB PC-wireless monitor links in office environment)



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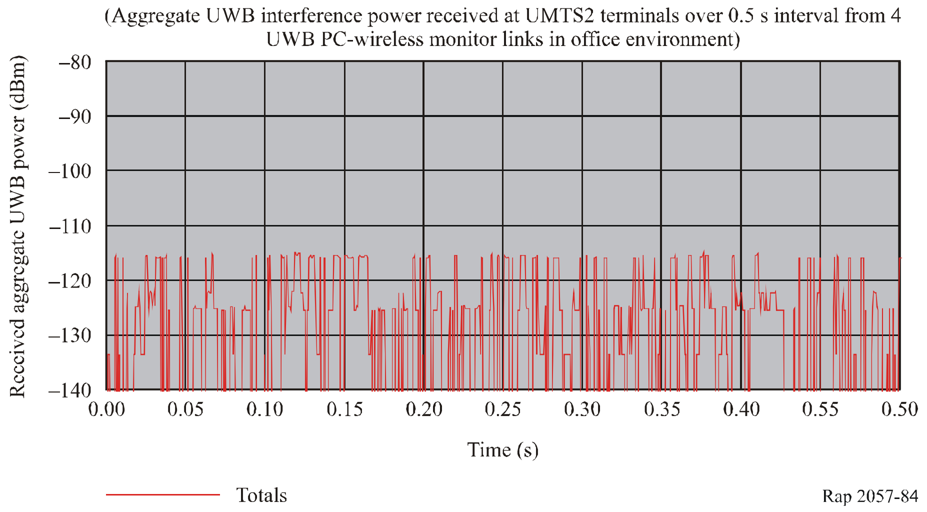
The IMT-2000 mobile station 2 receives the greatest UWB interference. For the sake of clarity, the total interference at IMT-2000 2 is shown in Fig. 84:

FIGURE 84

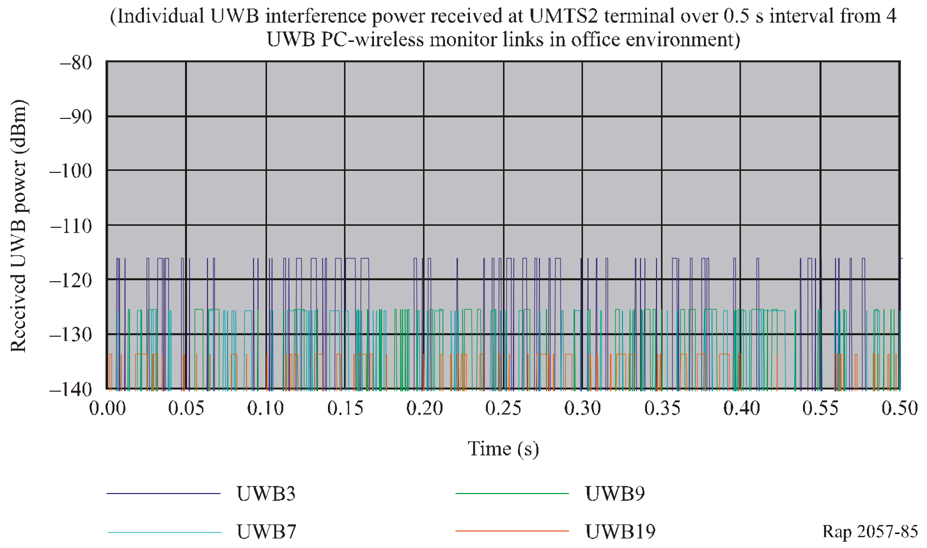
Total UWB interference seen by IMT-2000 2



And the individual UWB contributions to this interference:

FIGURE 85

Individual UWB contributions to the interference seen at mobile station 2



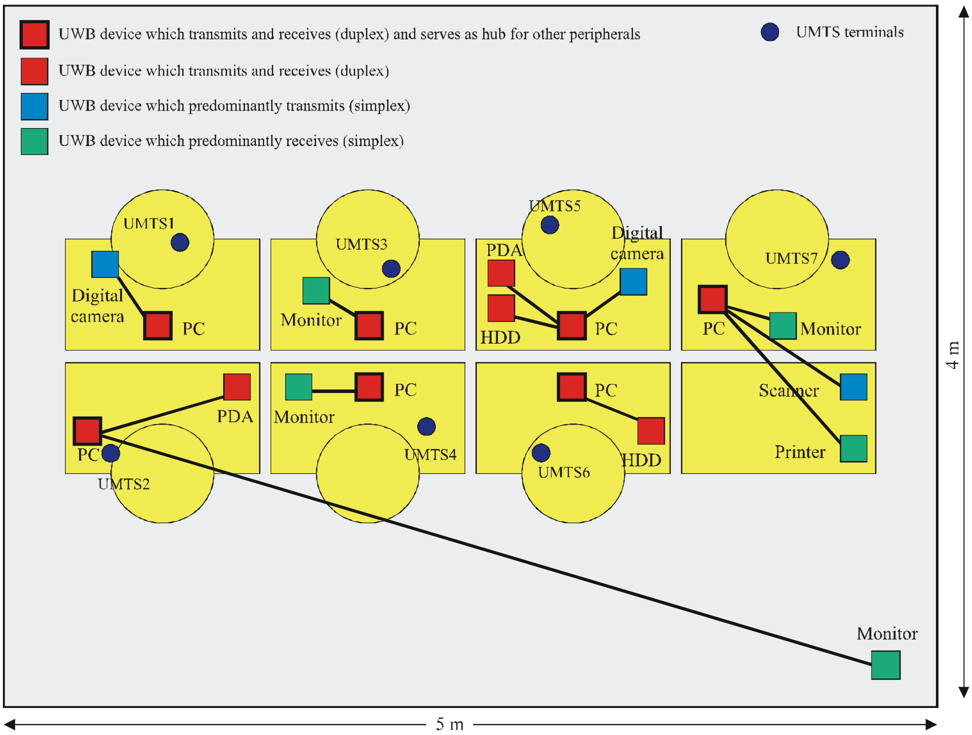
It can be seen that the total interference experienced at mobile station 2 is dominated by UWB3, the PC-monitor link, close to the mobile station 2. The effects of aggregated power can be seen occasionally at mobile station 2; in fact, small incremental steps on the mobile station 2 waveform are present.

If mobile station 2 were to move much closer to the PC communicating with the wireless monitor, then the aggregation effects become much weaker and virtually all the UWB interference is due to the PC to wireless monitor UWB link.

Figure 86 depicts the worst-case scenario for UWB interference. The UWB transmission source communicates with its peripheral (e.g. PC to wireless video monitor) over a distance of 5 m and as a result requires 250 Mbit/s transmission at full UWB power with a 4% activity factor. The IMT-2000 mobile station is next to the PC UWB source with a coupling loss of 20 dB representing a distance of certainly less than 0.1 m between UWB source and IMT-2000 mobile station. In this case, the UWB PC e.i.r.p. density transmits at its maximum power, –65 dBm/MHz.

FIGURE 86

Worst case scenario IMT-2000 close the UWB, on maximum power



Rap 2057-86

4.8 Summary and conclusions

The study results summarized here allow to identify two main aspects of the protection of IMT-2000 systems from devices using UWB technology. These can be found in the single UWB device to single IMT-2000 mobile station, and in the multiple UWB interferers to base stations and the Monte-Carlo analysis.

The results tend to show that UWB interference would be more critical into the IMT-2000 mobile stations, and confirm that an IMT-2000 mobile station will potentially suffer interference from its closest UWB device (see § 4.7.3.2).

The main deployment of devices using UWB technology will be most likely indoors. Furthermore, the IMT-2000 mobile stations are more sensitive to interference when being indoors and communicating with an outdoor macro base station. Therefore, the focus of interference investigations into the IMT-2000 mobile station has been on the indoor scenario.

In several investigations, devices using UWB technology are modelled as continuously emitting a white Gaussian spectrum. In this case, if an e.i.r.p. density level was derived for the case of a single UWB device interfering with a single IMT-2000 mobile station, a value of –72.8 dBm/MHz in the frequency band 2 GHz. would be deemed acceptable with a separation distance of 1 m, assuming an

I_{UWB}/N_{th} criterion of -6 dB. For a reference separation distance of 0.2 m, the resulting maximum UWB e.i.r.p. density is -86.8 dBm/MHz (see § 4.7.1.1.1).

In § 4.7.1.1.2, the assessment of the actual impact of UWB bursty emissions (the UWB transmission being at maximum e.i.r.p. density) on the BLER together with the degradation of the IMT-2000 fast power control performance, shows that a UWB e.i.r.p. density of –105 dBm/MHz has no noticeable impact on the BLER at the IMT-2000 mobile terminal with 10 dB coupling loss between the device using UWB technology and the IMT-2000 terminal. The impact begins to be noticeable under the same conditions with a UWB e.i.r.p. density of –95 dBm/MHz, where the BLER is still not impacted, but the resulting downlink transmit power rise becomes significant and will impact the overall capacity of the cell, potentially to a great extent when the base station transmits at maximum power or numerous IMT-2000 mobile stations of the same cell are simultaneously impacted by UWB localized interference.

The coupling loss can be linked to an expected separation distance between the UWB and IMT-2000 terminal devices using a free-space loss propagation model. A 30 dB coupling loss would correspond to a separation distance of approximately 36 cm, which is felt realistic. The corresponding maximum required UWB e.i.r.p. density is –85 dBm/MHz to protect the most sensitive IMT-2000 mobile stations with no noticeable impact.

Simulation results in § 4.7.3.2 include some scenarios involving power controlled devices using UWB technology, where the actual individual UWB e.i.r.p. density are lower than the assumed maximum UWB e.i.r.p. density of –65 dBm/MHz due to power control and short UWB links of the order of a few m. This particular scenario, involving a typical dense UWB deployment and IMT-2000 devices, gives a clear indication that some IMT-2000 receivers would be affected because the critical interference level of –115 dBm/MHz may sometimes be exceeded. This leads to the conclusion that a value of –65 dBm/MHz is not sufficient to protect IMT-2000.

Additional consideration to take into account the mitigating impact of statistics and/or UWB power control would be expected to enhance its impact on other systems and improve the maximum permissible UWB e.i.r.p. density levels to a limited extent. If power control is taken into account in the UWB impact assessment, some consideration may be appropriate as to how such devices with power control would be assured by means of regulations.

With respect to the interference from devices using UWB technology to IMT-2000 base stations, the following table contains the maximum UWB e.i.r.p. density levels required to meet the IMT-2000 base stations protection criteria (see § 4.7.2.2) at 2 GHz, as a function of UWB simultaneously active device densities, transmitting at maximum power.

TABLE 61

Maximum UWB e.i.r.p. densities to meet the IMT-2000 base station protection criteria

UWB transmitters/km^2	10	100	1 000	10 000	100 000
e.i.r.p. density UWBmax (dBm/MHz)	–57.5	–64.2	–70.8	–78.2	–87.0

As expected, these values are deeply linked to the UWB population density and activity factors models, revealing also that a high level of interference experienced at base stations would be caused by the aggregation of multiple UWB sources of interference. Unless new information is provided, it is assumed that the appropriate density of simultaneously active devices using UWB technology transmitting at maximum power should be taken between 10 000 and 100 000 devices/km^2.

It can be noted that the more constraining reference UWB maximum e.i.r.p. density values may be the ones required by the mobile or the base station (–85 dBm/MHz), depending on the density of devices using UWB technology simultaneously transmitting at maximum power. For device densities smaller than about 100 000 devices/km^2, the UWB interference is less severe for IMT-2000 base stations than for protecting the most sensitive IMT-2000 mobile station. Therefore the following maximum UWB e.i.r.p. density would be tolerable:

TABLE 62

UWB e.i.r.p. density values to protect the most sensitive IMT-2000 mobile stations in a typical IMT-2000 deployed network at a reference distance of 36 cm[(1)]

Frequency band	1 710-1 885 MHz	1 885-2 025 MHz	2 110-2 170 MHz	2 500-2 690 MHz
Maximum UWB e.i.r.p. density (dBm/MHz)	–86.4	–85.9	–85	–83.1

(1) The maximum UWB e.i.r.p. density value was obtained in the 2 110-2 170 MHz band, the values for the other bands have been extrapolated using free-space propagation model.

Most studies summarized here assumed a UWB device activity factor of 100%. However it has been proven that the device using UWB technology may operate at very much lower activity factors than 100%: Paragraph 4.7.1.1.2 results show that this impact is not trivial, and is a non-linear phenomenon in the case of UWB localized interference into an IMT-2000 mobile station. The effects of bursty UWB interference attack the fast power control and, finally, has systemic effects of UWB interference in terms of quality of service degradation. The effect of bursty emissions is rather like an old electronic warfare (EW) technique where pulses of RF energy are at such a repetition rate that they attack the AGC features of a radio. Such techniques in EW can prove more disabling to a radio than raw radio interference power. Table 63 offers data on the resulting downlink power increases for a particular IMT-2000 service and coupling loss (CL), for different UWB burst duty cycles (services) in this case (see § 4.7.1.1.2 for more details on the parameters used in the complete study).

TABLE 63

Increase in DL power (dB) at 40 dB CL (UWB e.i.r.p. density = –65 dBm/MHz)

	UWB wireless monitor	**UWB set-top box (3 channels)**	**UWB digital camera**
UWB burst duty cycle (%)	4	30	96
Voice 12.2 DL DPCH power rise (dB)	1.7	3.8	4.8
CS144 DL DPCH power rise (dB)	3.1	4.3	5.8
PS384 DL DPCH power rise (dB)	0.6	2.5	0.6

For example, in Table 63, a voice service receiving UWB interference from a UWB wireless monitor at 40 dB CL means that the DL DPCH power rises by 1.7 dB (over the case of no UWB interference and no OLPC/FPC), and a power rise of 4.8 dB is observed for the UWB digital camera interference. The average net power for the wireless monitor is about 24 times less than that for the digital camera due to 4% duty cycle for wireless monitor and 96% duty cycle for digital camera; yet, only a 3 dB increase in DL power is seen between these two UWB interference conditions.

The UWB activity factors considerations when addressing victim IMT-2000 base stations has not been studied specifically.

It should also be noted that the UWB interference has always been considered as white Gaussian noise. This assumption on UWB interference may not be appropriate for all types of UWB technologies, and further investigation on this point would also be beneficial (as an example, see the discussion on the peak to average ratio in § 4.3.3).

5 Wireless access systems including RLANs

5.1 Introduction and summary

This section considers the effect of UWB deployment on RLAN systems. Using the United States emission limits and the proposed European sloped mask for UWB transmitters, the amount of interference is computed that will be experienced at a RLAN node as a function of the UWB transmitter density. Furthermore, UWB transmitter densities can be computed if it is assumed a given maximum performance degradation for the RLAN system. These results show by how much the range, or cell coverage, of an access point will be reduced, corresponding to varying degrees of interference into the RLAN system.

The characteristics of RLANs, including IEEE 802.11a, HIPERLAN/2, IEEE 802.11b, and MMAC HSWA HiSWANa are summarized in Recommendation ITU-R M.1450, including the operational frequency bands.

The analysis shows that for a single *I*/*N* degradation of 1 dB a minimum separation is required up to 6 m depending on the data rate, receiver sensitivity and frequency range. The results show also that besides the UWB density the aggregation factor (which takes into account the effect of multiple devices, the average activity factor and the victim immunity) strongly determines the interference in the WAS/RLAN receiver. For the aggregation factors 0.04, 0.2 and 0.5 the impact on WAS/RLAN are determined.

The theoretical analysis for IEEE 802.11a was supported by measurements showing which *C*/*I* can be tolerated.

5.2 Model and scenario

In this section, we introduce the model used to compute the interference resulting from the deployment of UWB devices as well as the model to determine the coverage by an individual RLAN cell.

5.2.1 UWB interference model

The model scenario where a RLAN node is surrounded by UWB transmitters in a two-dimensional setting is considered in the following and illustrated in Fig. 87. The victim receiver is placed at the centre of two concentric circles. The inner circles defines the boundary of an UWB-free zone, i.e. no UWB transmitters are closer to the victim that r_{min}. In between the inner and the outer circle (given by R_r), the UWB transmitters are distributed uniformly over the surface. All the interfering UWB devices are assumed to be transmitting with equal power, given by the maximum power spectral density defined in the relevant frequency band by the United States emission mask and the proposed European sloped mask, as well as the actually employed bandwidth of the victim system. Furthermore, it is assumed that there is no co-channel interference, i.e. no interference from other access points using the same frequency. Especially in a likely indoor environment, this is a reasonable assumption.

If now R_r tend to infinity, the victim receiver experiences a total interference power due to the UWB devices given by:

$$P_R(r) = k_{agg} \times 2\pi\rho \times P_{UWB} \times \left(\frac{\lambda}{4\pi}\right)^2 \times I(r_{min}, d_0) \qquad (56)$$

where:

k_{agg}: aggregation factor to take into account the effect of multiple devices, the average activity factor and the victim immunity factor

ρ: UWB density in users/m^2

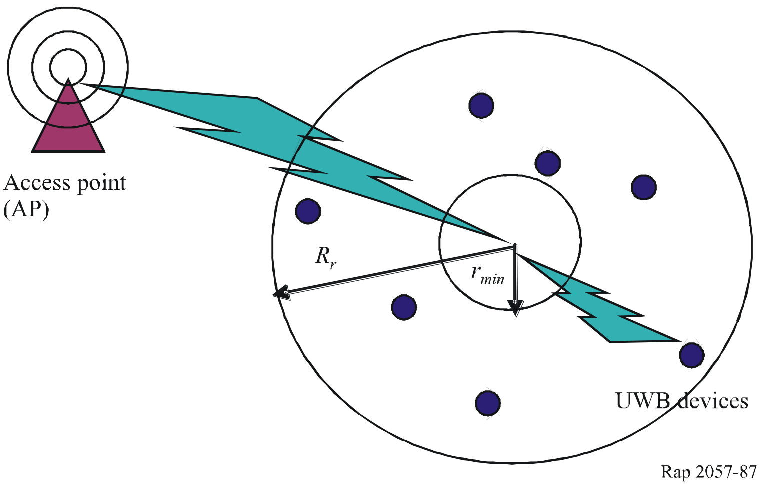
P_{UWB}: transmission power for each UWB device

λ: wavelength

$I(r_{min}, d_0)$: propagation attenuation factor depending on the environment through the breakpoint d_0 and r_{min}.

FIGURE 87

The interference scenario considered:
ANRLAN node, placed among UWB transmitters in communication with an access point



NOTE 1 – If the access point were surrounded by the UWB devices, the total system impact would be much higher. This should be considered in further studies.

The single *I*/*N* at the victim receiver is defined by:

$$\text{Single} \quad I/N = \frac{P_T \times Const}{N + UWB\ interference} \tag{57}$$

where P_T the transmit power at the access point, *Const* is the path loss as a function of distance, *UWB interference* represents the total received power from all the UWB devices around the victim receiver, and *N* is given by:

$$N = N_0 + N_F + L_{IMP} \tag{58}$$

where N_0 is the thermal noise, N_F represents the noise figure of the receiver, and L_{IMP} is the implementation loss due to digital processing in the receiver. Thus in dBm, we get:

$$\text{Single } I/N \text{ (dB)} = P_T \text{ (dB)} + Const \text{ (dB)} - N \text{ (dB)} - M \text{ (dB)}$$
$$\text{Single } I/N \text{ (dB)} = S/N \text{ (dB)}_{Without\ UWB} - M \text{ (dB)} \tag{59}$$

where *M* is defined such that:

$$10 \times \log_{10}\left(\frac{N + UWB\ interference}{10^{-3}}\right) = 10 \times \log_{10}\left(\frac{N}{10^{-3}} \times \frac{N + UWB\ interference}{N}\right) = N(\text{dBm}) + M(\text{dB}) \tag{60}$$

Therefore, any increase of *M* dB due to UWB interference will result in an equal decrease in the single *I*/*N*.

We have also found a general value for the *UWB interference* as a function of the UWB transmitter density from r_{min} to infinity, such that:

$$UWB\ interference = k_{agg} \times 2\pi\rho \times P_{UWB} \times \left(\frac{\lambda}{4\pi}\right)^2 \times I(r_{min}, d_0) \tag{61}$$

with:

$$I(r_{min}, d_0) = \begin{cases} \ln(d_0) - \ln(r_{min}) + 0.5 & \text{for } r_{min} \le d_0 \le \infty \\ 0.5 \times \left(\frac{d_0}{r_{min}}\right)^2 & \text{for } d_0 \le r_{min} \end{cases}$$

and P_{UWB} is the UWB transmit power (fixed by the maximum of the emission mask). So, the maximum potential UWB transmitter density ρ under the constraint that the Single I/N decreases not more than M dB is given by:

$$\rho = \frac{UWB\ interference}{k_{agg} \times 2\pi \times I(r_{min}, d_0) \times P_{UWB} \times \left(\frac{\lambda}{4\pi}\right)^2} \quad \text{users/m}^2 \tag{62}$$

Therefore, the potential UWB density can be evaluated for different decreases in the SINR and effects due to an introduction of UWB devices can be estimated on IEEE 802.11a/b RLANs.

5.2.2 RLAN cell coverage

In order to obtain more meaningful results with respect to the resulting loss in RLAN performance due to UWB interference, the performance of a RLAN cell as a function of the signal strength is considered. For a given the signal strength, the *S*/*N* can be computed with and without UWB interference. The data rates that can be provided by a RLAN cell are a function of the *S*/*N* while the *S*/*N* depends on the signal strength and the amount of interference. This allows us to draw conclusions about the effects of UWB interference on RLAN performance, as measured by investigating the data rate that can be provided as a function of distance.

Again, the *S*/*N* should include at a minimum the noise figure and implementation loss due to digital processing in the receiver. Generally, it is assumed a minimum *S*/*N* that must be provided for a specific data rate. The following relations allow to compute the maximum coverage range, r_{MAX}, that can be obtained by the RLAN access point under the constraint that a certain minimum *S*/*N* (related to a certain data rate) must be maintained:

$$S/N_{min} = \frac{Useful\ signal(r_{MAX})}{Noise}$$

where *Noise* is equal to the *Thermal Noise*, N_0, plus *Noise Figure*, N_F, and *Implementation Loss* due to digital processing in the receiver, L_{IMP}.

$$S/N = \begin{cases} \dfrac{P_T\left(\dfrac{\lambda}{4\pi r_{MAX}}\right)^2}{N} & \text{for } d_0 \ge r_{MAX} \\ \dfrac{P_T\left(\dfrac{\lambda}{4\pi d_0}\right)^2\left(\dfrac{d_0}{r_{MAX}}\right)^4}{N} & \text{for } d_0 \le r_{MAX} \end{cases} \tag{63}$$

Therefore, r_{MAX} results in:

$$r_{MAX} = \begin{cases} \dfrac{\lambda}{4\pi}\sqrt{\dfrac{P_T}{S/N_{min}}} & \text{for } d_0 \geq r_{MAX} \\ \sqrt{\dfrac{d_0\lambda}{4\pi}}\sqrt[4]{\dfrac{P_T}{S/N_{min}}} & \text{for } d_0 \leq r_{MAX} \end{cases} \tag{64}$$

Hence, with the above formulas, the maximum range for a given *S*/*N* can be computed. In the following sections, the results of this section are applied to both IEEE 802.11a and IEEE 802.11b. For a more general overview of those technologies and some background information, the standards referenced in Recommendation ITU-R M.1450 should be consulted.

5.3 UWB interference effects on IEEE 802.11a

In this section, the specific performance degradations to IEEE 802.11a systems are considered resulting from UWB Interference. Since IEEE 802.11a is located in the 5 GHz band, the technology is particularly affected as it is lying in the main UWB transmission band. This is in contrast to the IEEE 802.11b that is affected only by out of band interference. The degradation in RLAN performance is computed in the following.

5.3.1 IEEE 802.11a cell coverage

As a result of WRC-03, the bands 5 150-5 350 MHz and 5 470-5 725 MHz have been allocated to the mobile service on a PRIMARY basis for use by wireless access systems, including RLANs covered in Recommendation ITU-R M.1450. Additionally, the band 5 725-5 850 MHz is available for use in some countries on a national basis.

The cell coverage is a main consideration of RLAN systems as it defines the maximum possible data rates as a function of the distance and, more directly, as a function of the single *I*/*N*. In practice, the receiver sensitivity is used in order to define the cell radius to ensure a desired quality of service. The coverage range is evaluated with maximum transmission power at the access point (AP).

The IEEE 802.11a standard requires receivers to have a minimum sensitivity ranging from –82 to –65 dBm at different supported data rates, with the lower data rates being used as “fall-back modes” when the highest data rate cannot be supported by link conditions Recommendation ITU-R M.1450. In the Table 64, an overview is given.

TABLE 64

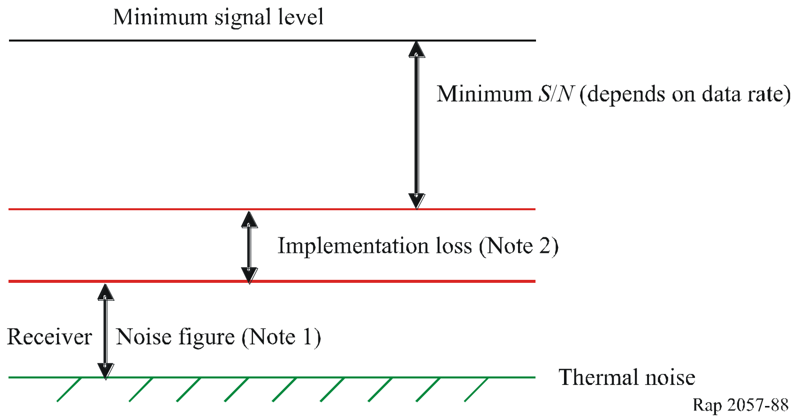
Minimum signal level, data rate and *S*/*N*

Data rate (Mbit/s)	Minimum signal level (dBm)	Minimum *S*/*N*
6	–82	5
9	–81	6
12	–79	8
18	–77	10
24	–74	13
36	–70	17
48	–66	21
54	–65	22

From the standard described in Recommendation ITU-R M.1450, the minimum signal level is measured at the antenna connector with a 5 dB implementation loss and 10 dB receiver noise figure.

FIGURE 88

Minimum signal level



Note 1 – Exact values depending on manufacturers, must be ≤ 10 dB as stated in the standard.
Note 2 – Exact values depending on manufacturers, must be ≤ 5 dB as stated in the standard.

Therefore, from Fig. 89 the different minimum signal levels (≤ values from Table 64) can be taken for each data rate according to the manufacturer (Implementation Loss + Receiver Noise Figure ≤ 15 dB).

As indoor cells are in general not very large, co-channel interference due to other access points using the same frequency can be neglected. Indeed, considering for example a typical office building, with dimensions 20 m x 50 m and floor number *N*, where 3 APs are sufficient for coverage but also 4 APs in order to take capacity into account, since the coverage is primarily determined by the expected range for the 54 Mbit/s mandatory mode (assuming an AP cell radius of 19 m, see also Fig. 90) Therefore, with a number of available channels, co-channel RLAN interference is not a problem, even if the interference from floor N – 1 and N + 1 is considered, as neighbouring channel RLAN interference can be avoided if the other available, non-interfering channels defined in the standard are not used for floor *N*. Signals from other floors will be very attenuated due to penetration losses and hence the interference from other floors will be small even if the same frequency is used. Therefore, the coverage is determined by a noise limited environment.

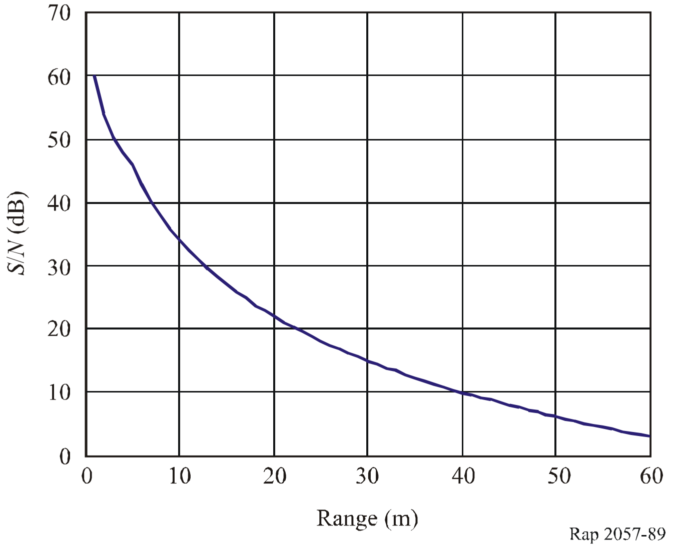
In order to assess the effect of the UWB interference, a maximum distance fixed by the *S*/*N* is computed in such a way that the maximum range is reached at the minimum *S*/*N* (5 dB from Table 64) at this distance. In general, typical coverage is obtained through the receiver sensitivity, but as described before, there are different margins according to manufacturers, therefore different minimum signal levels are obtained and thus different topologies. This consideration does not provide information about link quality or data rate (i.e. *S*/*N* defines the link quality and therefore data rate).

Figure 90 shows the relationship between *S*/*N* and distance, achievable link data rate and *S*/*N* and, finally, achievable link data rate and the distance between the user and AP for an indoor environment using IEEE 802.11a RLAN. From Fig. 91, the highest data rate of 54 Mbit/s is achievable when the distance between the user and AP is about 19 m. When user is located about 53 m away from the AP, 6 Mbit/s data rate is achievable.

The following curves were generated assuming a transmit power of 100 mW at a frequency of 5.3 GHz. In addition, the standard assumptions for noise figure (10 dB) and implementation loss (5 dB) were assumed.

FIGURE 89

S/N as a function of range



The useful signal decreases whereas the noise is constant, therefore the S/N decreases in the same manner.

The propagation loss formula used is free-space propagation loss and inverse fourth power law before and after the breakpoint value d_0 = 5 m, respectively.

Devices utilizing IEEE 802.11a are required to support rates of up to 54 Mbit/s.

FIGURE 90

Data rate versus range

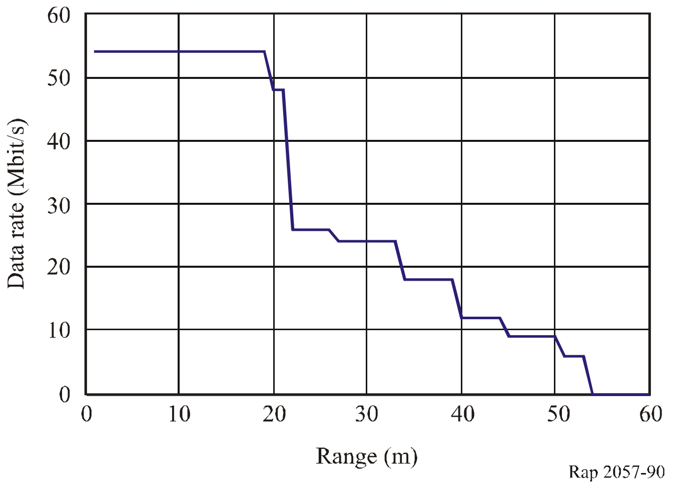


Figure 90 gives the coverage with maximum possible data rates as a function of the distance.

5.3.2 UWB emission limit in the IEEE 802.11a band

For both the United States emission limits and the proposed European sloped mask, the spectrum used for UWB communication devices is between 3.1 GHz and 10.6 GHz with a maximum power spectral density of –41.3 dBm/MHz. The receiver bandwidth for an IEEE 802.11a device is 16 MHz. Because of the ultra wide bandwidth of UWB devices, the UWB spectrum can be considered as flat in the IEEE 802.11a device bandwidth, therefore the UWB spectrum is considered like white noise above a particular minimum PRF. The UWB power spectral density is:

$$P_{UWB in 802.11a BW} = 29.2 \text{ dBm}/16 \text{ MHz} \qquad (65)$$

for both the United States emission limits and the proposed European sloped mask.

5.3.3 Interference as a function of UWB transmitter density

A uniform distribution of UWB systems around the victim receiver is assumed from r_{min} to infinity, as previously detailed. In indoor environments, like homes and offices, it would be expected to find high UWB transmitter densities. Therefore, it is emphasized that only the active UWB devices are considered. In the following example, values from 0.01 to 0.2 users/m^2 are assumed. From the calculations Figs. 91 a), b) and c) are obtained as a function of r_{min}, (active) UWB device densities, and various values are assumed for the aggregation factor k_{agg} = 0.04, 0.20 and 0.50.

Considering free-space propagation loss before and inverse fourth power law after the breakpoint value d_0 = 5 m, respectively, the introduction of the UWB devices around the victim receiver results in:

$$S/N = \frac{Useful\ signal}{Noise} \overset{with\ UWB\ introduction}{\Rightarrow} \text{Single} \quad I/N = \frac{Useful\ signal}{Noise\ +\ UWB\ interference}$$

In Figs. 92 a), b) and c), effects due to introduction of UWB devices on the victim RLAN single *I/N* with UWB density ρ = 0.2 users/m^2 are considered and the degradation of the performance can be observed. Therefore, in Fig. 93 the effects due to introduction of UWB devices on the victim RLAN single *I/N* with UWB density ρ = 0.2 users/m^2 and potential degradations in the performance are shown.

FIGURE 91

Cumulative UWB interference at the victim receiver

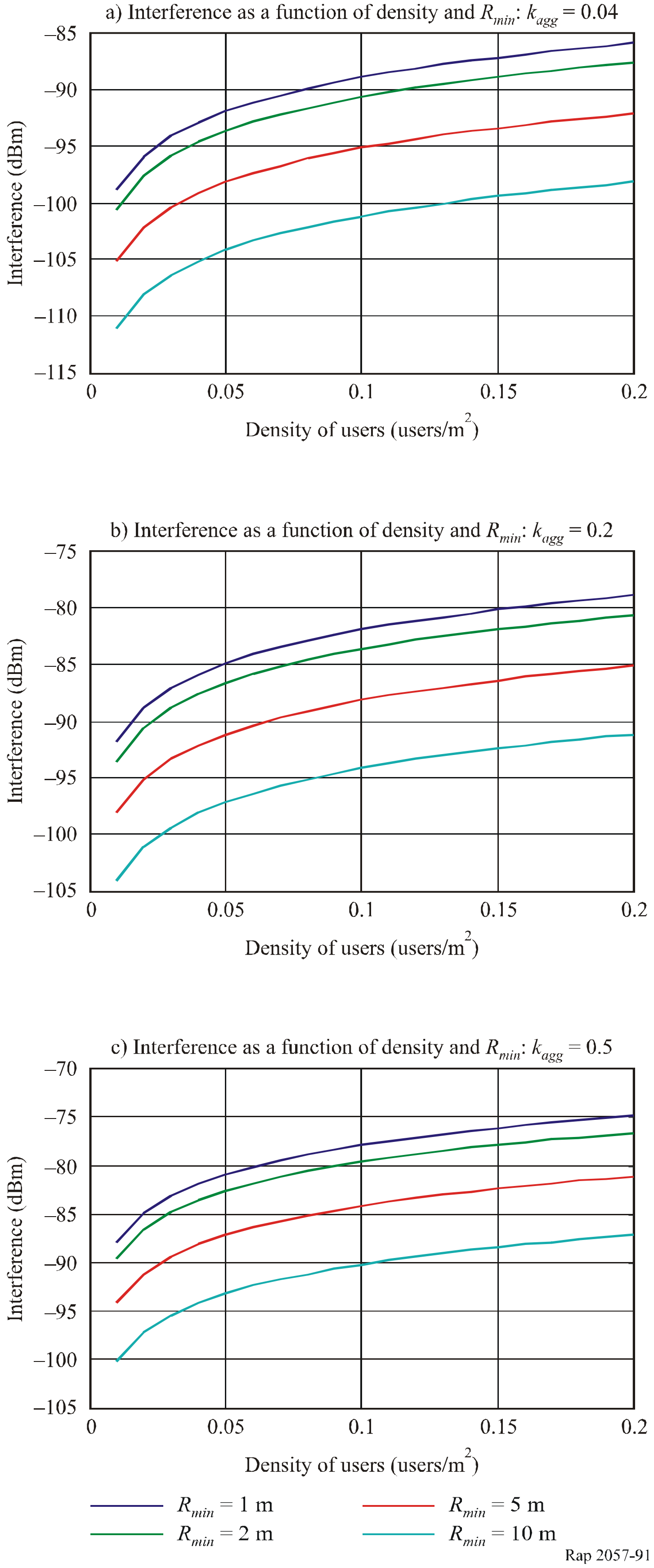
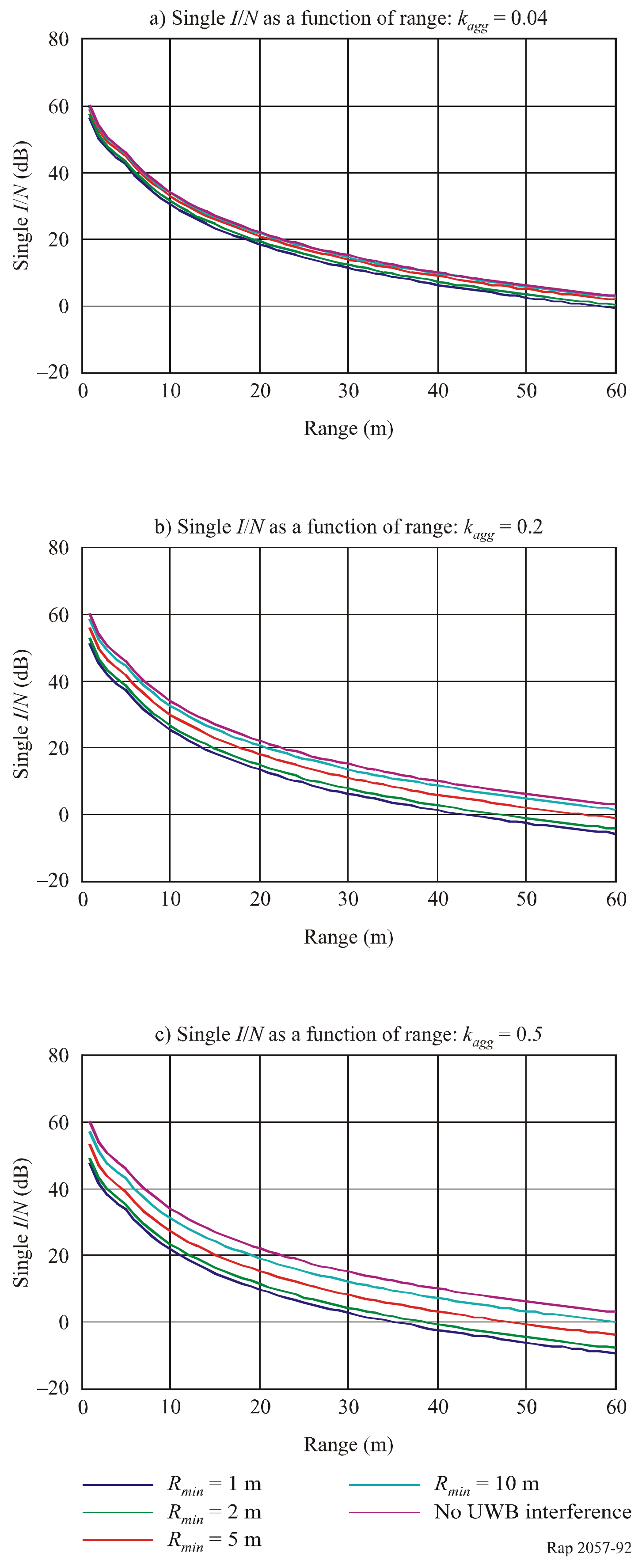


FIGURE 92

Single *I*/*N* as a function of range



The useful signal decreases whereas the noise plus UWB interference is the same, therefore the single *I*/*N* decreases in the same manner.

The propagation loss used is free-space propagation loss before and inverse fourth power law after the breakpoint value d_0 = 5 m, respectively.

Figures 93a), b) and c) gives the coverage with possible data rate as a function of the distance. With introduction of UWB devices, we observe reductions of both coverage and achievable data rate. For example, with R_{min} = 1 m and k_{agg} = 0.04, the coverage is reduced by approximately 18% at the lowest data rate of 6 Mbit/s (i.e. without UWB introduction).

IEEE 802.11a uses a physical carrier sensing protocol besides the virtual carrier sensing. The most typical carrier sense algorithm is based on correlating the received signal with the short and long preamble. If the correlation is successful, the IEEE 802.11a device declares the channel busy. In addition, it is also possible to combine the preamble carrier sense with energy detect to improve the robustness of the algorithm. However, it is remote that energy detect would ever be used by itself. Therefore, it is unlikely that a strong UWB signals will appear to a node like another RLAN user that is transmitting.

5.3.4 UWB density resulting in 1 dB degradation in the *S*/*N*

For a protection criteria for RLANs of 1 dB degradation, we can calculate the permissible received UWB interference at the victim node.

With N_0 (thermal noise) which is equal to –102 dBm, including the noise figure and implementation margin as defined in the IEEE 802.11a standard, the noise floor is raised to –87 dBm. So, the resulting UWB interference (W) and the UWB transmitter density (active users) can be estimated:

$$UWB\ interference(\text{dBm}) = -93\ \text{dBm}$$

Therefore, for various values of the aggregation factor k_{agg} (= 0.04, 0.20, 0.50), the UWB density is given as:

$$\rho = \frac{UWB\ interference}{k_{agg} \times 2\pi \times I(r_{min}, d_0) \times P_{UWB} \times \left(\frac{\lambda}{4\pi}\right)^2} = 0.04 \quad \text{users/m}^2,\ k_{agg} = 0.04$$

$$\rho = \frac{UWB\ interference}{k_{agg} \times 2\pi \times I(r_{min}, d_0) \times P_{UWB} \times \left(\frac{\lambda}{4\pi}\right)^2} = 0.008 \quad \text{users/m}^2,\ k_{agg} = 0.20$$

$$\rho = \frac{UWB\ interference}{k_{agg} \times 2\pi \times I(r_{min}, d_0) \times P_{UWB} \times \left(\frac{\lambda}{4\pi}\right)^2} = 0.003 \quad \text{users/m}^2,\ k_{agg} = 0.50$$

where $I(r_{min}, d_0)$ is computed with r_{min} = 1 m and d_0 = 5 m and P_{UWB} is the UWB emission limit fixed by ETSI and United States in IEEE 802.11a bandwidth.

5.3.5 Minimum distance with one UWB transmitter

In order to represent the effect of UWB interference IEEE 802.11a devices, it is interesting to consider only one UWB transmitter and estimate the necessary minimum separation distance to degrade the signal by no more than *M* dB.

FIGURE 93

Data rate as a function of range

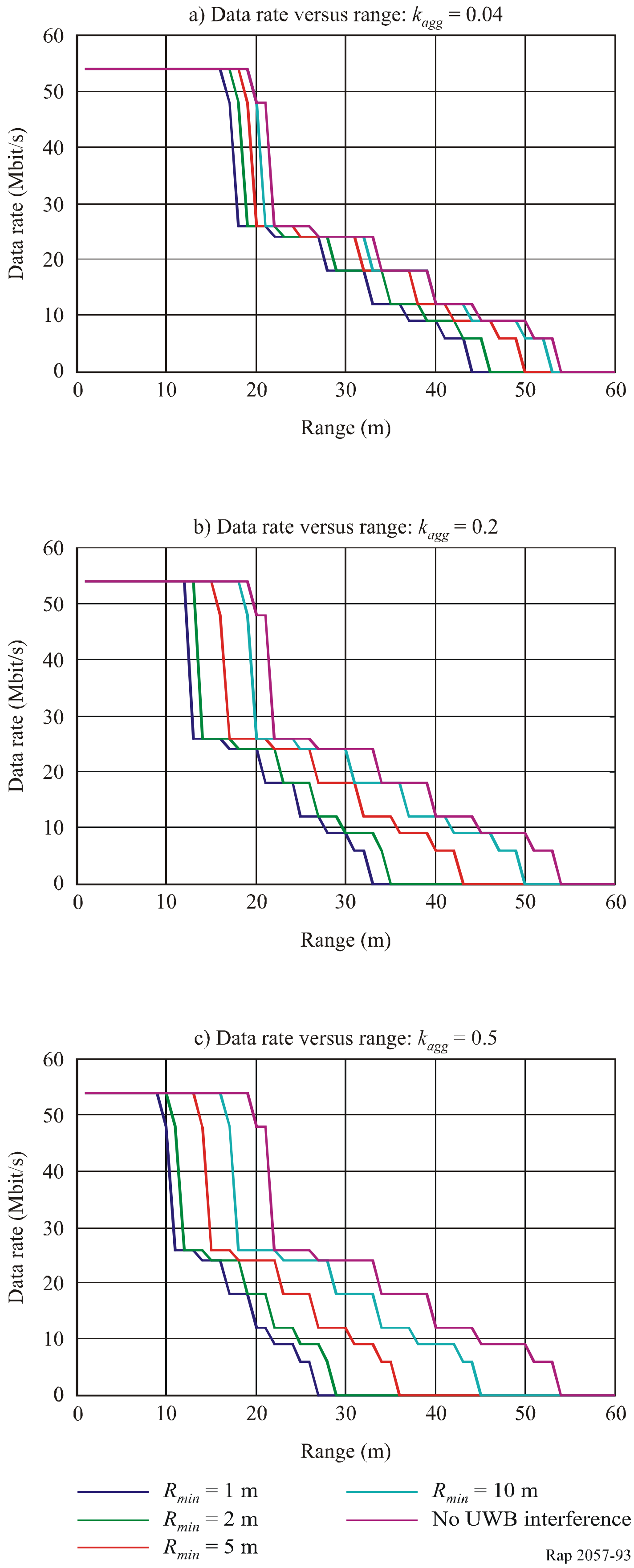
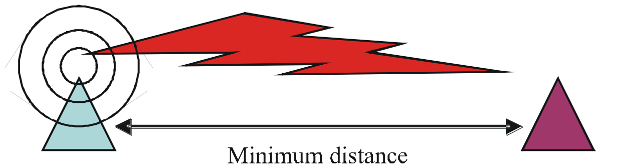


FIGURE 94

Minimum distance between UWB device and victim receiver



If we consider an M dB degradation in the S/N, the maximum UWB interference level will be the following:

$$\textit{Power received from UWB transmitter}_0 \leq N\left(10^{\frac{M}{10}}-1\right)$$

Introducing the path-loss expression:

$$N\left(10^{\frac{M}{10}}-1\right) \geq \begin{cases} P_{UWB}\left(\dfrac{\lambda}{4\pi r_{MAX}}\right)^2 & d_0 \geq r_{MAX} \\ P_{UWB}\left(\dfrac{\lambda}{4\pi d_0}\right)^2\left(\dfrac{d_0}{r_{MAX}}\right)^4 & d_0 \leq r_{MAX} \end{cases}$$

the minimum separation can be derived:

$$r_{MAX} = \begin{cases} \dfrac{\lambda}{4\pi}\sqrt{\dfrac{P_{UWB}}{N\left(10^{\frac{M}{10}}-1\right)}} & d_0 \geq r_{MAX} \\ \sqrt{\dfrac{d_0\lambda}{4\pi}}\sqrt[4]{\dfrac{P_{UWB}}{N\left(10^{\frac{M}{10}}-1\right)}} & d_0 \leq r_{MAX} \end{cases}$$

Therefore, from equation (4), the minimum separation distances with either the current United States emission limits or proposed European sloped mask (i.e. P_{UWB} = –29.2 dBm/16 MHz) and d_0 = 5 m are:

Degradation	Separation distance
1 dB	5.8 m

5.3.6 Maximum possible UWB transmission power in order to have a UWB density of 0.2 users/m^2

Considering a given UWB density, taken here as 0.2 user/m^2, and the maximum permissible UWB interference power such that:

$$\rho = \frac{UWB\ interference}{k_{agg} \times 2\pi \times I(r_{\min}, d_0) \times P_{UWB} \times \left(\frac{\lambda}{4\pi}\right)^2} \quad \Rightarrow \quad P_{UWB} = \frac{UWB\ interference}{k_{agg} \times 2\pi\rho \times I(r_{\min}, d_0) \times \left(\frac{\lambda}{4\pi}\right)^2}$$

Then, from equation (), for an M dB decrease in the S/N permitted by the system can be obtained:

For a 1 dB decrease in the S/N:

P_{uwb} = –48.3 dBm/MHz for k_{agg} = 0.04

P_{uwb} = –55.3 dBm/MHz for k_{agg} = 0.20

P_{uwb} = –59.3 dBm/MHz for k_{agg} = 0.50

5.3.7 Summary IEEE 802.11a

For the analysis the two-slope propagation model (r^{-2}, r^{-4}) is used with the breakpoint 5 m and assuming that within 1 m around the victim no UWB device is deployed.

For a single I/N degradation of 1 dB in the mobile terminal and applying the current United States emissions limits, a minimum separation distance of 5.8 m is required.

Assuming a UWB density of 0.2 user/m^2, the maximum permissible UWB interference power and a single I/N degradation of 1 dB, then the maximum possible UWB transmissions power density results in:

–48.3 dBm/MHz for the aggregation factor 0.04

–55.3 dBm/MHz for the aggregation factor 0.20

–59.3 dBm/MHz for the aggregation factor 0.50

The aggregation factor takes into account the effect of multiple devices, the average activity factor and the victim immunity factor but not the UWB density.

5.4 UWB interference effects on IEEE 802.11b

As IEEE 802.11b is not located in the proposed 3.1-10.6 GHz UWB transmission band, it is affected somewhat less in that the interference is out of band interference. An IEEE 802.11b may be more interfered by co-channel and adjacent channel interference from other IEEE 802.11b device. However, this analysis does not include co-channel and adjacent channel interference.

5.4.1 IEEE 802.11b coverage

Coverage is an important factor for IEEE 802.11b systems. There is no information in the IEEE standard about minimum S/Ns as a function of the data rates but in general typical minimum sensitivities range from –93 to –84 dBm, depending on the data rate (see Table 65). Therefore the coverage here is based directly on sensitivity levels. Assuming a total noise figure and implementation loss of 10 dB, the minimum required S/N for each data rate of the IEEE 802.11b system can be determined.

TABLE 65

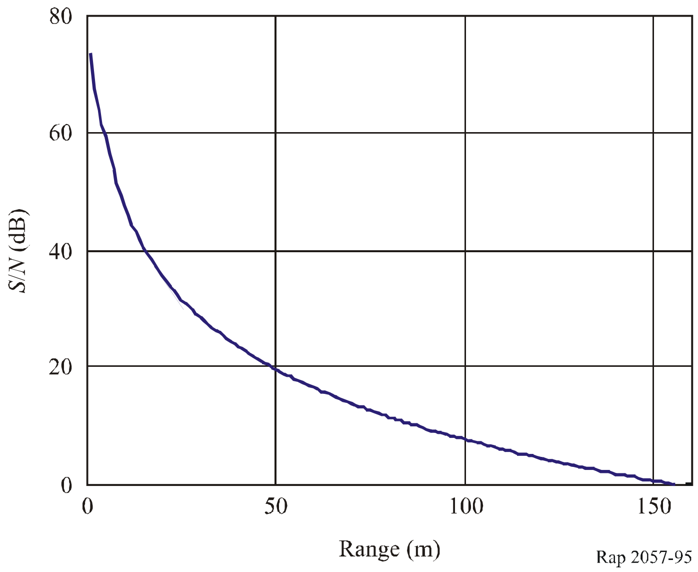
Data rate and receiver sensitivity

Data rate (Mbit/s)	Receiver sensitivity (dBm)
1	–93
2	–90
5.5	–87
11	–84

Figs. 95 and 96 shows the European emission limit for the RLAN access point.

FIGURE 95

***S/N* as a function of range**



The S/N for an indoor environment is computed with transmit power = 100 mW e.i.r.p.

The propagation loss used is free-space propagation loss before and inverse fourth power law after the breakpoint value d_0 = 5 m, respectively.

Devices utilizing IEEE 802.11b are required to support speed up to 11 Mbit/s. This depends strongly on the *S*/*N*. Therefore, from Figs. 95 and 96 the possible data rate as a function of distance can be estimated:

FIGURE 96

Data rate versus range

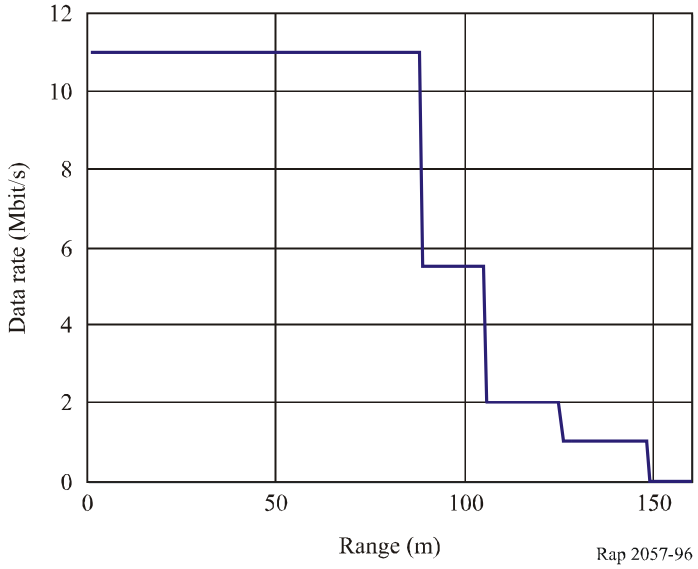


Figure 96 gives the coverage with possible data rate as a function of the distance.

The highest data rate of 11 Mbit/s is achievable when the distance between the user and AP is around 88 m. When user is located about 148 m away from the AP, 1 Mbit/s data rate is achievable.

5.4.2 UWB emission limit in the IEEE 802.11b band

In the United States rules in the IEEE 802.11b band for UWB, the power e.i.r.p.limits are –51.3 dBm/MHz for indoor and –61.3 dBm/MHz for outdoor applications.

In the proposed European sloped mask, however, the e.i.r.p. density levels are:

$$\text{Indoor: e.i.r.p.} = -51.3 + 87 \times \log_{10}(f_{GHz}/3.1) \text{ dBm/MHz}$$

$$\text{Outdoor: e.i.r.p.} = -61.3 + 87 \times \log_{10}(f_{GHz}/3.1) \text{ dBm/MHz.}$$

As was the case for the IEEE 802.11a computations, the UWB signal is considered to be white in the bandwidth of interest.

a) With United States mask:

$$\begin{cases} P_{UWB\ in\ 802.11b\ BW} = -40.9 \text{ dBm/11 MHz} & \text{for indoor} \\ P_{UWB\ in\ 802.11b\ BW} = -50.9 \text{ dBm/11 MHz} & \text{for outdoor.} \end{cases}$$

b) With proposed European sloped mask at 2.4 GHz:

$$\begin{cases} P_{UWB\ in\ 802.11b\ BW} = -50.6 \text{ dBm/11 MHz} & \text{for indoor} \\ P_{UWB\ in\ 802.11b\ BW} = -60.6 \text{ dBm/11 MHz} & \text{for outdoor.} \end{cases}$$

Even though the IEEE 802.11b standard defines a Tx mask of 22 MHz, the 3 dB bandwidth is only 11 MHz.

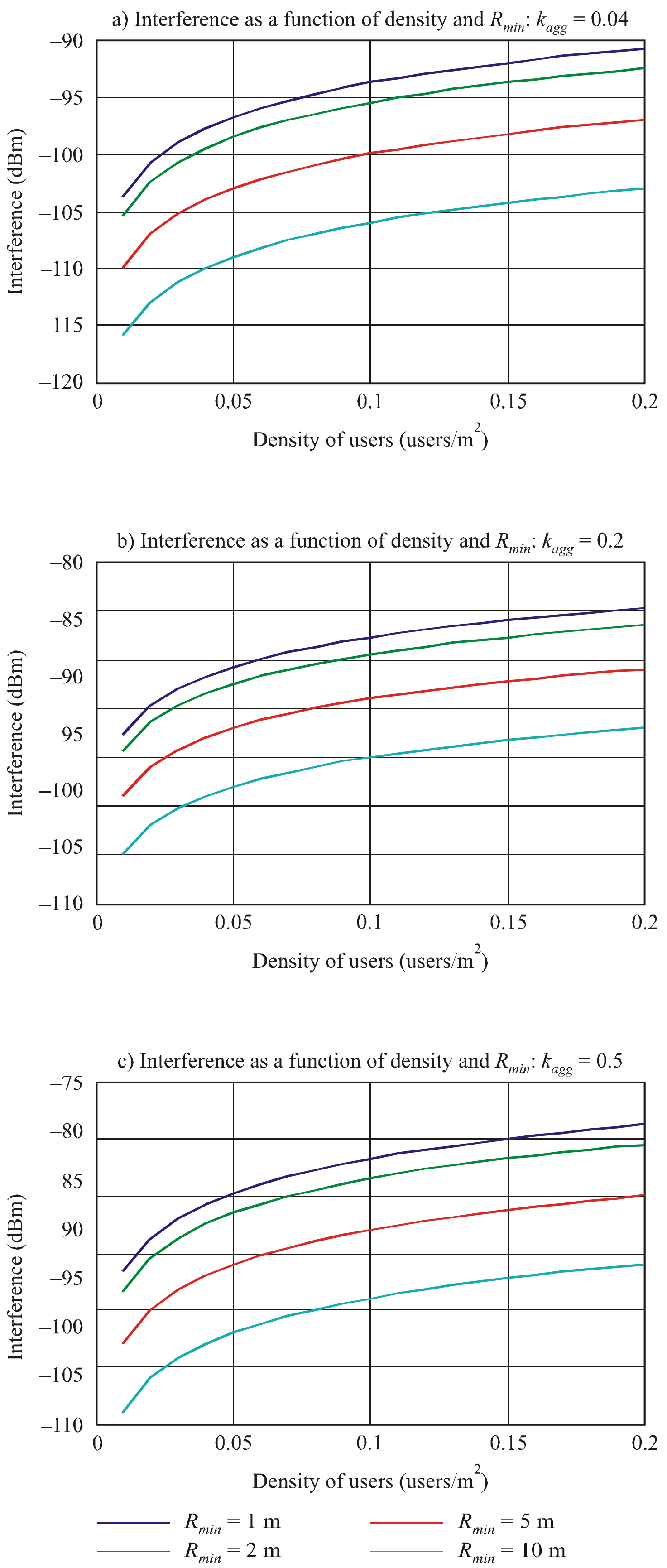
5.4.3 UWB interference as a function of transmitter density

A uniform distribution of UWB systems is considered around the victim receiver taken from R_{min} to infinity, as previously detailed. In indoor environments, like homes and offices, we would expect to find high UWB transmitter densities. It is emphasized that only the active devices are taken into account. In § 5.4.3 the indoor scenario is considered as the most critical case, only. In the following example, values from 0.01 to 0.2 users/m^2 are analysed. From equation (2), the following figures for IEEE 802.11b are obtained as a function of R_{min}, (active) UWB device densities, and various values of the aggregation factor k_{agg} (= 0.04, 0.20, 0.50).

a) With United States mask: indoor => –40.9 dBm/11 MHz and outdoor =>–50.9 dBm/11 MHz.

FIGURE 97

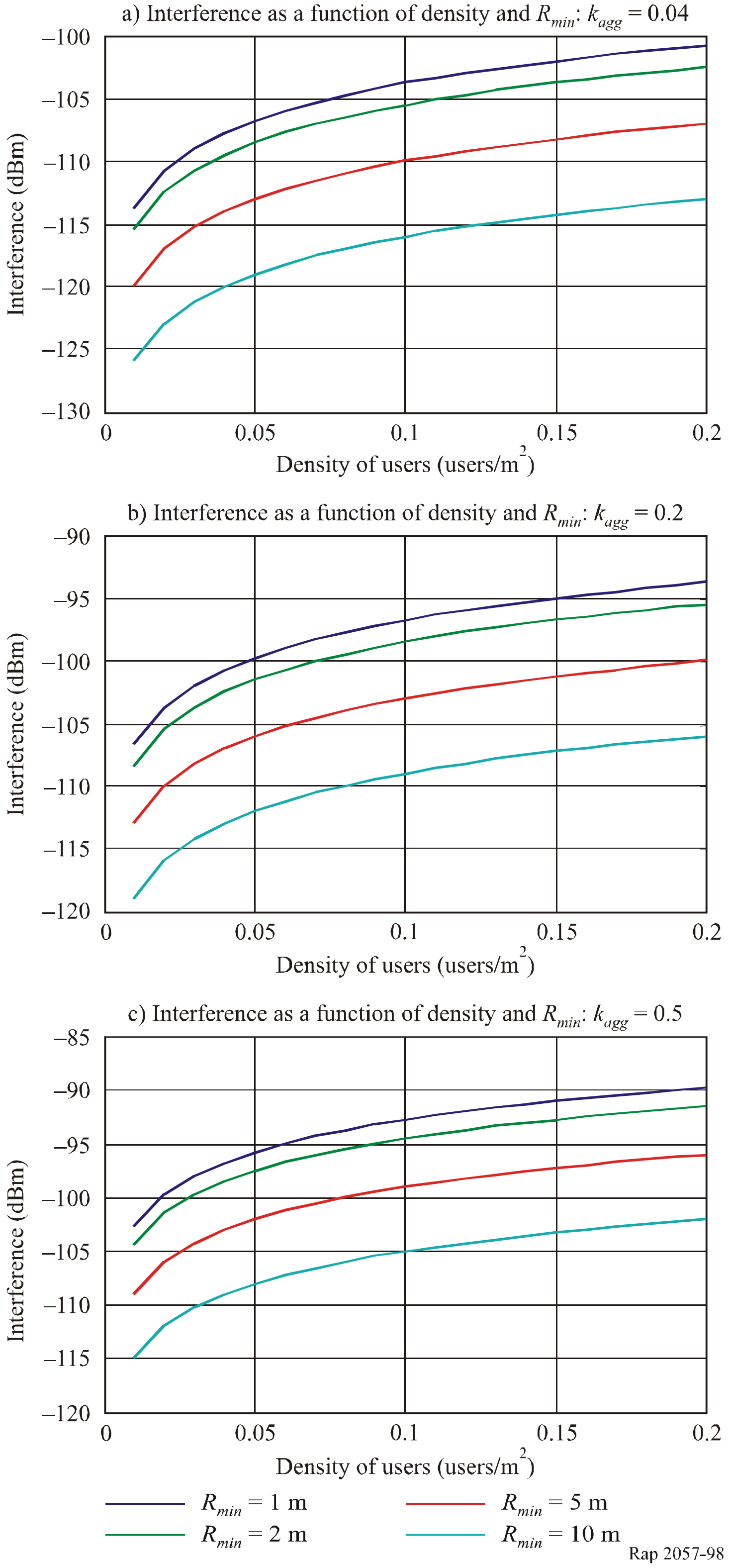
UWB interference as a function of density and R_{min} for P_{uwb} = –40.9 dBm



Rap 2057-97

FIGURE 98

UWB interference as a function of density and R_{min} for P_{uwb} = –50.9 dBm



Free-space propagation loss before and inverse fourth power law after the breakpoint value d_0 = 5 m is considered, respectively.

FIGURE 99

Single I/N as a function of range for P_{uwb} = –40.9 dBm

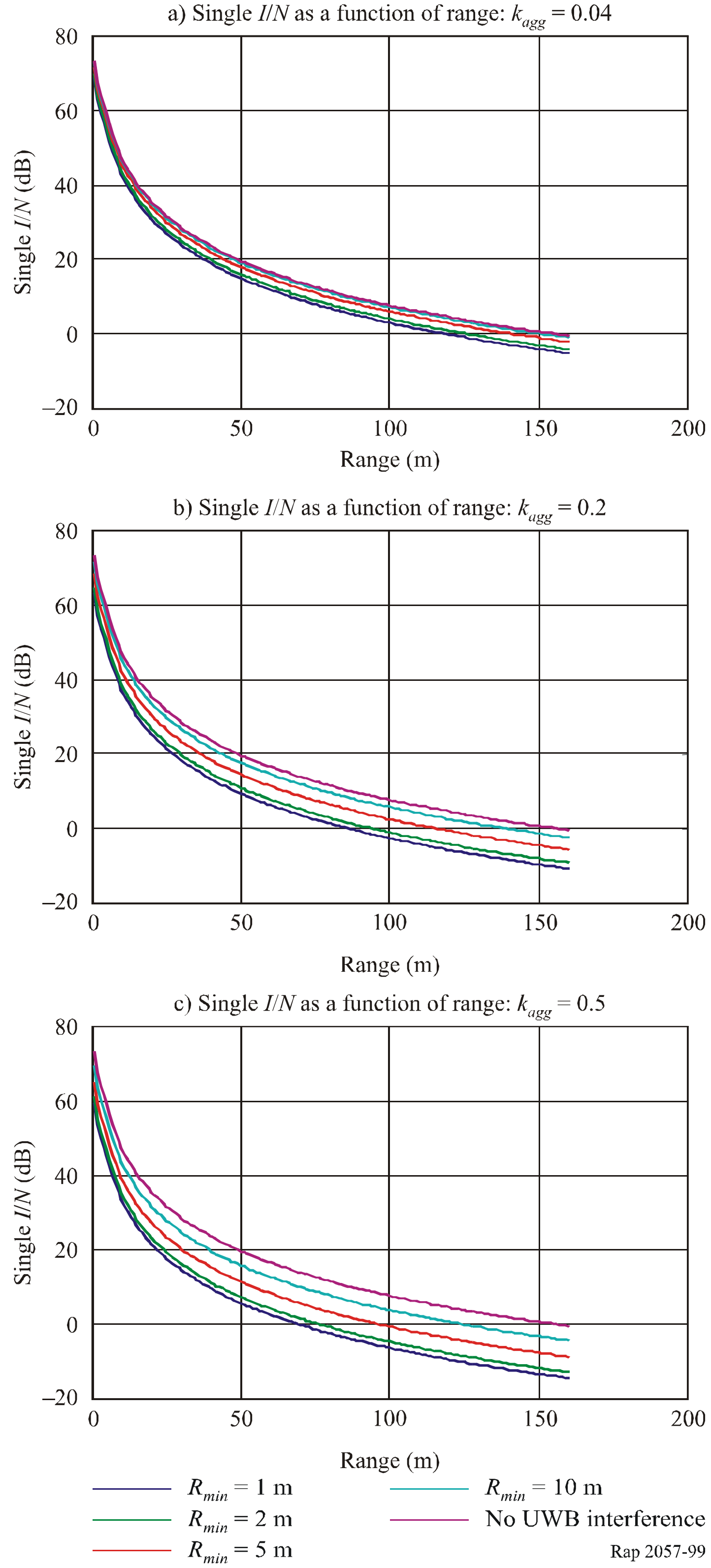
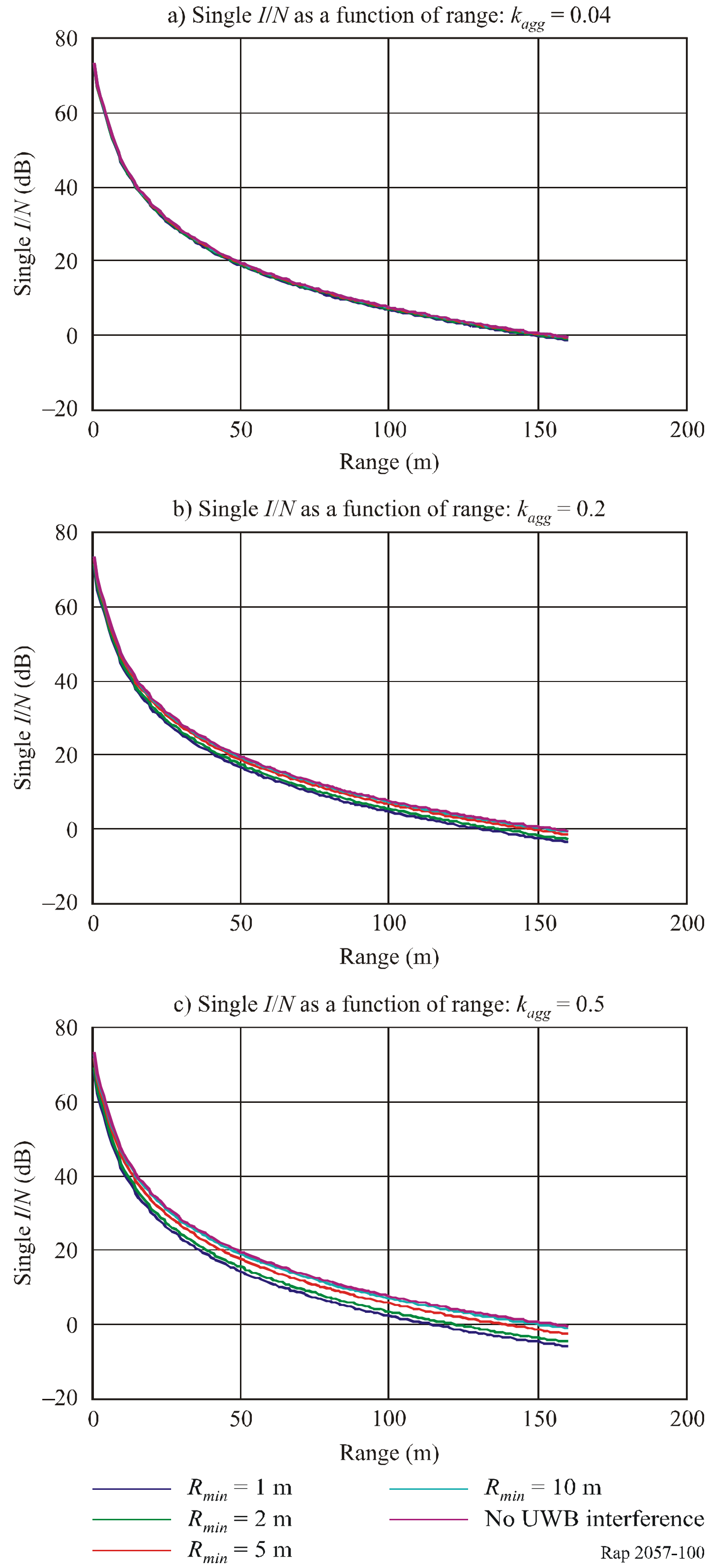


FIGURE 100

Single I/N as a function of range for P_{uwb} = –50.9 dBm



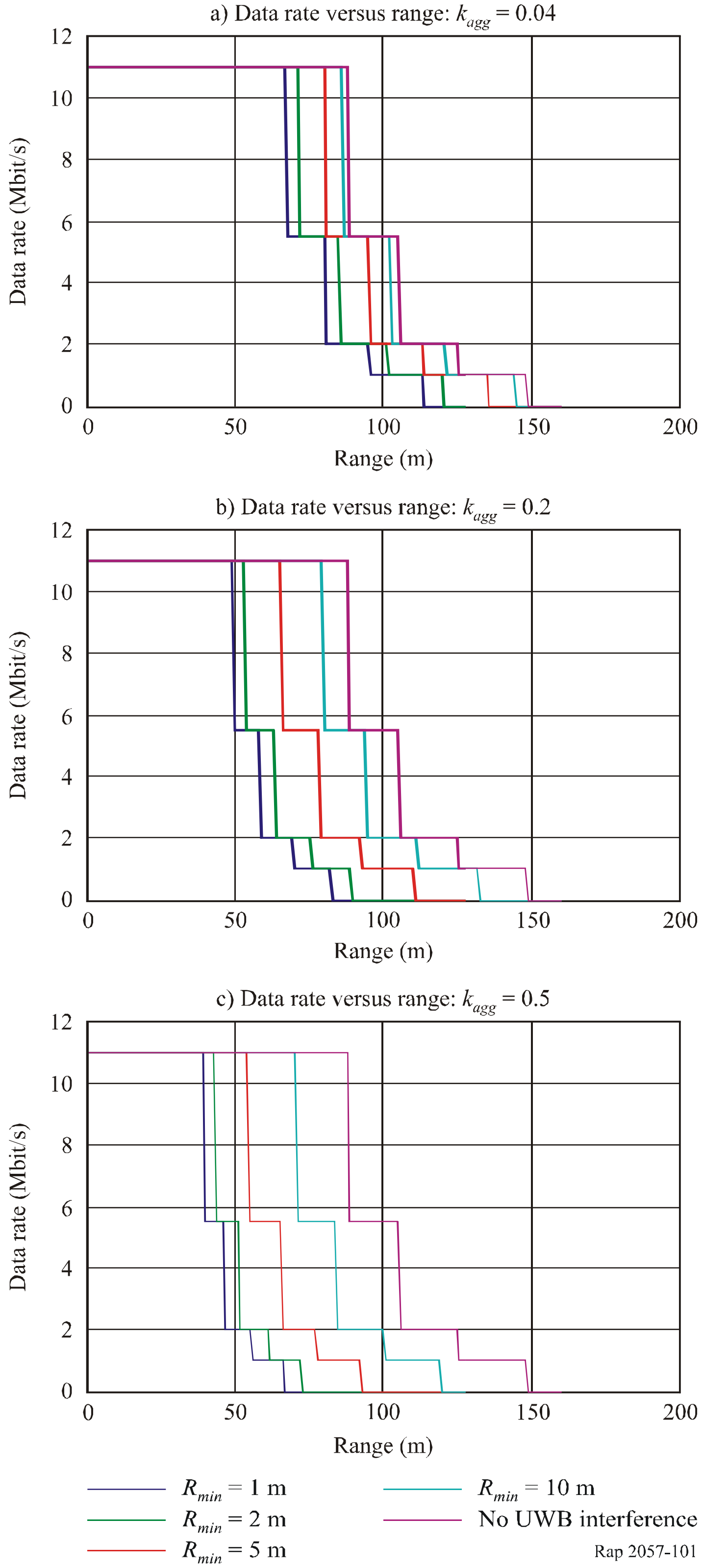
Rap 2057-100

With UWB introduction having a density = 0.2 users/m^2 the S/N for an indoor environment with transmit power = 100 mW for different r_{min} (minimum distance between the victim receiver and the first UWB device) is computed.

The propagation loss used is free-space propagation loss before and inverse fourth power law after the breakpoint value d_0 = 5 m, respectively.

FIGURE 101

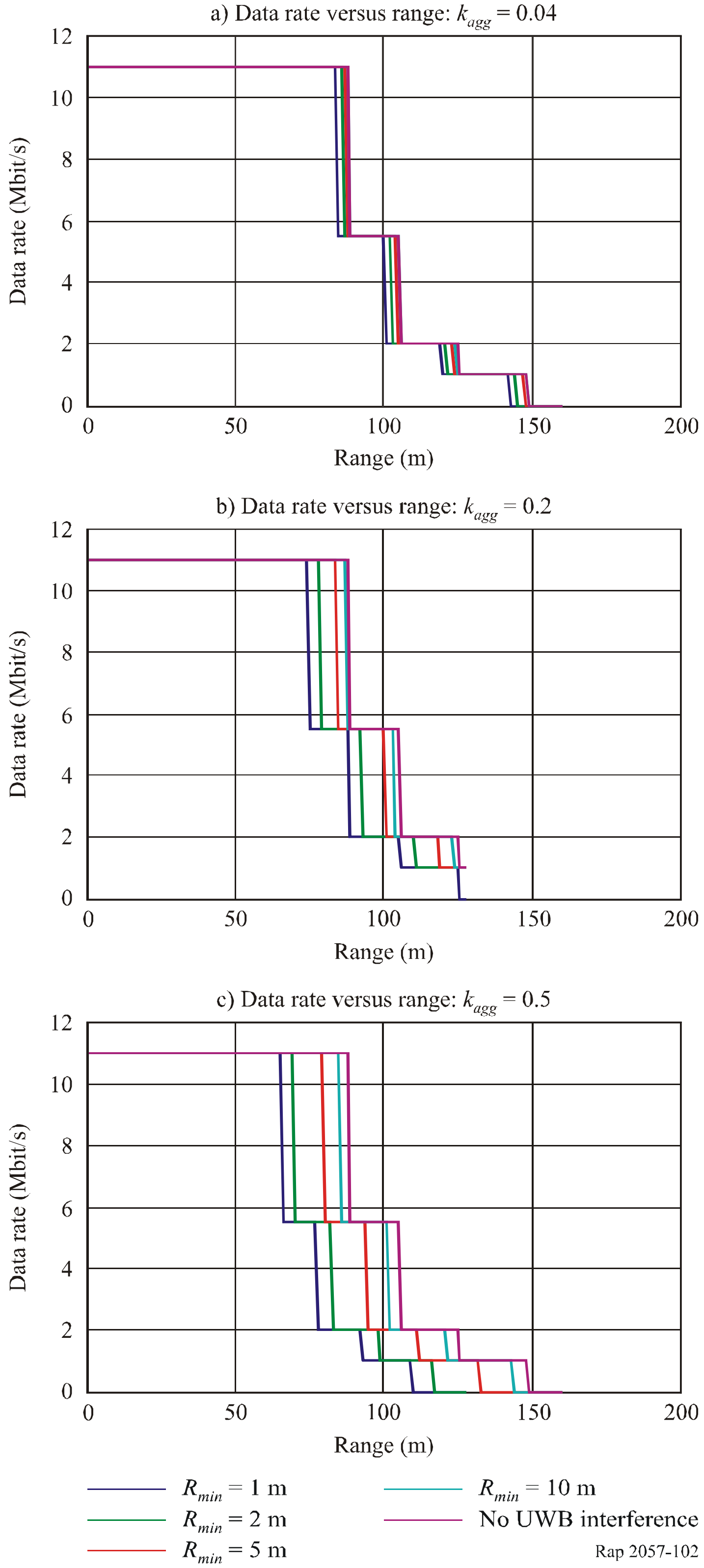
Data rate as a function of range for P_{uwb} = –40.9 dBm



Rap 2057-101

FIGURE 102

Data rate as a function of range for P_{uwb} = –50.9 dBm



b) With proposed European sloped mask: –50.6 dBm/11 MHz indoor, and –60.6 dBm/11 MHz outdoor

FIGURE 103

UWB interference as a function of density and R_{min} for P_{uwb} = –50.6 dBm

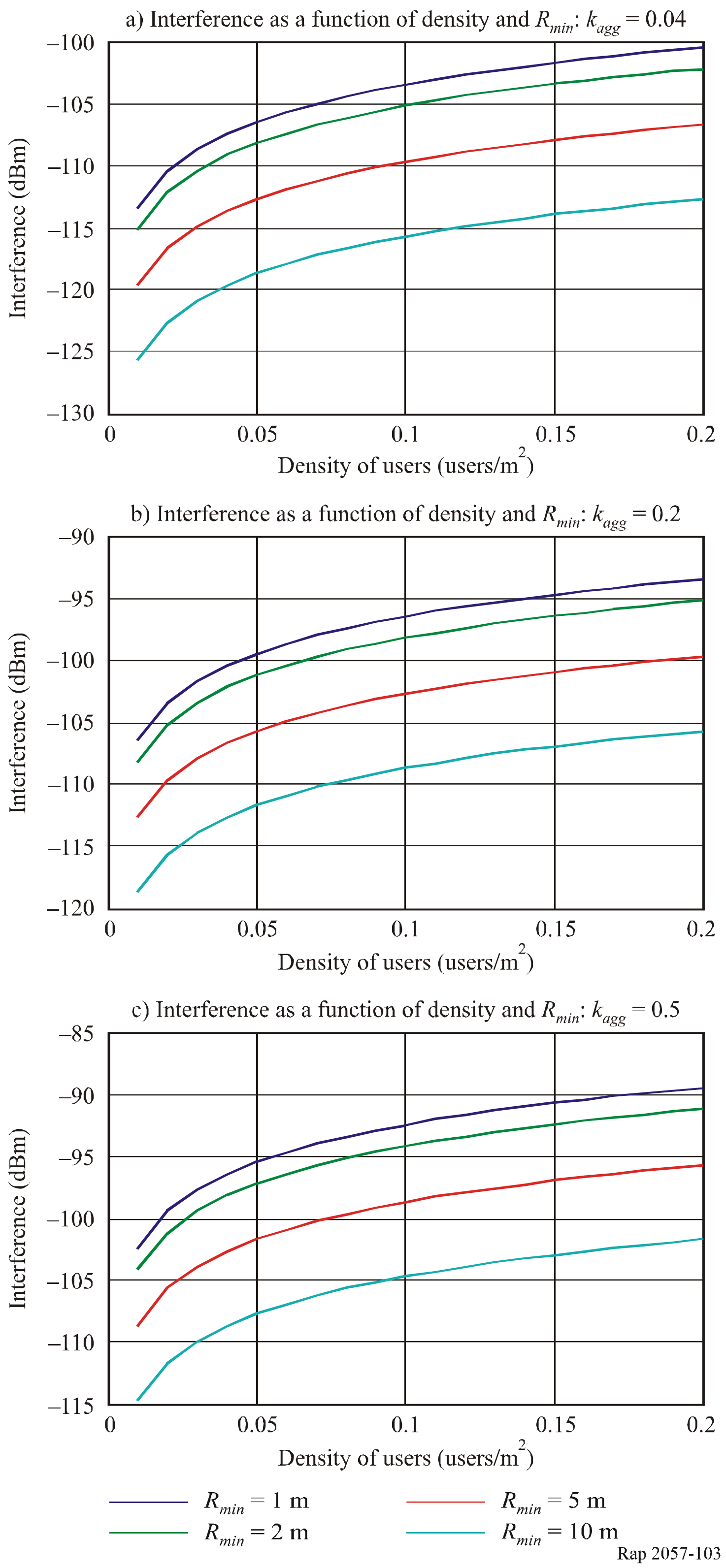
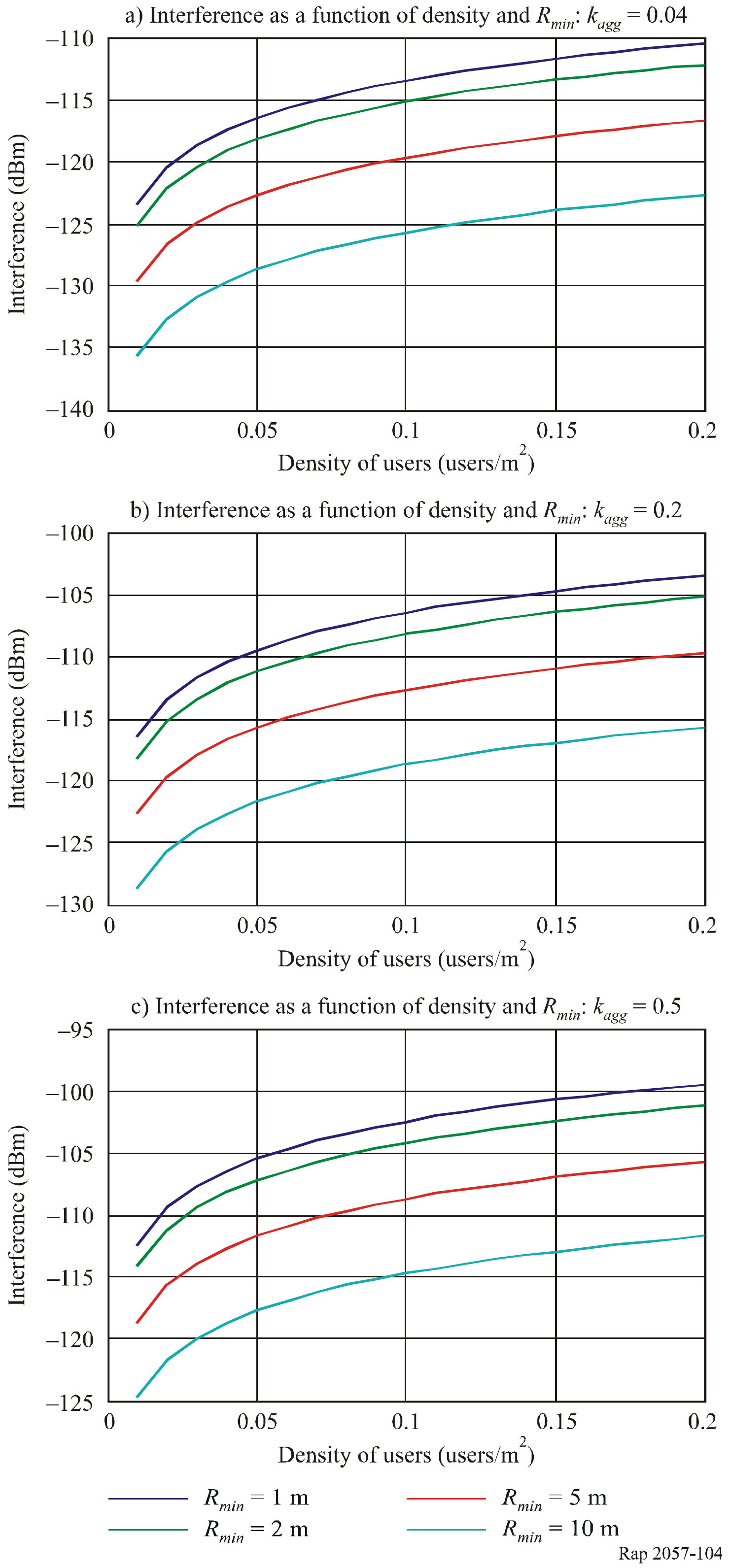


FIGURE 104

UWB interference as a function of density and R_{min} for P_{uwb} = –60.6 dBm



Free-space propagation loss is used before and inverse fourth power law after the breakpoint value d_0 = 5 m, respectively.

FIGURE 105

Single *I*/*N* as a function of range for P_{uwb} = –50.6 dBm

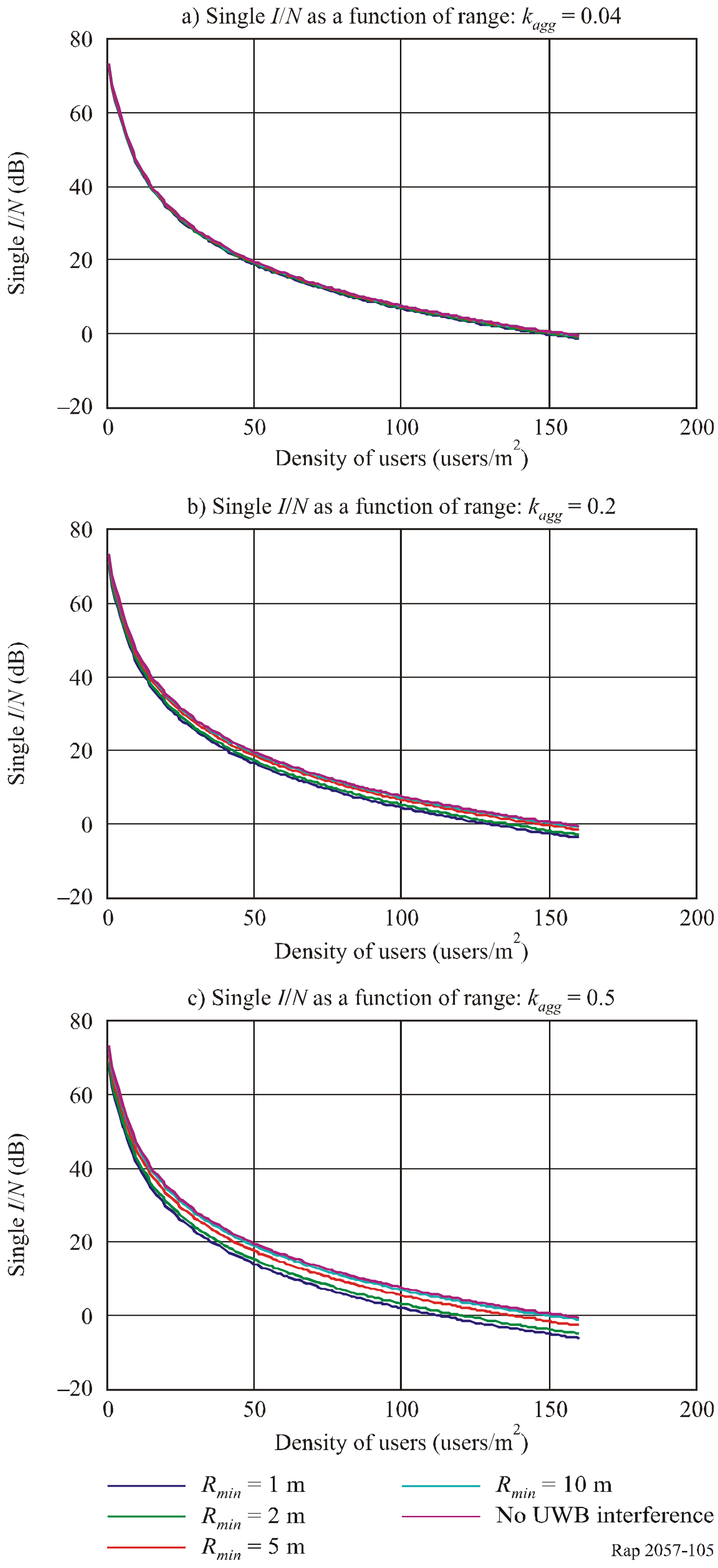
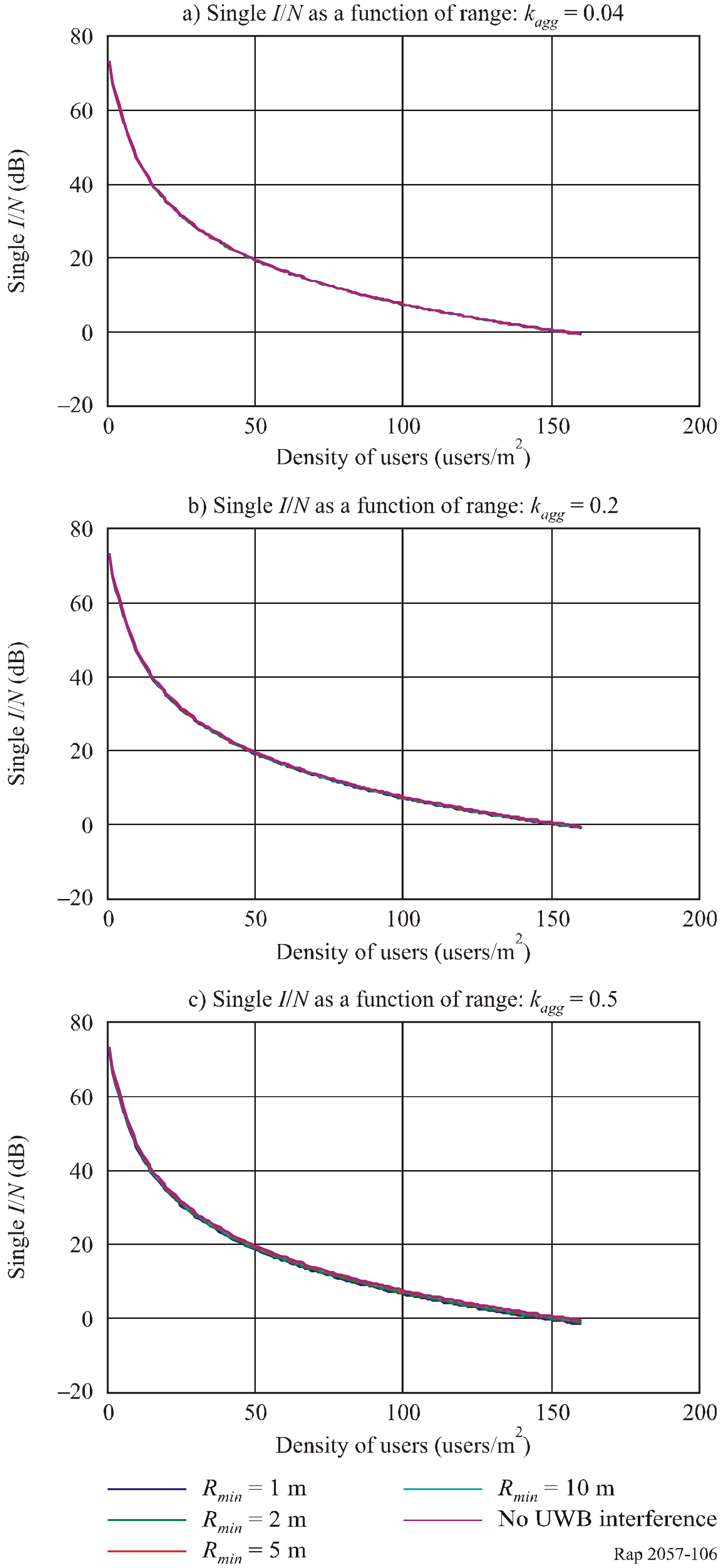


FIGURE 106

Single *I*/*N* as a function of range for P_{uwb} = –60.6 dBm



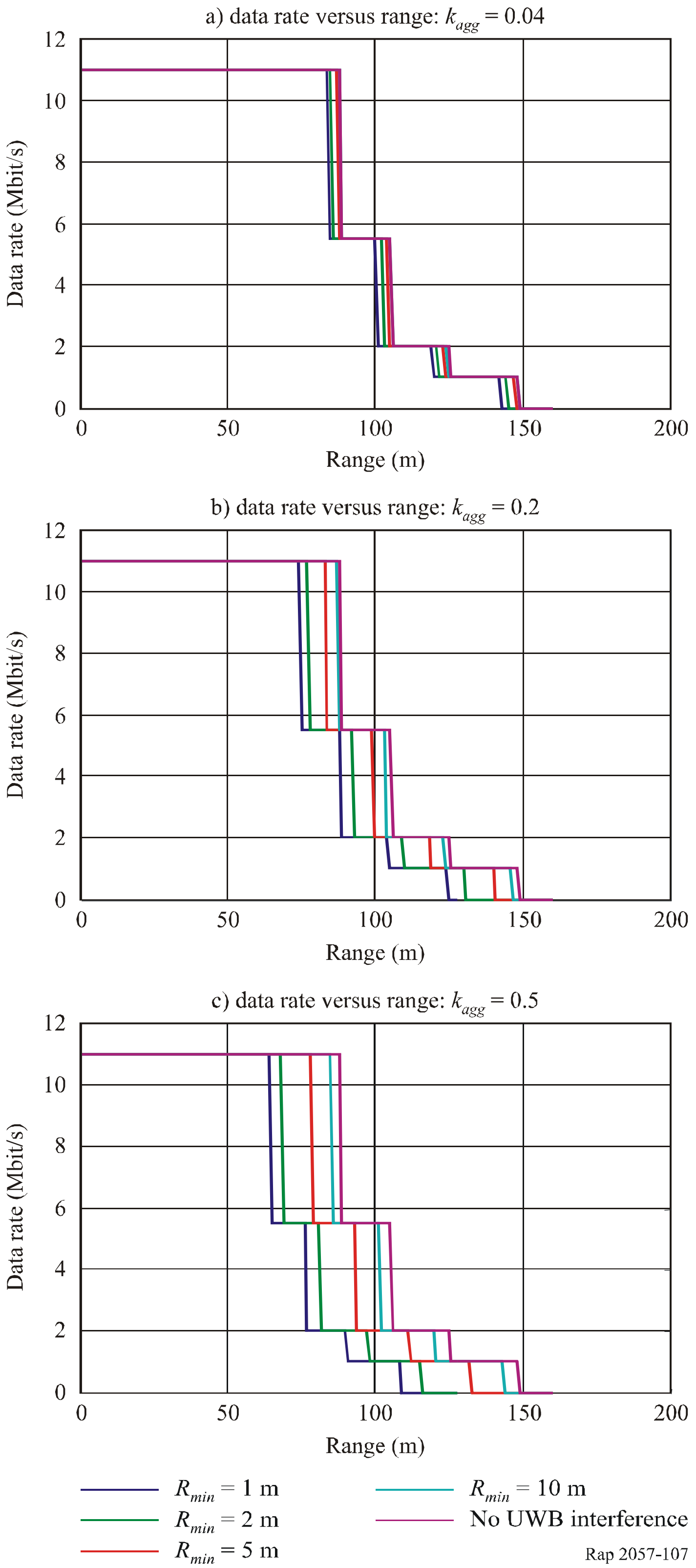
Rap 2057-106

With UWB introduction having a density = 0.2 users/m^2 the Single *I*/*N* for an indoor environment with transmit power = 100 mW for different r_{min} (minimum distance between the victim receiver and the first UWB device) is computed.

The propagation loss used is free-space propagation loss and inverse fourth power law before and after the breakpoint value d_0 = 5 m, respectively.

FIGURE 107

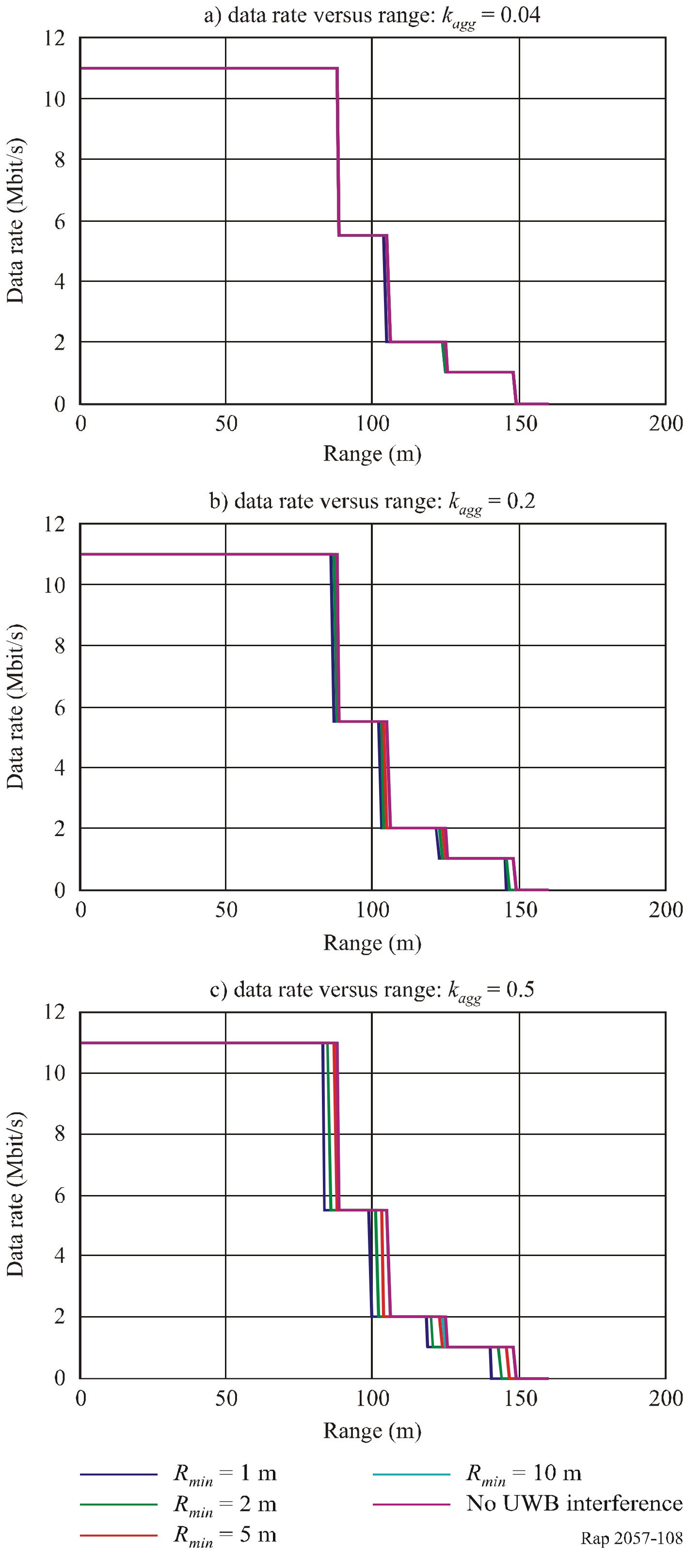
Data rate as a function of range for P_{uwb} = –50.6 dBm



Rap 2057-107

FIGURE 108

Data rate as a function of range for P_{uwb} = –60.6 dBm



This figure gives the coverage with possible data rate as a function of the distance.

5.4.4 UWB density resulting in 1 dB degradation in the S/N

Again, if the protection criteria for RLANs were determined to be a 1 dB degradation in the RLAN S/N, from the calculations below, the permissible received UWB interference at the victim node would be:

$$UWB\ interference(W) = N\left(10^{\frac{M}{10}} - 1\right) \cong 0.25 \times N$$

With N_0 the thermal noise which is equal to –103.6 dBm in the IEEE 802.11b receiver bandwidth (i.e. 11 MHz). The resulting UWB interference, W, and the UWB transmitter density (active users) for a 1 dB degradation in single I/N can be estimated:

$$UWB\ interference = -99.5\text{ dBm}$$

a) With United States mask:

For indoor:

$$\rho = \frac{UWB\ interference}{k_{agg} \times 2\pi \times I(r_{min}, d_0) \times P_{UWB} \times \left(\frac{\lambda}{4\pi}\right)^2} = 0.03\text{ users/m}^2,\ k_{agg} = 0.04$$

$$\rho = \frac{UWB\ interference}{k_{agg} \times 2\pi \times I(r_{min}, d_0) \times P_{UWB} \times \left(\frac{\lambda}{4\pi}\right)^2} = 0.005\text{ users/m}^2,\ k_{agg} = 0.20$$

$$\rho = \frac{UWB\ interference}{k_{agg} \times 2\pi \times I(r_{min}, d_0) \times P_{UWB} \times \left(\frac{\lambda}{4\pi}\right)^2} = 0.002\text{ users/m}^2,\ k_{agg} = 0.50$$

Where $I(r_{min}, d_0)$ is computed with r_{min} = 1 m and d_0 = 5 m. P_{UWB} is the UWB emission limit fixed by the United States in the IEEE 802.11b bandwidth.

For outdoor:

$$\rho = \frac{UWB\ interference}{k_{agg} \times 2\pi \times I(r_{min}, d_0) \times P_{UWB} \times \left(\frac{\lambda}{4\pi}\right)^2} = 0.26\text{ users/m}^2,\ k_{agg} = 0.04$$

$$\rho = \frac{UWB\ interference}{k_{agg} \times 2\pi \times I(r_{min}, d_0) \times P_{UWB} \times \left(\frac{\lambda}{4\pi}\right)^2} = 0.05\text{ users/m}^2,\ k_{agg} = 0.20$$

$$\rho = \frac{UWB\ interference}{k_{agg} \times 2\pi \times I(r_{min}, d_0) \times P_{UWB} \times \left(\frac{\lambda}{4\pi}\right)^2} = 0.02\text{ users/m}^2,\ k_{agg} = 0.50$$

Where $I\ (r_{min}, d_0)$ is computed with r_{min} = 1 m and d_0 = 5 m. P_{UWB} is the UWB emission limit fixed by United States in IEEE 802.11b bandwidth.

b) With proposed European sloped mask (with the same parameters as used in a)):

For indoor:

$$\rho = \frac{UWB\ interference}{k_{agg} \times 2\pi \times I(r_{min}, d_0) \times P_{UWB} \times \left(\frac{\lambda}{4\pi}\right)^2} = 0.26 \text{ users/m}^2,\ k_{agg} = 0.04$$

$$\rho = \frac{UWB\ interference}{k_{agg} \times 2\pi \times I(r_{min}, d_0) \times P_{UWB} \times \left(\frac{\lambda}{4\pi}\right)^2} = 0.05 \text{ users/m}^2,\ k_{agg} = 0.20$$

$$\rho = \frac{UWB\ interference}{k_{agg} \times 2\pi \times I(r_{min}, d_0) \times P_{UWB} \times \left(\frac{\lambda}{4\pi}\right)^2} = 0.02 \text{ users/m}^2,\ k_{agg} = 0.50$$

For outdoor:

$$\rho = \frac{UWB\ interference}{k_{agg} \times 2\pi \times I(r_{min}, d_0) \times P_{UWB} \times \left(\frac{\lambda}{4\pi}\right)^2} = 2.5 \text{ users/m}^2,\ k_{agg} = 0.04$$

$$\rho = \frac{UWB\ interference}{k_{agg} \times 2\pi \times I(r_{min}, d_0) \times P_{UWB} \times \left(\frac{\lambda}{4\pi}\right)^2} = 0.5 \text{ users/m}^2,\ k_{agg} = 0.20$$

$$\rho = \frac{UWB\ interference}{k_{agg} \times 2\pi \times I(r_{min}, d_0) \times P_{UWB} \times \left(\frac{\lambda}{4\pi}\right)^2} = 0.2 \text{ users/m}^2,\ k_{agg} = 0.50$$

5.4.5 Minimum distance with one UWB transmitter

In order to represent the effect of interference from UWB transmitters to IEEE 802.11b devices, it is interesting to consider only one UWB transmitter and estimate the necessary minimum separation distance to degrade the signal by no more than *M* dB. If we consider *M* dB degradation in the *S*/*N*, the maximum UWB interference level will be the following:

$$Power\ received\ from UWB\ transmitter_{r_0} \le N\left(10^{\frac{M}{10}} - 1\right)$$

Together with the path-loss expression given by:

$$N\left(10^{\frac{M}{10}} - 1\right) \ge \begin{cases} P_{UWB}\left(\frac{\lambda}{4\pi r_{MAX}}\right)^2 & d_0 \ge r_{MAX} \\ P_{UWB}\left(\frac{\lambda}{4\pi d_0}\right)^2\left(\frac{d_0}{r_{MAX}}\right)^4 & d_0 \le r_{MAX} \end{cases}$$

The minimum separation:

$$r_{MAX} = \begin{cases} \dfrac{\lambda}{4\pi}\sqrt{\dfrac{P_{UWB}}{N\left(10^{\frac{M}{10}}-1\right)}} & d_0 \geq r_{MAX} \\ \sqrt{\dfrac{d_0\lambda}{4\pi}}\sqrt[4]{\dfrac{P_{UWB}}{N\left(10^{\frac{M}{10}}-1\right)}} & d_0 \leq r_{MAX} \end{cases} \tag{66}$$

Therefore, from equation (66) the minimum separation distance with the current United States limits or proposed European sloped mask and with d_0 = 5 m, we find:

a) With United States mask:

For indoor:

– With 1 dB degradation:

Minimum distance = 5.9 m.

For outdoor:

– With 1 dB degradation:

Minimum distance = 2.2 m.

b) With proposed European sloped mask:

For indoor:

– With 1 dB degradation:

Minimum distance = 2.3 m.

For outdoor:

– With 1 dB degradation:

Minimum distance = 0.7 m.

5.4.6 Maximum possible UWB transmission power in order to have a UWB density of 0.2 users/m²

Similarly to the case of IEEE 802.11a, the maximum permissible transmit power in the IEEE 802.11b band can be computed for a given density. For a given UWB density, taken here as 0.2 user/m^2, the maximum permissible UWB interference power can be determined such that:

$$\rho = \frac{UWB\ Interference}{k_{agg} \times 2\pi \times I(r_{min}, d_0) \times P_{UWB} \times \left(\dfrac{\lambda}{4\pi}\right)^2} \Rightarrow P_{UWB} = \frac{UWB\ Interference}{k_{agg} \times 2\pi\rho \times I(r_{min}, d_0) \times \left(\dfrac{\lambda}{4\pi}\right)^2}$$

(67)

Therefore, from equation (67), for a 1 dB decrease in the single I/N we obtain:

P_{uwb} = –60.1 dBm/MHz for k_{agg} = 0.04

P_{uwb} = –67.1 dBm/MHz for k_{agg} = 0.20

P_{uwb} = –71.1 dBm/MHz for k_{agg} = 0.50

5.4.7 Summary IEEE 802.11b

For the analysis the two-slope propagation model (r^{-2}, r^{-4}) is used with the breakpoint 5 m and assuming that within 1 m around the victim no UWB device is deployed.

For a single *I*/*N* degradation of 1 dB in the mobile terminal and applying the current United States emissions limits and the proposed European sloped mask, the following minimum separation distances are required:

Indoor:	5.9 m using the United States mask	2.3 m using the sloped mask
Outdoor:	2.2 m using the United States mask	0.7 m using the sloped mask.

Assuming a UWB density of 0.2 user/m², the maximum permissible UWB interference power and a single *I*/*N* degradation of 1 dB, then the maximum possible UWB transmissions power density results in:

–60.1 dBm/MHz	for the aggregation factor 0.04
–67.1 dBm/MHz	for the aggregation factor 0.20
–71.1 dBm/MHz	for the aggregation factor 0.50.

The aggregation factor takes into account the effect of multiple devices, the average activity factor and the victim immunity factor but not the UWB density.

5.5 Interference distances for IEEE 802.11a derived from measured *C*/*I*

This section discusses 5 GHz RLANs and the impact of UWB interference on the these RLANs. HIPERLAN/2 and IEEE 802.11a are two different standards for RLAN systems that operate in the 5 GHz band.

The 802.11a standard has been modified and resulted in the 11h extension. This includes functions such as DFS and transmitter power control (TPC) which enables equipment to be used over all of the available bands in 5 GHz. The impact of peak power UWB emission on the DFS is estimated.

5.5.1 Description of measurement of *C*/*I* for RLAN tolerable

The HIPERLAN/2 standard focuses on the MAC and PHY protocols for access point based networks. HIPERLAN/2 uses the same OFDM modulation as 802.11a and data rates in the range 6-54 Mbit/s, however HIPERLAN/2 uses a slightly other set: 6, 9, 12, 18, 27, 36 and 54 Mbit/s, where 802.11a has 6, 9, 12, 18, 24, 36, 48 and 54 Mbit/s. Further, the HIPERLAN/2 MAC structure is fully different from the 802.11 one. The HIPERLAN/2 MAC is based on fixed 2 ms (MAC) frame structure and centralized control by the access point. Some intervals within the 2 ms frames are assigned for the access control function.

The IEEE 802.11a receiver sensitivities are based on a reference model with 15 dB degradation (due to the noise factor and system degradation). Table 66 shows the receiver sensitivities as specified by the HIPERLAN/2, IEEE 802.11a standard.

TABLE 66

5 GHz RLAN receiver sensitivity at different data rates

Data rate (Mbit/s)	HIPERLAN/2(1) (dBm)	IEEE 802.11a(2) (dBm)
6	–85	–82
9	–83	–81
12	–81	–79
18	–79	–77
24	Not available	–74
27	–75	Not available
36	–73	–70
48	Not available	–66
54	–65	–65

(1) HIPERLAN Type 2, ETSI TS 101 475 V.1.1.1 (2000-4), § 5.11.3.1: 10% error rate for 54 byte PDUs.

(2) IEEE Std802.11a-1999 (ISO/IEC 8802:1999/Amd 1:2000(E)), § 17.3.10.1: 10% error rate for 1000 byte PSDUs.

The tolerable *C*/*I* levels for RLAN victims and UWB interference were measured with respect to a frame error rate of 10% (@ 1 500 byte frames). The 10% frame error rate criterion is close the error criterion as used with the IEEE 802.11a standard to specify the receiver sensitivity. HIPERLAN/2 uses a criterion based on smaller frame size.

Recommendation ITU-R M.1739 – Protection criteria for wireless access systems, including radio local area networks, operating in the mobile service in accordance with Resolution 229 (WRC-03) in the bands 5 150-5 250 MHz, 5 250-5 350 MHz and 5 470-5 725 MHz indicates that for WAS/RLAN protection the *I*/*N* of –6 dB at the WAS/RLAN receiver should not be exceeded, assuring that the degradation to a WAS/RLAN receiver's sensitivity will not exceed approximately 1 dB. This criterion corresponds to the tolerable *C*/*I* measured and used in this section further on.

For the relevant calculations, the *C*/*I* values for 5 GHz RLAN victims are given in Table 67.

TABLE 67

Measured *C*/*I* level for 5 GHz RLAN with UWB interference

Data rate (Mbit/s)	Modulation and coding rate	Tolerable *C*/*I* (dB)
6	BPSK, 1/2	6 dB
9	BPSK, 3/4	9 dB
12	QPSK, 1/2	9 dB
18	QPSK, 3/4	10 dB
24	16-QAM, 1/2	13 dB
27		Not available
36	16-QAM, 3/4	–
48	64-QAM, 2/3	–
54	64-QAM, 3/4	26

These laboratory measurements were made conducted using IEEE 802.11a RLAN devices and the UWB transmitter. RLAN configurations for both infrastructure and ad hoc are considered.

RLAN infrastructure:

As shown in Fig. 109 the AP (access point) that is connected by Ethernet to a 1st laptop, has a wireless connection to nearby horn antenna. The AP has a patch antenna in its top, the nearby horn antenna is directed to it. From the horn antenna a cable connection outside the isolation cabinet goes through splitters to the device under test: the adapter card in the 2nd laptop. The adapter card has been modified by disconnecting (desoldering) the two integrated antennas and connecting two cables with SMA connectors. These two connectors go through two 10 dB attenuator blocks to a splitter.

The unwanted signal from the UWB transmitter was injected through the splitter, after some control stages, to get a variable *C*/*I* level for the device under test (adapter card in 2nd laptop). The signal from the UWB transmitter is fed to a wideband amplifier and next to a mixer that introduces a drop in level. The mixer allows timed control by the ON/OFF behaviour of the pulse generator.

RLAN ad hoc:

As shown in Fig. 109 a second RLAN adapter card in a 3rd laptop was used. For this second adapter the same approach with cables replacing the antenna connections is followed as described above for the device under test.

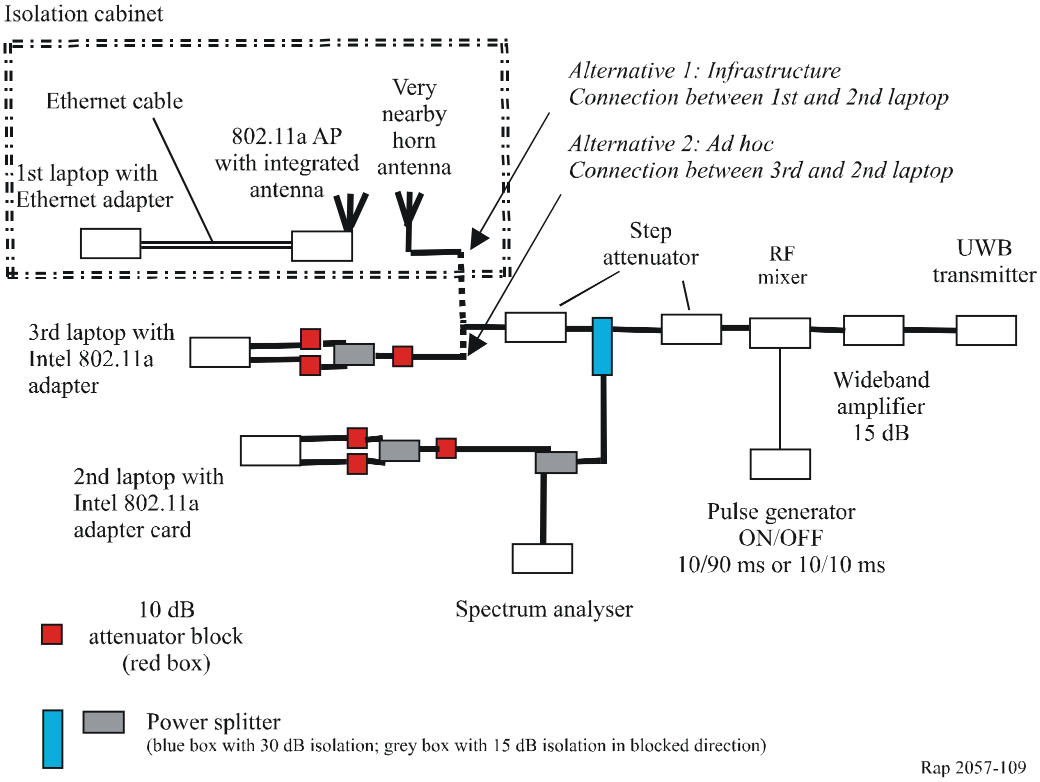
The traffic behaviour can be observed to and from the device under test by the spectrum analyser. This analyser shows in zero-span mode, 10 MHz RBW, centre frequency equal to channel in use (5.18 and 5.26 GHz) the levels during transmission of payload and ACK (acknowledgement) frames. When the frame transmission is evoked by a file transfer we observe the payload frames that are followed after a very short gap by an ACK frame. The presence of ACK frames from the device under test show if it has received payload frames correctly.

Intervals are observed only during which the mixer forwards the UWB signal. The timed ON/OFF behaviour prevents hang-up situations for the (TCP) connection between the two computers because of a sufficiently long period without interference and recovery.

Fixed IP addresses are used for the computers because there is no (DHCP) server present. The frame traffic is evoked by the ping command (infrastructure) and a LANMark throughput test application (ad hoc).

FIGURE 109

Test configuration



The on-airtime refers only to the burst measurement mode of the pulse generator. The PRF, within the on-airtime, of the UWB transmitter.

Observations for ad hoc: The LANMark test application allows transmission of larger sizes. Longer periods are got now to observe by up and down copying a 3 Mbyte file. Therefore, it is easier to display on the spectrum analyser the relevant information. Here below, only the results are given which were found with ad hoc because the device under test is the same as with infrastructure.

The used UWB interference levels are around of –78 dBm at the device under test input because of practical constraints to evaluate the impact of the interference with varied level. This level corresponds to a level of –55 dBm/10 MHz at the spectrum analyser due to a difference in bandwidth (+2 dB; 16.5 MHz vs. 10 MHz) and a difference in attenuation (–25 dB; 2 blocks of 10 dB, 3.5 dB in the splitter's forward path and some extra cable and connector loss). The output level for the 5 GHz frequencies in question is somehow under the United States limits (–41.2 dBm/MHz) and around –35 dBm/10 MHz.

Table 67 shows the measured required *C*/*I* for the various data rates. The receive level are also given.

Table 68 gives background data on the RLAN 802.11a frame transmission times. The payload frames are 1 500 byte (~ Ethernet). These transmission times are calculated and quickly verified during the evaluation.

Table 66 shows the RLAN receiver sensitivity according the 802.11a standard and the corresponding theoretical *S*/*N*. The 802.11a standard is based on the theoretical required *S*/*N*, a noise factor of 10 dB and a system degradation of 5 dB at any rate. (NOTE – In nowadays practical design the noise factor might be a few dB better and the system degradation will be data rate dependent, better at 6 Mbit/s worse at 54 Mbit/s.)

In Table 68 the measured *C*/*I* values as given in Table 67 are added.

The measurement evaluation of the tolerable *C*/*I* was for practical reasons based on observing the percentage of non-ACK-ed frames around 10% (BER ~ 10^{-5}). Sometimes measurement around a 10% frame error rate was not well reproducible and dependent on the receive level.

The measurement evaluation was based receive levels to measure the *C*/*I* were largely above the minimum usable sensitivity (MUS) or receiver sensitivity as specified in the 802.11a standard. These applied receive levels were from 7 dB above MUS @ 6 Mbit/s to 15 dB above MUS @ 54 Mbit/s. Thus, these were around the often used MUS + 10 dB.

TABLE 68

Measured tolerable *C*/*I* for an RLAN 802.11a link in presence of UWB interference

Data rate (Mbit/s)	RLAN receive level at DUT (laptop) (dBm/16.5 MHz)	RLAN receive level at spectrum analyser (dBm/10 MHz)	UWB interference level at spectrum analyser (dBm/10 MHz)	Measured *C*/*I* resulting in about 10% frame errors (~ BER 10^{-5}) (dB)
6[(1)]	–75	–52	–58	6
9	–72	–49	–58	9
12	–72	–49	–58	9
18	–71	–48	–58	10
24 [(2)]	–65	–42	–55	13
48 [(3)]	–	–	–	–
54	–52	–29	–55	26

(1) Some other measurements at higher receive level showed a higher *C*/*I* required.

(2) Some other measurement at a higher receive level showed a higher *C*/*I* required.

(3) There have not been found stable results for this data rate.

TABLE 69

Transmission time of 802.11a frames at different data rates
(by calculation and verified on the spectrum analyser)

Data rate (Mbit/s)	Transmission time of 1 500 byte frame 20 + (34 + 1 500) *8/rate (μs)	Transmission time of ACK 20 + 14*8/rate (μs)
6	2 065	40
9	1 385	37
12	1 045	30
18	702	28
24	532	25
36	362	24
48	276	24
54	248	22

TABLE 70

RLAN 802.11a receiver performance

Data rate (Mbit/s)	Receiver sensitivity according to 802.11a Std. (dBm)	Modulation and coding rate	Theoretical *S/N* (dB)	Measured *C/I* resulting in about 10% frame errors (~ BER 10^{-5}) (dB)
6	–82	BPSK, 1/2	5	6
9	–81	BPSK, 3/4	6	9
12	–79	QPSK, 1/2	8	9
18	–77	QPSK, 3/4	10	10
24	–74	16-QAM, 1/2	13	13
36	–70	16-QAM, 3/4	17	24
48	–66	64-QAM, 2/3	21	–
54	–65	64-QAM, 3/4	22	26

5.5.2 Interference distance for UWB interference to R-LAN

In the following, we determine the interference distance for UWB interference to different R-LAN systems. The first step of the procedure used to estimate the distance is to calculate the minimum coupling loss (MCL) based on the sensitivity P_{RX} and the C/I value of the different victim receivers on the one side and the UWB radiated power density $P_{UWB-RAD}$ on the other side.

$$MCL = P_{UWB-RAD}/\text{MHz} + 10 \log BW_{victim} - P_{RX} + C/I$$

where:

$P_{UWB-RAD}$: radiated power density inside the victim bandwidth BW_{victim}

P_{RX}: victim receiver sensitivity as given in Table 69

C/I: measured carrier to interference ratio as given in Table 69.

For the UWB radiated power density $P_{UWB-RAD}$, the flat limit –41.3 dBm/MHz is considered corresponding to the United States mask.

The second step is then to convert the MCL into the interference distance by using an appropriate propagation model. In the following we will consider purely indoor scenario that means UWB and the R-LAN victim systems are both indoor. The propagation models considered are free-space and Recommendation ITU-R P.1238-2. The worst-case situation is considered where UWB-interferers and victims are operated at the same floor of an office building. An additional attenuation can be inserted in the case where the systems operate at different floors. Finally, for all systems omni-directional antennas with 0 dBi gain are assumed. The UWB antenna height is set to 1.5 m. The different characteristics and parameters of the R-LAN victim used for the calculation are given in Table 71 together with the calculated interference distances.

TABLE 71

Measured interference from UWB to R-LAN

Victim operating mode	6 Mbit/s BPSK 1/2	9 Mbit/s BPSK 3/4	12 Mbit/s QPSK 1/2	18 Mbit/s QPSK 3/4	24 Mbit/s 16-QAM 1/2	54 Mbit/s 64-QAM 3/4
Frequency (MHz)	5 250	5 250	5 250	5 250	5 250	5 250
Victim MUS (dBm)	–82.0	–81.0	–79.0	–77.0	–74.0	–65.0
Bandwidth (MHz)	16.500	16.500	16.500	16.500	16.500	16.500
Antenna height (m)	2.0	2.0	2.0	2.0	2.0	2.0
Building attenuation, indoor – outdoor (dB)	15.0	15.0	15.0	15.0	15.0	15.0
Building attenuation, indoor or outdoor (dB)	0.0	0.0	0.0	0.0	0.0	0.0
N, distance power loss coefficient (Rec. ITU-R P.1238)	31.0	31.0	31.0	31.0	31.0	31.0
Proposed UWB spectrum masks:						
– indoor (dBm/MHz)	–41.3	–41.3	–41.3	–41.3	–41.3	–41.3
– outdoor (dBm/MHz)	–41.3	–41.3	–41.3	–41.3	–41.3	–41.3
Measured C/I (dB)*:*	6	9	9	10	13	26
MCL for victim receiver at MUS (dB), indoor	58.9	60.9	58.9	57.9	57.9	61.9
MCL for victim receiver at MUS (dB), outdoor	58.9	60.9	58.9	57.9	57.9	61.9
MCL for victim receiver at MUS +10 dB, (dB), indoor	48.9	50.9	48.9	47.9	47.9	51.9
MCL for victim receiver at MUS +10 dB, (dB), outdoor	48.9	50.9	48.9	47.9	47.9	51.9
Free-space propagation model:						
Protection distance at MUS (m) indoor	4.01	5.05	4.01	3.58	3.58	5.67
Protection distance at MUS +10 dB, (m), indoor	1.27	1.60	1.27	1.13	1.13	1.79
Rec. ITU-R P.1238 propagation model, indoor:						
Protection distance at MUS (m)	2.53	2.93	2.53	2.34	2.34	3.16
Protection distance at MUS +10 dB, (m)	1.20	1.39	1.20	1.12	1.12	1.50

The results in Table 71 are derived from measurements with IEEE 802.11a equipment. The free-space propagation model corresponds to the two-slope model up to about 5 m. For information only, the NLoS indoor model given in Recommendation ITU-R P.1238 was used which resulted in a reduction of the separation distances by the factor two. Taking into account the slightly larger receiver sensitivity for HIPERLAN/2 (up to 3 dB depending on the data rate) larger interference distances may be expected.

5.5.3 Impact of peak power UWB emission on DFS mechanisms

DFS and TPC have been developed in order to enable sharing between RLANs and the other services using the 5 GHz band. The objective of using DFS is to provide adequate protection to radar use in the 5 GHz band within the existing primary allocations to the radiodetermination services. This is achieved by avoiding the use of, or vacating, a channel identified as being occupied by radar equipment based on detection of radar signals above a defined receiver threshold.

It is surmised that as the DFS performance requirements are stated in terms of response to detection of an interfering radar signal, a strong enough pulsed UWB signal may cause the DFS mechanism to trigger a false alarm. Such a false alarm could be potentially disastrous, since the pulsed UWB signal could overlap many or possibly all of the available RLAN channels, causing them all to be triggered as “not available”. This could either severely restrict the channels available for RLAN networks or possibly in the worst case close down the RLAN networks for at least 30 min.

In the bands 5 250-5 350 MHz and the bands 5 470-5 725 MHz the DFS mechanism should be able to detect interference signals above a minimum DFS detection threshold of –62 dBm for RLAN devices with a maximum e.i.r.p. < 200 mW and –64 dBm for all other devices with a maximum e.i.r.p. < 1 W[39] averaged over 1 µs. Figures for DFS in fixed networks using the 5 725-5 875 MHz band are yet to be determined but due to the higher power systems being proposed they may end up with a DFS threshold level lower than −64 dBm. DFS detection threshold is defined as the received signal strength (RSS) (dBm), normalized to the output of a 0 dBi receive antenna, which is required to be detected within the RLAN channel bandwidth.

In the following, the DFS detection threshold considered is therefore set to the minimum value of –64 dBm in a RLAN channel and the peak power level of UWB emission to avoid the risk to have false alarm or to trigger DFS mechanism in RLAN applications is calculated. Two levels of detection threshold are considered to evaluate peak power of UWB emission. First value is –64 dBm extract of Recommendation ITU-R M.1652 and the second value is an assumption made to be sure to detect systems operating in the radiolocation service taking into account 6 dB margin.

The separation distance between the RLAN device and the UWB is assumed by 36 cm.

Values considered in Table 72 are:

– Threshold detection: −64 dBm, −70 dBm.

– Free-path loss at 36 cm giving 37.5 dB at 5 GHz.

– Bandwidth of WAS: 20 MHz.

– Bandwidth of UWB: 500 MHz.

TABLE 72

DFS level of sensitivity to UWB peak power

Threshold detection for RLAN (dBm)	–64	–70
Path loss at 36 cm (dB)	37.5	37.5
Factor correction 10 log (B_{was}/B_{uwb}) (dB)	–14	–14
UWB peak power (dBm)	–40.5	–46.5

[39] In practice, it may not be necessary for each device to implement full DFS functionality, provided that such devices are only able to transmit under the control of a device that ensures that all DFS requirements are fulfilled.

From Table 72 it can be seen that if the peak power of UWB devices is limited below −46.5 dBm in 20 MHz then the detection threshold seen at an RLAN receiver 36 cm away should be less than −70 dBm.

In addition, Recommendation ITU-R M.1652 contains a table of radar parameters that the RLAN DFS mechanism should be able to recognize, for example a range of radar PRF values between 200 to 3 000 Hz are shown. If UWB devices were to avoid using similar characteristics such as these PRF values in their implementations for products that will operate across the 5 GHz RLAN bands then the likelihood of a false alarm being triggered in an RLAN by its DFS mechanism could be reduced significantly.

5.5.4 Implementation of DFS mechanism in RLAN devices

The description of testing the DFS mechanism presented in this section refers to the latest version of the ETSI standard EN 301893. The presentation is done only for RLAN devices in service monitoring and consider that preamble to operate in this channel has been verified.

During in-service monitoring, radar emissions can occur at any time in any channel used by RLAN and in this case, RLAN devices shall stop all transmissions in the channel (see Fig. 110). The type of radar emission depends on element chosen in Table 73 which it is representative of most radar equipment.

FIGURE 110

Example of timing for radar testing during in-service monitoring

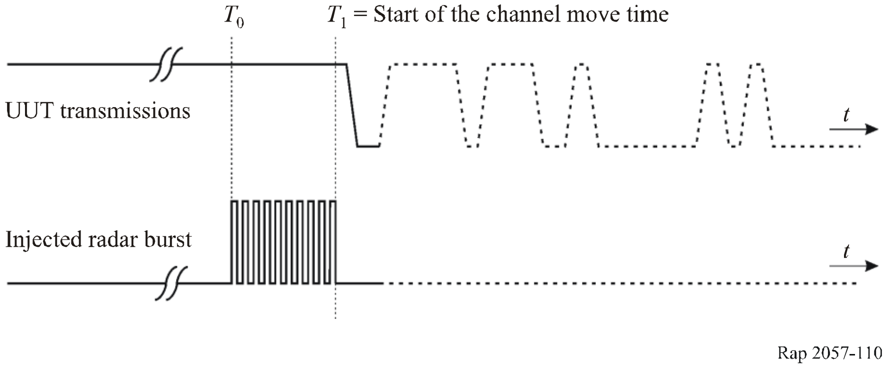


TABLE 73

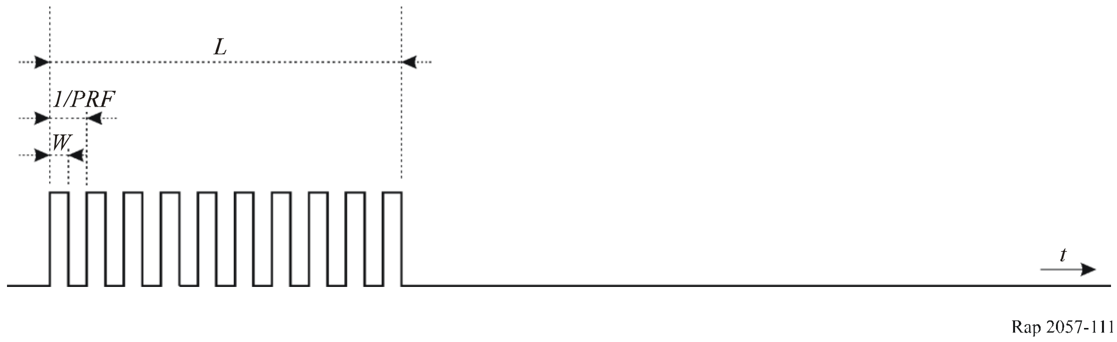
Parameters of DFS test signals

Radar test signal	Pulse width, *W* (µs)	Pulse repetition frequency, *PRF* (pps)	Pulses per burst *L*	Detection probability with 30% channel load
1 – Fixed	1	750	15	P_d > 60%
2 – Variable	1, 2, 5	200, 300, 500, 800, 1 000	10	P_d > 60%
3 – Variable	10, 15	200, 300, 500, 800, 1 000	15	P_d > 60%
4 – Variable	1, 2, 5, 10, 15	1 200, 1 500, 1 600	15	P_d > 60%
5 – Variable	1, 2, 5, 10, 15	2 300, 3 000, 3 500, 4 000	25	P_d > 60%
6 – Variable modulated	20, 30	2 000, 3 000, 4 000	20	P_d > 60%

Figure 111 describes most in detail how radar parameters are interpreted by DFS mechanism. It appeared that the PRF parameter is a factor which could be used to detect radar emissions.

FIGURE 111

General structure of single burst DFS test transmission



In fact, other mechanism could be performed to detect radar emission not only based on PRF parameters but also on peak power detection.

These two elements will be performed on impact of uwb emission in DFS mechanism.

5.5.5 Analysis of DFS mechanism with UWB emissions

UWB technology presents different type of modulation which are pulsed, MB OFDM and DS CDMA. However, whatever the UWB technology used, it appears always some streak line in spectrum. These streak lines come from impulse data or carriers. Although, DFS mechanism is defined by manufacturer, it is far to consider two assumptions to clarify the risk of false alarm from UWB emissions.

The first assumption is to look at the PRF implication and the second is the detection of peak power.

The UWB technology studied indicates that PRFs used by UWB devices are from 0.1 to 200 MHz.

These values are greater than those considered in the radar parameter which range goes from 0.2 to 4 kHz. However, the implementation of DFS mechanism should be able to control the number of pulse in order to identify a real radar emission and to ignore UWB emission. So, it seems very complex to develop this type of specification when a set of parameters must be covered to qualify devices.

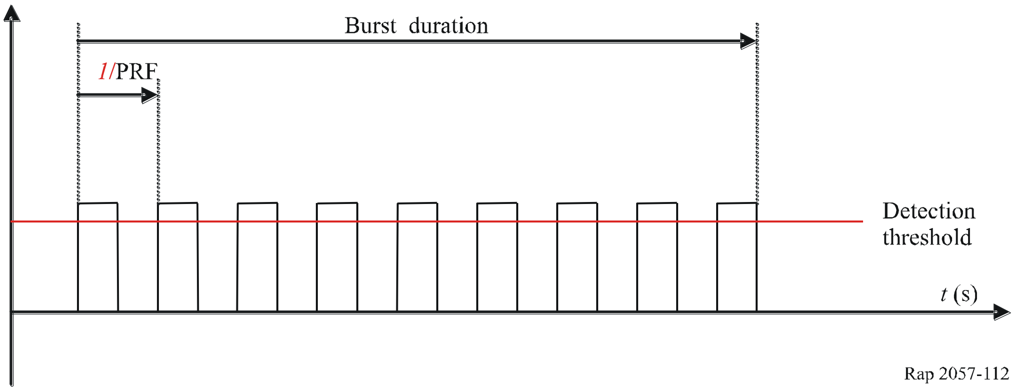
Probably, manufacturers have developed a system of detection probability based on time period of transmission. Two elements can be relevant for detection probability:

– the number of spectral line having reached detection threshold,

– all emission above detection threshold.

FIGURE 112

Pulse visible during burst duration



The value of PRF can increase or decrease the number of pulse during burst duration (see Fig. 112). In Table 74, it shows typical radar PRF and typical UWB PRF.

TABLE 74

Comparison of number of pulse seen by RLAN devices

Typical Radar PRF	**Typical UWB PRF**	**Number of pulse during burst duration**
200 Hz	100 kHz	R: 10 to 20(1) U:25(2)
500 Hz	1 MHz	R: 10 to 20 U:254
750 Hz	5 MHz	R: 10 to 20 U:1270
1 kHz	100 MHz	R: 10 to 20 U:2540
4 kHz	200 MHz	R: 20 to 25 U:5080

(1) Radar R: Number of pulse during burst time is indicated in Table 73.

(2) UWB U: Number of pulse is considered with a burst time 254 µs corresponding to super frame 65 ms/256 burst.

Looking at Table 74, the number of pulse per second during burst duration is very different when PRF exceeds 1 MHz. However, it does not mean that there is not influence on the DFS mechanism. So, two assumptions are made to understand the risk of false alarm created by UWB emission.

5.5.5.1 Number of pulse of detection

In order to evaluate the false alarm risk due to UWB, we simulate principal characteristics of UWB emissions and we compute the DFS. In this section, the number of pulse is simulated and in the next section, the PRF is simulated.

Under the assumption that the number of pulse Y obey a Poisson distribution :

$$P(Y = k) = \frac{\lambda^k .\ e^{-\lambda k}}{k!}$$

As an example, the parameter λ is considered to be equal to 4. This choice is also based on the preceding considerations and on UWB emissions observation, the parameter λ will be set on 4. Y varies from 1 to 10. The simulations of the Poisson distribution are done in the same period. The result in the Table 75 shows the probability that event can be reproduced.

TABLE 75

Poisson distribution

X	Y	Probability of DFS detection
4	1	0.09
4	2	0.24
4	3	0.43
4	4	0.63
4	5	0.79
4	6	0.89
4	7	0.95
4	8	0.98
4	9	0.99
4	10	1

Furthermore, this example shows that an event can be reproduced and as far as the pulse number detecting in window time is reached. In this case, UWB emission can be compared at this event and due to this fact to create false alarm.

5.5.5.2 Threshold detection

The principle of threshold detection is to measure all emissions above the threshold level (y) defined to protect the radar service. In this case, DFS mechanism captures emissions during burst duration and decides to free used channel when an emission is detected above the threshold level because of a possible radar emission.

This type of DFS mechanism is very simplified but it ensures a great performance of detection and protection of radar service. Through this example, an estimation of detection probability is evaluated in order to obtain a detection probability above 0.6 as mentioned in Table 73.

Prob detection (x<limit threshold) = (x<limit threshold; p(y);limit lower; limit higher).

TABLE 76

Probability to reach limit threshold

X<limit threshold	Estimation of probability detection p(Y)
–62	0.35
–64	0.5
–60	0.1
–66	0.05
Formula	**Description (result)**
0.5	Probability that *x* was at –64 (0.5)
0.85	Probability that *x* was between –64 and –62 (0.85)

This analysis shows that if RLAN devices implement only a detection system based on the threshold limit, in this case all emission will be treated by a DFS mechanism. No distinction will be done and it will lead to increase drastically the false rate error.

5.5.6 Summary

The 5 GHz RLANs operate at frequency bands for which the different UWB emission masks give all the same limit of –41.3 dBm/MHz. Therefore, the 5 GHz RLAN victim systems are subjected to co-channel interference and the different emission masks (–41.3 dBm/MHz flat limit, United States UWB limits) lead to equal interference distances per considered data rate. These data rates of 6, 9, 12, 18, 24, 36 and 54 Mbit/s that use OFDM modulation with respectively BPSK-1/2 (1/2 code rate), BPSK-3/4, QPSK-1/2, QPSK-3/4, QAM16-1/2, QAM16-3/4, QAM64-3/4, apply the same channel bandwidth.

Although the tolerable *C*/*I* is different per data rate, the interference distances of different data rates are for each path-loss model in the same order of magnitude, because the receiver sensitivity is also data rate dependent.

The interference distances are, for Free-space indoor: with Maximum Usable Sensitivity (MUS) "3.6 – 6.0 m" and with MUS +10 dB "1.1 – 2 m"; for Recommendation ITU-R P.1238 indoor: with MUS "2.3 – 3.2 m" and with MUS +10 dB "1.1 – 1.5 m". Thus, when an active UWB device is within a distance of 6.0 m we can expect RLAN receiver desensitizing and fallback in data rate.

The interference susceptibility for HIPERLAN/2 equipment is slightly poorer than for IEEE 802.11a depending on the used mode.

In order to avoid false alarm or untimely detection that will result to block up RLAN channels for long time, the peak power for UWB emission should be strictly limited to –46.5 dBm measured in the victim bandwidth of 20 MHz. Some other aspect may be considered to share the band with RLAN devices and UWB devices could be PRF parameter taking into account how mechanism DFS is implemented if the peak power limits is not satisfied. The risk to create false alarm exists and is not only due to the PRF but also all emissions showing similar characteristic close to a radar emission.

6 Amateur and amateur-satellite service

6.1 Amateur and amateur-satellite services in 420 MHz – 10.5 GHz

The amateur and amateur-satellite services have allocations in the frequency ranges in which UWB devices may operate, and the characteristics of the amateur and amateur-satellite stations are known.

6.2 Deployment scenarios

Most amateur stations operating in the UHF and SHF bands are situated in residences including urban, suburban and rural environments. In addition, there are some repeater stations located on high-rise buildings or towers, which use frequencies within these bands for linking between repeater stations. Hand-held transceivers used by amateur stations operate in the UHF bands but not yet at SHF. The stations most likely to be affected by UWB deployment operate at very low *S*/*N*, absolute minimum values such as 2 dB being used for Morse and 6 dB for SSB voice. Some specialized systems use lower or even negative *S*/*N*, but these systems are not currently widely used.

It is assumed that an interfering UWB transmission will have a noise-like (very low granularity) spectrum: this assumption may not be true in many cases and this may aggravate the situation with the very narrow-bandwidths used in amateur receivers. In a simplistic approach, the level of any discrete spectral lines (granularity) within a 1 MHz bandwidth would be reduced when measuring with a 1 kHz bandwidth to maintain the same overall power density/MHz. It is noted that the regulations of one administration do not reduce discrete spectral lines pro-rata as this approach should suggest, and this approach thus potentially leads to a much higher level of interference to stations in the amateur and amateur-satellite services where the granularity leads to the discrete spectral lines falling within the amateur bands.

6.3 Activity factor

6.3.1 Amateur transmission

Amateur stations use listen-before-transmit (LBT) access techniques. An amateur station listens for a time sufficient to determine that a frequency is not in use by another station or that the received noise level is suitable for communications.

Amateurs receive more than they transmit, perhaps on the order of a 95/5 ratio. Communications are normally conducted in sessions called "contacts" or "schedules" if prearranged. Such contacts may last a few minutes or perhaps as long as an hour. Within a contact, stations in communication alternate their transmissions.

6.3.2 UWB activity factor

Especially in domestic deployment scenarios employing effectively continuous operation, such as streamed audio or video, the UWB activity factor is 1 i.e. 0 dB. Even where applications are such that the use of an activity factor is appropriate, the effect of the relatively strong amateur signal on the UWB requires consideration, especially where the UWB operates with a pre-emptive access system or with ARQ. This is because interference from the amateur signal may well lead to a large number of re-tries. This suggests that when considering the effects of UWB on the amateur and amateur-satellite services, except in identifiable special circumstances and where multiple sources are to be considered, the activity factor of UWB should be 0 dB.

6.4 Technical characteristics of amateur systems

There is no single set of characteristics for amateur systems. However, Recommendation ITU-R M.1732 provides technical characteristics for the various modes of amateur operation for the purpose of aiding sharing and impact studies. The parameters used in the following studies of potential interference from UWB devices to amateur stations have been based on the parameters within this Recommendation. Station operators are at liberty to select various emissions, transmitter power levels, antenna types and other parameters according to the operational application within national regulations and cost constraints.

6.5 Aggregation

While the scenarios used are "worst-case" analysis, the effects of aggregation have not been included, which in the case of a suburban location, could possibly be significant. The terrestrial situation is the most likely to suffer from the effects of aggregation, since the more distant UWB emitters will be in the main beam of the antenna, thus giving an effective increase of 20 dB or more. Additionally, the number of emitters in view of the main antenna lobe will also increase. Both of these effects will be counteracted by the increased distance from the antenna, and the probability that there will be an additional building attenuation. These effects are difficult to quantify: a victim receiver will receive between −95 dBm/MHz and −113 dBm /MHz, and this number will increase little, if at all, with an increase above 40 in the number of emitters. In the SSB receiver bandwidth, this will be equivalent to a noise level some 26 dB lower, representing an input level of −121 to −139 dBm. These results effectively assume isotropic performance in the victim receiver antenna, and the use of a directional antenna in the amateur station reduces the effects probably of the order of 10 dB, i.e. the side-lobe performance of the amateur antenna less the gain exhibited in the direction of interferers. There is additional attenuation to be considered in that a proportion of the emitters will be inside a building.

Additionally, not all the UWB emitters will have an activity factor of 0 dB, and those more removed are less likely to have the activity factor modified by the receipt of interference from the amateur station. In totality, it appears that in the case of the amateur and amateur-satellite services, aggregation is unlikely to have much effect on the results of the studies.

6.6 Mitigation techniques

Mitigation factors in the UWB transmitter, such as the use of energy reduction by UWB devices within the amateur bands by about 20 to 25 dB, would result in minimal disruption to the amateur services. Mitigation at the receiver is more problematical, in that the cases of Earth-Moon-Earth (EME) and the amateur-satellite service could theoretically be provided by improved antenna side-lobe rejection, such an approach is more problematical for terrestrial links. It is possible that in some cases, side lobe cancellation techniques could be used. Indoor usage with UWB equipment installed such that wall attenuation exists between the UWB equipment and the amateur station antennas will ease the coexistence difficulty.

6.7 Frequency bands of interest

The frequency bands in which UWB devices may operate and frequencies allocated to the amateur services are shown in Table 77.

TABLE 77

Comparable UWB and amateur frequencies

Frequency band	Allocation
<960 MHz	420-430 MHz in certain countries 430-440 MHz 440-450 MHz in certain countries 902-928 MHz only in Region 2
960-1 990 MHz	1 240-1 300 MHz
1 990-3 100 MHz	2 300-2 450 MHz
3 100-10 600 MHz	3 300-3 400 MHz in Regions 2 and 3 3 400-3 410 MHz in Region 1 5 650-5 850 MHz 5 850-5 925 MHz in Region 2 only 10-10.5 GHz
22-29 GHz	24-24.25 GHz

6.8 Characteristics of amateur stations

6.8.1 Terrestrial communications

TABLE 78

Typical UHF/SHF amateur station using Morse (CW) and SSB for terrestrial communications

Characteristics	Value	
Frequency bands (MHz)	430-440, 1 240-1 300, 2 300-2 450, 3 300-3 500, 5 650-5 925, 10 000-10 500	
Emission types	100HA1A (Morse CW)	2K70J3E
Transmitter power (dBW)	10 (typical) (maximum power subject to administration regulations – varies with frequency, generally being higher at lower frequencies)	

Characteristics	Value	
Antenna line loss (dB)	3	
Antenna gain (dBi)	Varies (directional antennas are used – 0 dBi typical for >45° off the main lobe)	
e.i.r.p. (dBW)	31 in higher frequency bands: 40 dBW in the bands below 1 300 MHz	
Polarization	Horizontal	
Receiver noise figure (dB)	1 (antenna mounted preamplifiers are generally used)	
Receiver bandwidth (Hz)	400 (typical)	2 700 (typical)
Receiver *S*/*N* (dB)	2	6

6.8.2 Earth-Moon-Earth communications

TABLE 79

Typical UHF/SHF amateur station using Morse (CW) and SSB for EME communications

Characteristics	Value	
Frequency bands (MHz)	430-440, 1 240-1 300, 2 300-2 450, 3 300-3 500, 5 650-5 925, 10 000-10 500	
Emission types	100HA1A (Morse CW)	2K70J3E
Transmitter power (dBW)	Up to 30 (typical) (maximum power subject to administration regulations – varies with frequency, generally being higher at lower frequencies)	
Antenna line loss (dB)	3	
Antenna gain (dBi)	Varies, 25 dB typical at lower frequencies (directional antennas are used – 0 dBi typical for >45° off the main lobe)	
E.i.r.p. (dBW)	43 (typical)	
Polarization	Plane or circular	
Receiver noise temperature K	<100 (antenna mounted preamplifiers are generally used)	
Receiver bandwidth (Hz)	400 (typical)	2 700 (typical)
Receiver *S*/*N* (dB)	2	6

6.9 Particular scenarios for study – Amateur service

6.9.1 Terrestrial propagation

6.9.1.1 Minimum separation distances – Scenario 1 – Off boresight

A "worst-case" deployment scenario for the UWB/amateur installation can be considered to be the situation where a UWB wireless loudspeaker system or video recorder to TV link is within a short distance (<1 m) of a relatively large window in terms of wavelength, and the amateur antenna is 10 m distant (slant distance). Such a deployment is not unlikely in urban areas. Under these circumstances, free-space propagation can be considered to be applicable, and a loss proportional to frequency may be assumed. Further, the amateur antenna will not have the UWB transmitter in its main beam, but a gain of 0 dBi is not unusual for typical amateur antennas when a separation from the main beam of 45° is achieved.

Domestic use of UWB in such equipments such as remote wireless loudspeakers, video recorders and other domestic entertainment equipment have been suggested as viable applications, requiring effectively continuous operation for extended periods.

6.9.1.1.1 Summary table – Scenario 1

Victim radiocommunication service	
	Amateur service
Application	
System description	Receiver stations in the amateur service
Frequency band	A. 10 000-10 500 MHz
	B. 5 650-5 850 MHz
	C. 3 400-3 500 MHz
	D. 2 300-2 450 MHz
	E. 1 260-1 300 MHz
Receiver station	
Station description	Low noise narrow-band receiver
Receiver characteristics	
Bandwidth	3 kHz or 500 Hz
Noise figure/Noise temperature	1 dB
Signal model	Signals to be received are SSB-telephony and/or Morse telegraphy
Receiver antenna	
Type	Parabolic dish
Gain	A. 33 dBi boresight/ 0 dBi off boresight
	B. 30 dBi boresight/ 0 dBi off boresight
	C. 27 dBi boresight/ 0 dBi off boresight
	D. 25 dBi boresight/ 0 dBi off boresight
	E. 22 dBi boresight/ 0 dBi off boresight
Model	--
Protection criteria	
Criterion	The receiver systems noise shall not increase by more than 1 dB due to the interfering UWB signal
	The “reference/protection distance” to the UWB device is 10 m

Interference scenario and methodology	
UWB characteristics	As currently considered in the impact study
e.i.r.p. density limit	A. –41.3 dBm/MHz
	B. and C. –41.3 dBm/MHz (limit of one administration)
	D. –61.3 dBm/MHz outdoor
	E. –85.5 dBm/MHz outdoor
Activity factor	
Category A	
Category B – Single entry	Single interferer; 100% activity

Category B & C – Aggregate

Single interferer

Methodology	Minimum coupling loss (MCL)
Propagation model	Free space
Mitigation techniques	---

Receiver antenna not directed towards UWB device

Result:

Required UWB emission limit to ensure given protection distance(s)

Protection distance:	10 m
A. 10-10.5 GHz	e.i.r.p. max –46 dBm/MHz
B. 5.65-5.85 GHz	e.i.r.p. max –51 dBm/MHz
C. 3.4-3.5 GHz	e.i.r.p. max – 55 dBm/MHz
D. 2.3-2.45 GHz	Above spectrum mask
E. 1.26-1.3 GHz	Above spectrum mask

6.9.1.1.2 Conclusions

The interference criterion for amateur service receivers is < 1 dB rise of the receiver noise level at a "protection distance" of 10 m. The impact of a single UWB device deployed in closest vicinity of the amateur station is analysed, and the separation distance computed for an increase in the receiver noise level of 1 dB, assuming the spectrum mask of one administration. The required protection distances are 18 m at 10.25 GHz, 32 m at 5.7 GHz and 53 m at 3.45 GHz. Due to the fall of the UWB spectrum mask below 3 GHz, no interference in the 2.4 and 1.3 GHz amateur band will be encountered in the modelled situation. Note that no mitigation is assumed as a result of cross polarization between the UWB and amateur antennas.

6.9.1.2 Minimum separation distances – Scenario 2 – On boresight

Scenario 2 for the terrestrial case is that of the amateur antenna with characteristics as in Scenario 1, mounted at a height of 10 m in a suburban environment. It is assumed that the interfering UWB equipment will be inside domestic buildings, with a wall attenuation arbitrarily set at 20 dB. It is further assumed that the closest interferer is 10 m away.

Domestic use of UWB in such equipments such as remote wireless loudspeakers, video recorders and other domestic entertainment equipment have been suggested as viable applications, requiring effectively continuous operation for extended periods. No allowance is made here for aggregation effects, as not all the UWB systems will be in applications that require continuous operation, and so the increased interference caused by aggregation can be assumed to be reduced by the activity factor.

6.9.1.2.1 Summary table – Scenario 2

Victim radiocommunication service	
Application	Amateur service
System description	Receiver stations in the amateur service
Frequency band	A. 10 000-10 500 MHz
	B. 5 650-5 850 MHz
	C. 3 400-3 500 MHz
	D. 2 300-2 450 MHz

		E. 1 260-1 300 MHz
Receiver station		
Station description		Low noise narrow-band receiver
Receiver characteristics		
	Bandwidth	3 kHz or 500 Hz
	Noise figure/Noise temperature	1 dB
	Signal model	Signals to be received are SSB-telephony and/or Morse telegraphy
Receiver antenna		
	Type	Parabolic dish
	Gain	A. 33 dBi boresight/ 0 dBi off boresight
		B. 30 dBi boresight/ 0 dBi off boresight
		C. 27 dBi boresight/ 0 dBi off boresight
		D. 25 dBi boresight/ 0 dBi off boresight
		E. 22 dBi boresight/ 0 dBi off boresight
	Model	--
Protection criteria		
Criterion		The receiver systems noise shall not increase by more than 1 dB due to the interfering UWB signal
		The "reference/protection distance" to the UWB device is 10 m

Interference scenario and methodology

UWB characteristics		As currently considered in the impact study
e.i.r.p. density limit		A. –41.3 dBm/MHz
		B. and C. –41.3 dBm/MHz (limit of one administration)
		D. –61.3 dBm/MHz outdoor
		E. –85.5 dBm/MHz outdoor
Activity factor		
	Category A	
	Category B – Single entry	Single interferer; 100% activity
	Category B & C – Aggregate	
Single interferer		
Methodology		Minimum coupling loss (MCL)
Propagation model		Free space + 20 dB wall attenuation
Mitigation techniques		---
Receiver antenna directed towards UWB device		

Result:

Required UWB emission limit to ensure given protection distance(s)

Protection distance:	10 m
A. 10-10.5 GHz	e.i.r.p. max –59 dBm/MHz

B. 5.65-5.85 GHz	e.i.r.p. max –61 dBm/MHz
C. 3.4-3.5 GHz	e.i.r.p. max – 63 dBm/MHz
D. 2.3-2.45 GHz	Above spectrum mask
E. 1.26-1.3 GHz	Above spectrum mask

6.9.1.2.2 Conclusions

The interference criterion for amateur service receivers is < 1 dB rise of the receiver noise level at a "protection distance" of 10 m. The impact of a single UWB device deployed inside a building in the main beam of the amateur station is analysed, and the separation distance computed for an increase in the receiver noise level of 1 dB, assuming the spectrum mask of one administration. The required protection distances are 80 m at 10.25 GHz, 102.5 m at 5.7 GHz and 119 m at 3.45 GHz. Due to the fall of of the UWB spectrum mask below 3 GHz, no interference in the 2.4 and 1.3 GHz amateur band will be encountered in the model situation with the limits imposed by one administration.

The effects of aggregation will be mitigated by the lower activity factor of many (but not all) of the interferers. Note that no mitigation is assumed as a result of cross polarization between the UWB and amateur antennas

6.9.2 Minimum separation distances – Scenario 3 – Earth/Moon/Earth

Scenario 3 for the terrestrial case is that of the amateur antenna with characteristics as in Scenario 1, mounted to allow tracking of the moon. The receiver used is very low noise, with antenna mounted preamplifiers, but because of the narrow antenna beam width on frequencies of 2.3 GHz and above, the moon effectively "fills" the antenna aperture, and its noise is considered to be the dominant source. The interferer is considered to be "off boresight".

Domestic use of UWB in such equipments such as remote wireless loudspeakers, video recorders and other domestic entertainment equipment have been suggested as viable applications, requiring effectively continuous operation for extended periods. No allowance is made here for aggregation effects, not all the UWB equipments will be in applications that require continuous operation, and so the increased interference caused by aggregation can be assumed to be reduced by the activity factor. Note that no mitigation is assumed as a result of cross polarization between the UWB and amateur antennas.

6.9.2.1 Summary table – Scenario 3

Victim radiocommunication service	
Application	Amateur service
System description	Receiver stations in the amateur service using E/M/E
Frequency band	A. 10 000-10 500 MHz
	B. 5 650-5 850 MHz
	C. 3 400-3 500 MHz
	D. 2 300-2 450 MHz
	E. 1 260-1 300 MHz
Receiver station	
Station description	Low noise narrow-band receiver
Receiver characteristics	
Bandwidth	3 kHz or 500 Hz
Noise temperature	A., B., C., D. 240 K

	E. 150 K
Signal model	Signals to be received are SSB-telephony and/or Morse telegraphy
Receiver antenna	
Type	Parabolic dish
Gain	A. 33 dBi boresight/ 0 dBi off boresight
	B. 30 dBi boresight/ 0 dBi off boresight
	C. 27 dBi boresight/ 0 dBi off boresight
	D. 25 dBi boresight/ 0 dBi off boresight
	E. 22 dBi boresight/ 0 dBi off boresight
Model	--
Protection criteria	
Criterion	The receiver systems noise shall not increase by more than 1 dB due to the interfering UWB signal
	The "reference/protection distance" to the UWB device is 10 m

Interference scenario and methodology

UWB characteristics	As currently considered in the impact study
e.i.r.p. density limit	A. –41.3 dBm/MHz
	B. and C. –41.3 dBm/MHz (limit of one administration)
	D. –61.3 dBm/MHz outdoor
	E. –85.5 dBm/MHz outdoor
Activity factor	
Category A	
Category B – Single entry	Single interferer; 100% activity
Category B & C – Aggregate	
Single interferer	
Methodology	Minimum coupling loss (MCL)
Propagation model	Free space
Mitigation techniques	---

Receiver antenna not directed towards UWB device

Result:

Required UWB emission limit to ensure given protection distance(s)

Protection distance:	10 m
A. 10-10.5 GHz	e.i.r.p. max –48 dBm/MHz
B. 5.65-5.85 GHz	e.i.r.p. max –53 dBm/MHz
C. 3.4-3.5 GHz	e.i.r.p. max –58 dBm/MHz
D. 2.3-2.45 GHz	Above spectrum mask
E. 1.26-1.3 GHz	Above spectrum mask

6.9.2.2 Conclusions

The interference criterion for amateur service receivers is <1 dB rise of the receiver noise level at a "protection distance" of 10 m. The impact of a single UWB device deployed in LoS, but not on boresight, of the amateur station antenna is analysed, and the separation distance computed for an increase in the receiver noise level of 1 dB, assuming the spectrum mask of one administration. The required protection distances are 23 m at 10.25 GHz, 41 m at 5.7 GHz and 67 m at 3.45 GHz. Due to the fall of of the UWB spectrum mask below 3 GHz, no interference in the 2.4 and 1.3 GHz amateur band will be encountered in the model situation with the limits imposed by one administration.

The effects of aggregation will be mitigated by the lower activity factor of many (but not all) of the interferers.

Should the interferer be installed such that a building or wall attenuation is applicable, the situation may be eased.

6.10 Amateur satellite service

6.10.1 Amateur-satellite service frequencies

The frequency bands allocated to the amateur-satellite service in which UWB devices may operate are shown in Table 80.

TABLE 80

Comparable UWB and amateur-satellite frequencies

Frequency band	Allocation
<960 MHz	435-438 MHz
960-1 990 MHz	1 260-1 270 MHz E-s only
1 990-3 100 MHz	2 400-2 450 MHz
3 100-10 600 MHz	3 400-3 410 MHz in Regions 2 and 3 5 650-5 670 MHz E-s only 5 830-5 850 MHz s-E only 10.45-10.5 GHz
22-29 GHz	24-24.05 GHz

6.10.2 Technical characteristics of amateur-satellite systems

TABLE 81

Typical UHF/SHF amateur earth station using Morse (CW) and SSB for satellite communications

Characteristics	Value	
Frequency bands (MHz)	430-440, 1 240-1 300, 2 300-2 450, 3 300-3 500, 5 650-5 925, 10 000-10 500	
Emission types	100HA1A (Morse CW)	2K70J3E
Transmitter power (dBW)	Up to 13 (typical) (maximum power varies with frequency, generally being higher at lower frequencies, and is usually limited to prevent overload of the satellite transponder for those satellites that use linear transponders)	
Antenna line loss (dB)	3	

Characteristics	Value	
Antenna gain (dBi)	Varies, 10 dB typical at lower frequencies (directional antennas are used – 0 dBi typical for >45° off the main lobe)	
e.i.r.p. (dBW)	20 (typical)	
Polarization	Horizontal, vertical or circular	
Receiver noise figure (dB)	<1 (antenna mounted preamplifiers are generally used)	
Receiver bandwidth (Hz)	400 (typical)	2 700 (typical)
Receiver *S*/*N* (dB)	2	6

6.10.3 Effects of UWB deployment on the space segment of the amateur-satellite service

The effects of UWB on the amateur satellite segment are similar to those in the FSS, except that satellites in the amateur-satellite service are in either low (300 to 800 km) or Molniya (highly elliptical) orbits, with perigees as low as 500 km. Both LEO and FSS calculations suggest that for the 4/6 GHz band, 10^8 UWB emitters can be accepted, and these calculations have not taken into account any building or other attenuations. Although the effects of the lower orbit in reducing attenuation increases the amount of aggregate signal, it also reduces the area of the Earth that can be seen by the satellite and thus the number of UWB transmitters. The additional effects of building attenuations suggest that the Earth-to-space segment of the amateur-satellite service is unlikely to be affected by UWB deployment, and so has not been analysed in further detail.

6.10.4 Space-to-Earth

6.10.4.1 Minimum separation distances – Scenario 4

The characteristics of receiving stations in the amateur satellite service are very similar to those used for EME communication, with the exception that effective sky noise temperature is more variable, with a lower bound of around 3 to 10 K, depending on where the satellite is in the sky. This allows system noise temperatures to be as low as 100 K.

6.10.4.2 Summary table – Scenario 4

Victim radiocommunication service	
Application	Amateur (satellite) service
System description	Ground station receivers in the amateur (satellite) service
Frequency band	A. 10 000-10 500 MHz
	B. 5 650-5 850 MHz
…	C. 3 400-3 500 MHz
	D. 2 300-2 450 MHz
	E. 1 260-1 300 MHz
Receiver station	
Station description	Low noise narrow-band receiver
Receiver characteristics	
Bandwidth	3 kHz or 500 Hz
Noise temperature	100 K
Signal model	Signals to be received are SSB-Telephony and/or Morse telegraphy
Receiver antenna	

Type	Parabolic dish
Gain	A. 33 dBi boresight/ 0 dBi off boresight
	B. 30 dBi boresight/ 0 dBi off boresight
	C. 27 dBi boresight/ 0 dBi off boresight
	D. 25 dBi boresight/ 0 dBi off boresight
	E. 22 dBi boresight/ 0 dBi off boresight
Model	--
Protection criteria	
Criteria	The receiver systems noise shall not increase by more than 1 dB due to the interfering UWB signal
	The "reference/protection distance" to the UWB device is 10 m
Interference scenario and methodology	
UWB characteristics	As currently considered in the impact study
e.i.r.p. density limit	A. –41.3 dBm/MHz
	B. and C. –41.3 dBm/MHz (US limit and proposed European sloped mask)
	D. –61.3 dBm/MHz outdoor
	E. –85.5 dBm/MHz outdoor
Activity factor	
Category A	
Category B – Single entry	Single interferer; 100% activity
Category B & C – Aggregate	
Single interferer	
Methodology	Minimum coupling loss (MCL)
Propagation model	Free space
Mitigation techniques	---
Receiver antenna not directed towards UWB device	
Result:	
Required UWB emission limit to ensure given protection distance(s)	
Protection distance:	10 m
A. 10-10.5 GHz	e.i.r.p. max –52 dBm/MHz
B. 5.65-5.85 GHz	e.i.r.p. max –57 dBm/MHz
C. 3.4-3.5 GHz	e.i.r.p. max – 62 dBm/MHz
D. 2.3-2.45 GHz	e.i.r.p. max – 65 dBm/MHz
E. 1.26-1.3 GHz	Above spectrum mask

6.10.4.3 Conclusions

The interference criterion for amateur service receivers is < 1 dB rise of the receiver noise level at a "protection distance" of 10 m. The impact of a single UWB device deployed in closest vicinity of the amateur satellite (ground) station is analysed, and the separation distance computed for an increase in the receiver noise level of 1 dB, assuming the spectrum mask of one administration. The required protection distances are 35 m at 10.25 GHz, 24 m at 5.7 GHz, 102 m at 3.45 GHz and 14 m at 2.4 GHz. Due to the fall off of the UWB spectrum mask below 3 GHz, no interfence in the 1.3 GHz amateur band will be encountered in the model situation.

6.11 Overall conclusions

The analyses suggest that the deployment of the single UWB transmitter may lead to an increase in receiver noise floor of such level as to prevent weak signal communication for both the amateur and amateur-satellite services. Mitigation techniques that reduce the effective received level of the UWB emitter at a distance of 10 m by 20 to 25 dB would appear to be required: of these, the easiest is probably installation such that domestic installation of the UWB equipment such that wall attenuation reduces the out of building signals. In many cases, the use of vertical polarization by the UWB systems will provide further mitigation by between 10 and 20 dB. The UWB activity factor cannot be relied upon as a mitigating factor in a suburban domestic situation if UWB is used for streaming audio or video, although in terms of aggregate effects, it is probable that the aggregation will be cancelled by the activity factor. The satellite (Earth-to-space) segment of the amateur satellite service is most unlikely to be affected by UWB.

7 Meteorological ground based radars

7.1 System characteristics

7.1.1 UWB devices

Table 82 provides the full emission mask for frequencies ranging from 960 MHz to above 29 GHz for all types of UWB devices as allowed in the United States. The frequency ranges 1 990-3 100 MHz and 3 100-10 600 MHz are highlighted in bold since these rows contain the maximum UWB device e.i.r.p. (in 1 MHz reference bandwidth) that are allowed for each type of application that applies to the band 2 700-2 900 MHz, 5 600-5 650 MHz and 9 300-9 500 MHz. The first three system types, all imaging systems, use an analysis approach where the potential for interference from one device is analysed. The last three systems use an approach where aggregate interference from a number of systems is considered, and the maximum density of UWB devices that will not exceed the protection criteria is determined.

TABLE 82

UWB device e.i.r.p. (dBm/MHz) permitted under United States rules for each type of application

Frequency Band (MHz)	Imaging, below 960 MHz	Imaging, mid-frequency	Imaging, high frequency	Indoor applications	Hand-held, including outdoor	Vehicular radar
960-1 610	–65.3	–53.3	–65.3	–75.3	–75.3	–75.3
1 610-1 990	–53.3	–53.3	–53.3	–53.3	–63.3	–61.3
1 990-3 100	**–51.3**	**–41.3**	**–51.3**	**–51.3**	**–61.3**	**–61.3**
3 100-10 600	**–51.3**	**–41.3**	**–41.3**	**–41.3**	**–41.3**	**–61.3**
10 600-22 000	–51.3	–51.3	–51.3	–51.3	–61.3	–61.3
22 000-29 000	–51.3	–51.3	–51.3	–51.3	–61.3	–41.3
Above 29 000	–51.3	–51.3	–51.3	–51.3	–61.3	–51.3

In addition to the emission masks shown above, the communications UWB devices are assumed to have an omni-directional antenna type. Little information is known about the antenna pattern of the imaging systems, but for that type of application, a directional antenna will most likely be used. It is assumed that the antenna half-power beam width is 45º, and the back-lobe and side-lobe levels are 10 dB lower than the main beam.

7.1.2 Meteorological radar

Meteorological radars are designed to track particles in the atmosphere and utilize extensive processing to extract signals from received noise and mainly operate worldwide in the 2.7-2.9 GHz (2.8 GHz) band and in the 5.6-5.65 GHz (5.6 GHz) band.

In addition, the band 9 300-9 500 MHz (9.4 GHz) is also currently seen as the adequate band to improve the coverage of the current radar networks in a number of areas where precipitation detection are not satisfactory or even not manageable, due in particular to the relief.

Meteorological radars are in operation 24 h/day and detect more than just the presence of a return pulse. The processing derives data on return pulse characteristics (power received, Doppler, etc.) to determine factors such as wind velocity, wind shear, turbulence and precipitation intensity and type. This processing combined with the fact that meteorological radars require more than just the detection of the presence of a return pulse at negative *S*/*N* ratios makes them very vulnerable to interference.

The meteorological radar processing result in a volume scanning of the atmosphere providing the relevant meteorological factors for each cell of large grid. Each cell corresponds to a given azimuth and a given distance from the radar. Interference to these radars occurring in a given azimuth may have the potential to corrupt the measurements in the corresponding geographical sector.

Meteorological radars are mainly deployed in rural and suburban environments and the technical characteristics of representative meteorological radars that operate in the above mentioned frequency bands are provided in Table 83.

The characteristics of the radars deployed in the United States in the 2.8 GHz band are taken from Recommendation ITU-R M.1464 (radar G). These radars are the primary weather radar systems used for flight planning activities and are often collocated at airports worldwide, to provide accurate weather conditions for aircraft. For the other types of radars in the 2.8, 5.6 and 9.4 GHz bands, the characteristics are representative of current deployment of meteorological radars in Europe.

TABLE 83

Characteristics of the meteorological radar system used in the calculations

	2 700-2 900 MHz radars in the United States	**2 700-2 900 MHz radars in Europe**	**5 600-5 650 MHz radars in Europe**	**9 300-9 500 MHz radars in Europe**
Frequency (MHz)	2 800	2 800	5 600	9 375
Pulse power (kW)	500	600 to 800	250	7
Antenna main beam gain (dBi)	45.7	45.7, 43 and 39	45.7 and 43	33
Antenna pattern	See Fig. 113	Recommendations ITU-R F.699 (for the deterministic approach) and ITU-R F.1245 (for the statistical approach)	Recommendations ITU-R F.699 (for the deterministic approach) and ITU-R F.1245 (for the statistical approach)	Recommendations ITU-R F.699 (for the deterministic approach) and ITU-R F.1245 (for the statistical approach)
Occupied bandwidth (kHz)	600	600	600	600

	2 700-2 900 MHz radars in the United States	**2 700-2 900 MHz radars in Europe**	**5 600-5 650 MHz radars in Europe**	**9 300-9 500 MHz radars in Europe**
System noise figure (dB)	2.1	2.1	2	3
Antenna pattern type	Pencil	Parabolic dish	Parabolic dish	Parabolic dish
Antenna scan rate (degrees/s)	12 to 18	5 to 36	5 to 36	6
Antenna height (m)	30	7 to 21 13 average	7 to 29 16 average	5 to 15 10 average
Antenna beam width (degrees)	0.92	0.92 to 2	0.92 to 1.25	2.3
Antenna elevation (minimum) (degrees)	0.5	0.5	0.5	0.5
Polarization	Linear horizontal	Linear horizontal	Linear horizontal	Linear horizontal

TABLE 83 (*end*)

	2 700-2 900 MHz radars in the United States	**2 700-2 900 MHz radars in Europe**	**5 600-5 650 MHz radars in Europe**	**9 300-9 500 MHz radars in Europe**
Noise floor (dBm)	–114	–114	–114	–113
Minimum discernable signal (dBm)	–115	–115	–115	–112.5
Interference criterion(1) (dBm)	–124(1)	–124(1)	–124(2)	–123

(1) The –10 dB *I*/*N* criterion is consistent with the revised Recommendation ITU-R M.1464.

(2) The –10 dB *I*/*N* criterion is consistent with the revised Recommendation ITU-R M.1638.

Another important characteristic used for this study is the meteorological radar antenna pattern. Analysis for the radars in the 2.8 GHz band for the United States case have been performed with the antenna pattern as shown in Fig. 113 resulting from measurements performed on 2.8 GHz meteorological radars operating in the United States. The antenna pattern has a 45.7 dBi peak main beam gain. As the off-axis angle increases the antenna gain decreases until a constant gain of –8.3 dBi is attained from ±35º to ±180º. The constant value of –8.3 dBi represents the average of the antenna gain determined from the maximum and minimum gain points beyond 35º off-axis.

For the other cases, antenna patterns from Recommendations ITU-R F.699 and ITU-R F.1245 (see Fig. 113 *bis*) have been used since they correspond to typical representation of parabolic antennas, such as for meteorological radars, respectively for single entry and aggregate analysis.

FIGURE 113

2.8 GHz United States meteorological radar antenna pattern (45.7 dBi)

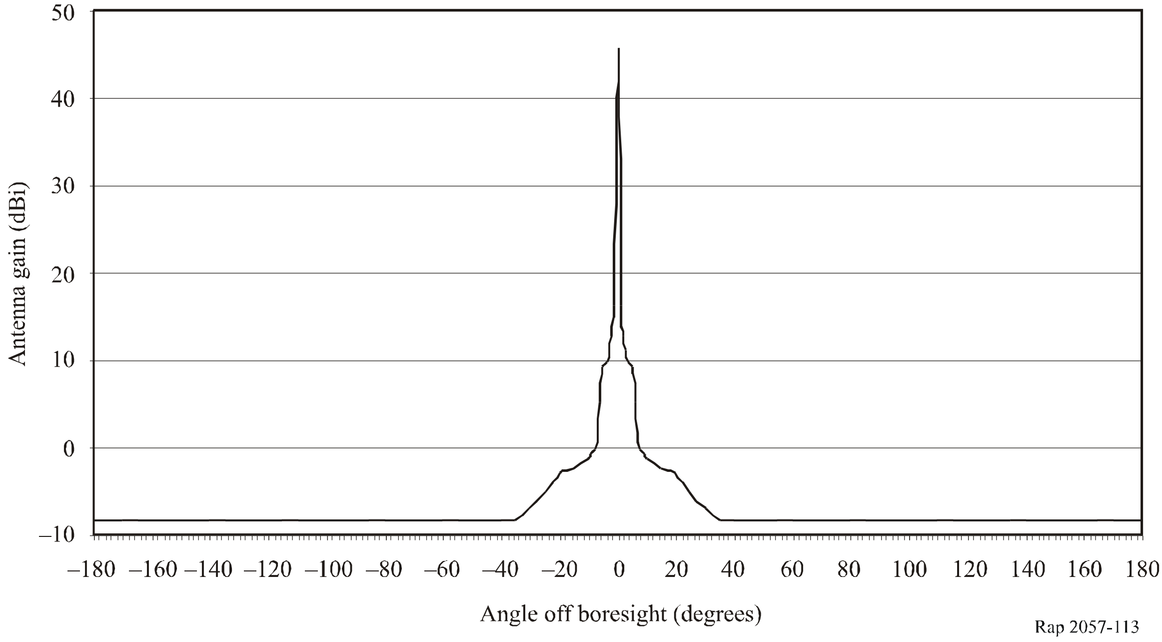
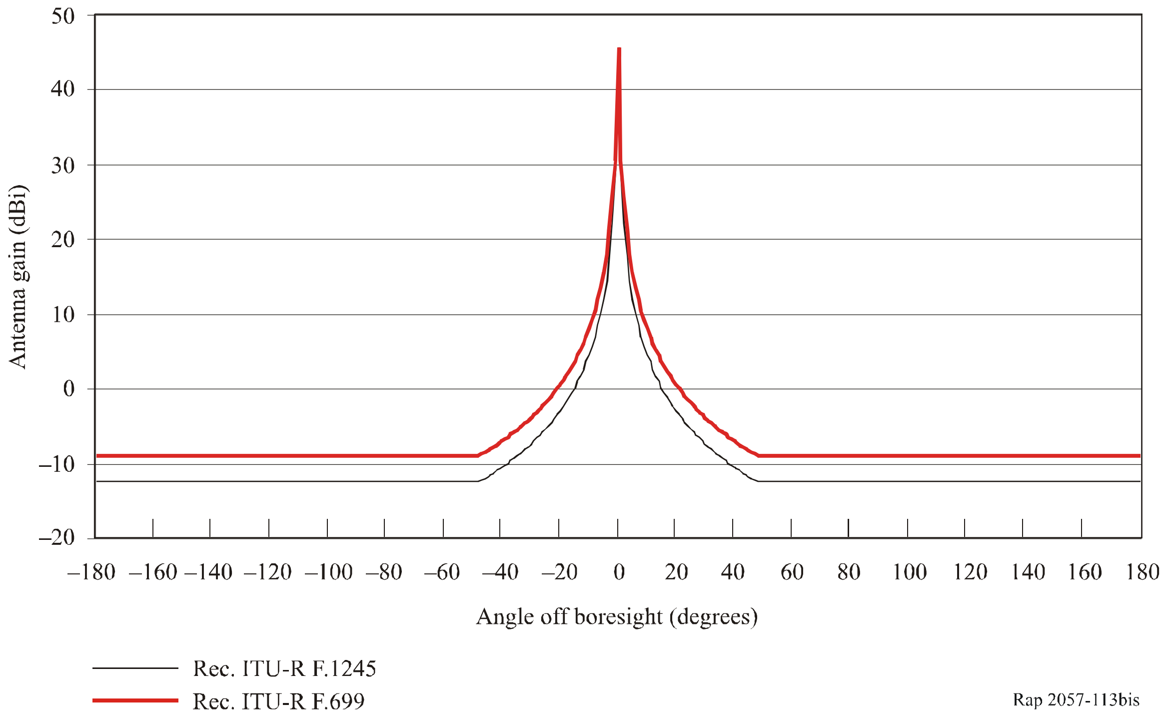


FIGURE 113 *bis*

Recommendations ITU-R F.699 and ITU-R F.1245 antenna patterns (45.7 dBi)



NOTE 1 – Aeronautical surveillance radars and other types of radars also operate in the 2.8, 5.6 and 9.4 GHz band. The typical parameters and scenarios considered in this analysis do not address these radars. Therefore, the typical radar parameters and scenarios included in the analysis and the conclusions of the analysis are should not be applied to the airport surveillance radars operating in this band.

7.2 Impact studies

The impact studies presented in this Report have considered two different approaches:

– deterministic approach, to determine the impact of a single UWB device;

– statistic approach, to determine the aggregate interference from a population of different UWB devices operating both indoor and outdoor.

For both approaches, and even though proposing similar methodologies, two different studies have been presented:

– Study A that only focus on the case of meteorological radars in the 2.8 GHz band consistent with deployment in the United States.

– Study B that consider typical meteorological radars in the 2.8, 5.6 and 9.4 GHz bands consistent with worldwide deployment.

7.2.1 Study A

Study A has first considered the case of single entry interference from imaging systems both on a deterministic and statistical approaches and secondly the case of aggregate interference from indoor devices and handheld indoor/outdoor devices on a statistical approach.

7.2.1.1 Imaging systems

The imaging systems operating in the 1.99-10.6 GHz band are limited to use by public safety entities and are to be utilized at disaster scenes (e.g. collapsed buildings) or for training purposes. Thus, these devices will not be deployed in areas around meteorological radars unless a disaster situation occurs, for which the devices will only be used for the duration of the incident. Imaging systems will not be deployed in an area in numbers greater than one or possibly a few. The typical deployment scenario involves a single device where a trained operator for a specific task operates it.

7.2.1.1.1 Deterministic approach

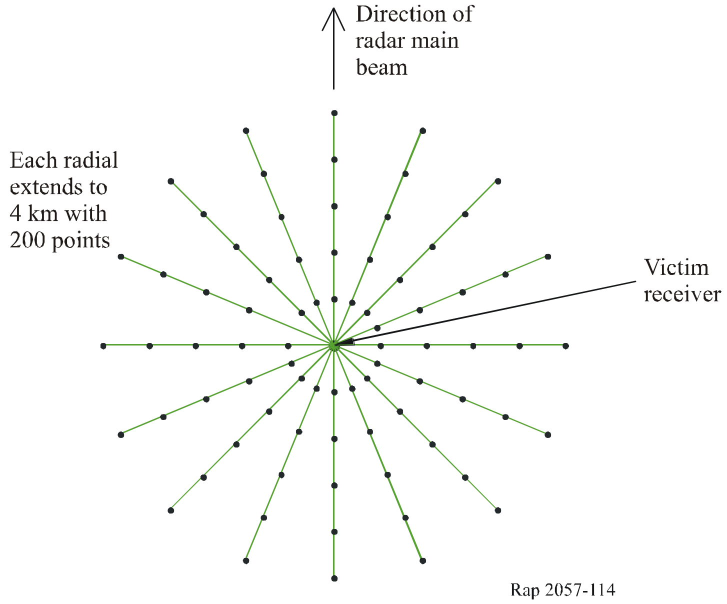
The potential for interference from a single imaging device was studied two different ways in this Report. The first approach was a deterministic analysis where the maximum interference into the radar was calculated without consideration for the probability that all the conditions for an interference event could be met. Based on the results of the deterministic analysis, a probabilistic analysis was conducted to address the statistics associated with interference to the radar actually occurring.

7.2.1.1.1.1 Methodology

A deterministic approach was used to verify whether interference was possible from an UWB imaging device into a meteorological radar. An analysis area was established where the victim receiver (radar) was placed in the centre and 360 radials, spaced at one degree, were established extending out from the radar. Points were then established along the radials at a 50 m spacing out to a distance of 4 km from the radar. An example of this setup can be seen in Fig. 114. The interference power from a single imaging device placed at each of these points was then calculated to determine the potential for interference from a single imaging device into the radar.

FIGURE 114

Diagram showing distribution of test points for calculating UWB imaging device (single emitter) interference into the radar



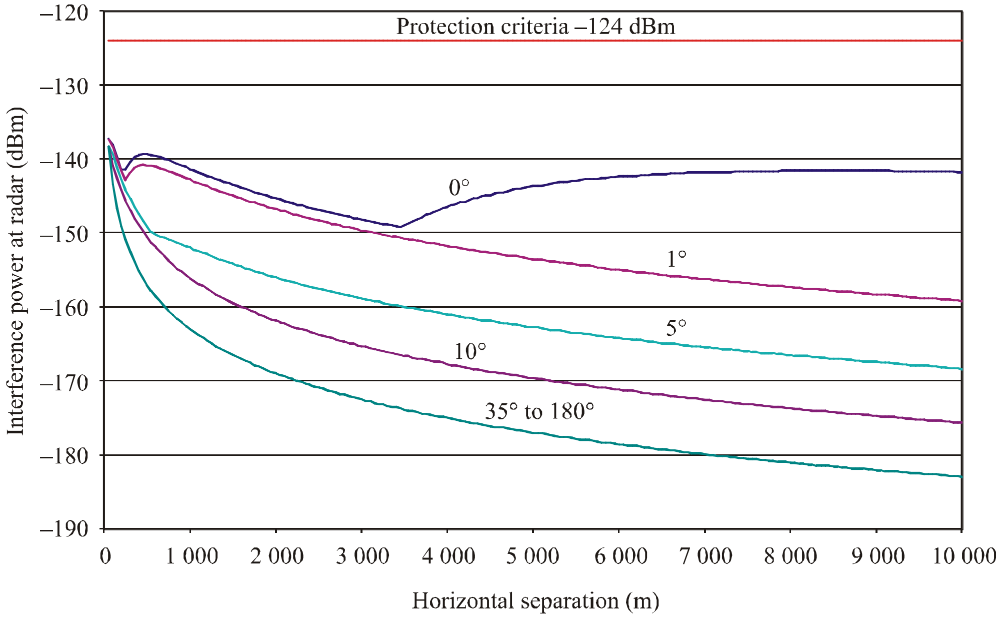
The calculations for the UWB device at each of the test points were run at several UWB device heights. The results provide an indication of the particular geometries around a meteorological radar where a UWB imaging device could potentially cause interference. This approach does not address the probability that interference would occur since the statistical nature of the sharing scenario is not addressed.

7.2.1.1.1.2 Results of deterministic approach

The results of the deterministic calculations show that the UWB imaging device would not interfere with the meteorological radar from any location at UWB device heights of 0 and 15 m, but that interference could occur at an unlikely UWB device height of 30 m in some locations relative to the main beam of the radar antenna. Figures 115, 116 and 117 provide the curves for interference level at the radar for UWB device heights of 0, 15, and 30 m, respectively. The various curves on a single plot are for an offset in azimuth between the radar main beam azimuth and the radial on which the points lie. Figure 117 shows that if the UWB imaging device lies on a point along the radial directly in line with the radar main beam, it can potentially cause interference to the radar out to a distance of 2 600 m. For a difference in azimuth of 1° between the radar main beam and the radial of UWB device test points, the maximum distance at which interference can occur drops to less than 200 m. This analysis simply looks at coupling between the radar and the UWB device. It does not consider factors that would reduce the probability of interference occurring, such as the rotation of the radar antenna, height variation of the UWB device, radar antenna elevation above 0.5 °, and other factors.

FIGURE 115

Plots showing interference levels from imaging device into radar for 0 m imaging device height

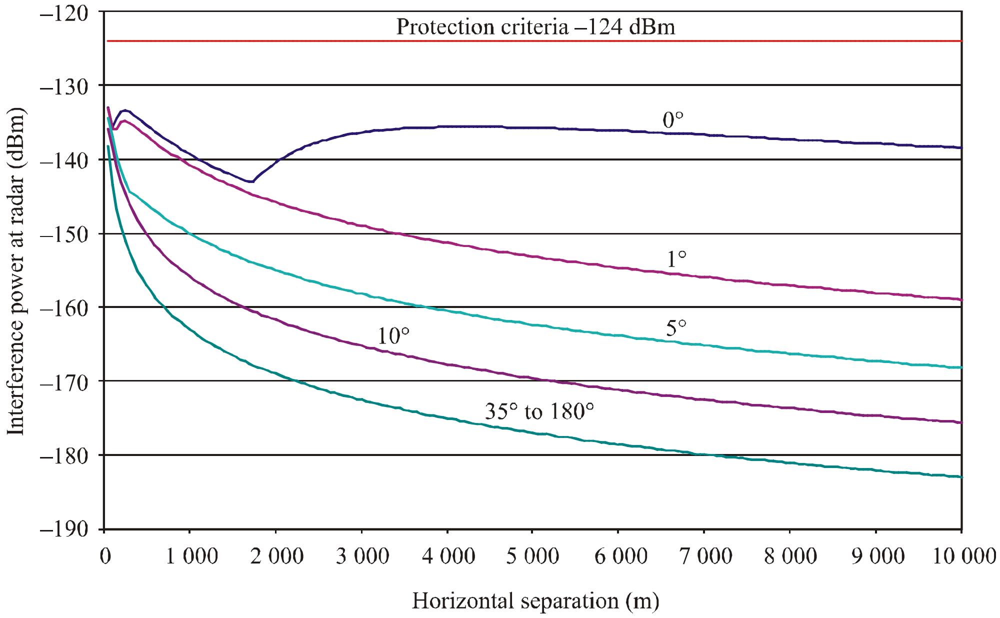


Note 1 – The notes next to the curves indicate the difference in azimuth between the radar main beam and the azimuth towards the UWB device.

Rap 2057-115

FIGURE 116

Plot showing interference levels from imaging device into radar for 15 m imaging device height

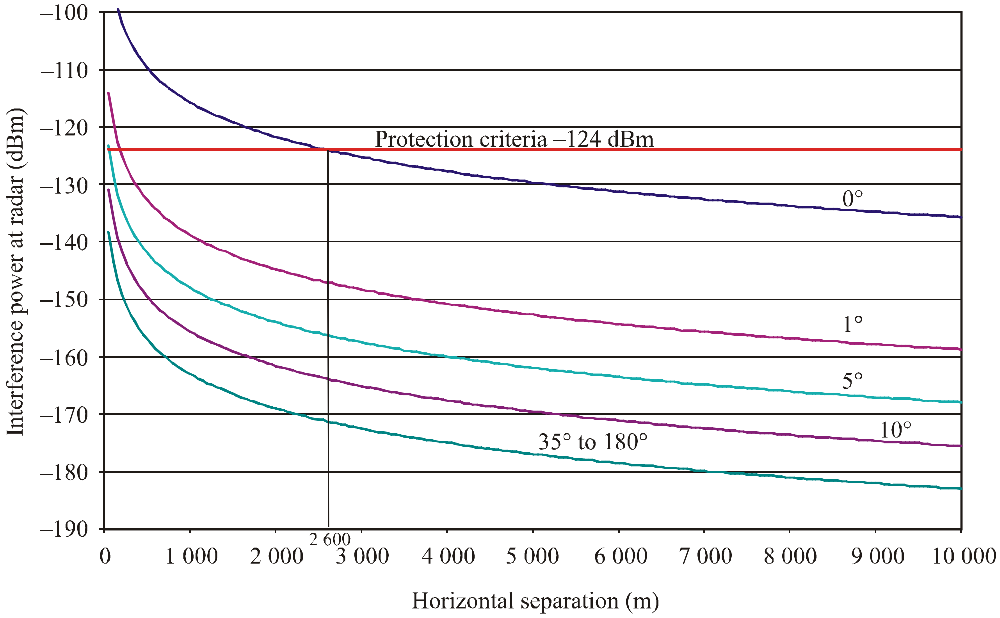


Note 1 – The notes next to the curves indicate the difference in azimuth between the radar main beam and the azimuth towards the UWB device.

Rap 2057-116

FIGURE 117

Plot showing interference levels from imaging device into radar for 30 m imaging device height



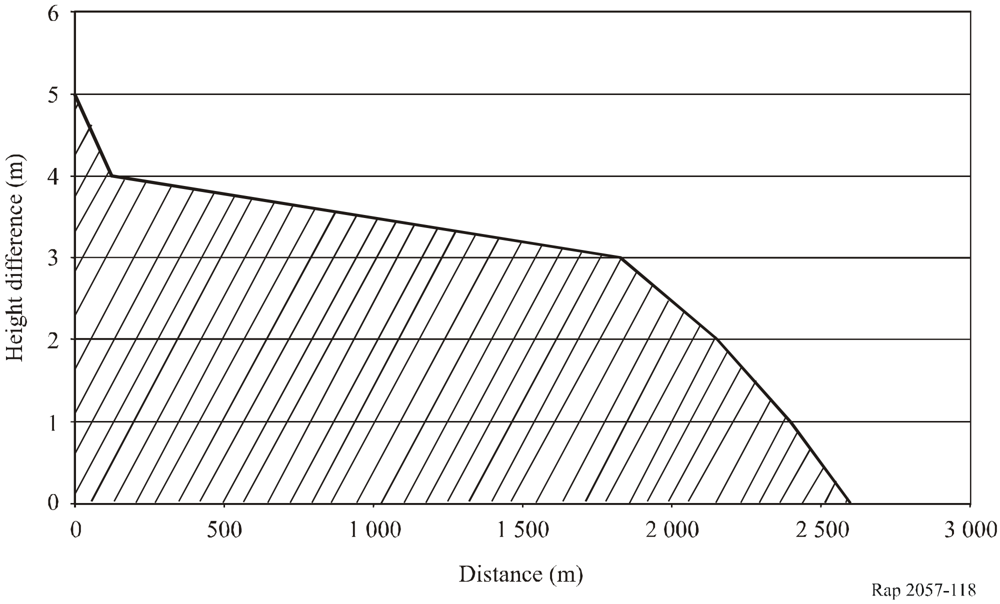
Note 1 – The notes next to the curves indicate the difference in azimuth between the radar main beam and the azimuth towards the UWB device.

Rap 2057-117

Additional calculations were then run at UWB device heights of 24, 25, 26, 27, 28 and 29 m to determine the height threshold at which the geometry is correct to possibly produce interference. Those calculations showed that a UWB device at greater than 25 m in height, positioned at the same azimuth as the radar main beam could cause interference. The calculations also revealed that the important parameter for determining whether interference can occur is the height difference between the radar antenna height and the UWB device height. These results can be applied to a meteorological radar of any height. Figure 118 plots the function of maximum interference distance against the height difference between the radar and the UWB imaging device, for the radial that is aligned in azimuth with the main beam of the radar antenna. The shaded area under the curve identifies the region, relative to the radar antenna, that the imaging device must operate within to cause interference to the radar. It is also worth noting that a height difference where the UWB device is greater in height than the radar can be disregarded. In order for a UWB device to be operating above the ground, it must be operated on or in a building or at a location that is equivalent in height to the radar. In order for a building to provide support above the radar height, the structure will extend into the main beam of the radar causing other operational problems.

FIGURE 118

A plot of distance from the radar and height difference between radar and UWB antenna where the UWB device could possibly cause interference



In summary, the deterministic approach shows that interference could occur from an imaging device into meteorological radar. However, considering all the conditions that must be met, interference seems unlikely.

In addition to the requirement that the UWB device be operating in the region shown in Fig. 117, interference could only occur if all the following conditions are met:

Radar antenna elevation at 0.5º: The meteorological radar used in this analysis performs a volume scan of the atmosphere where a number of rotations of the antenna are made at elevations starting at 0.5º and progressing up to 20º in step sizes dependent on the selected operating mode. Any time the radar antenna is at an elevation above 0.5º, the antenna discrimination is sufficient to prevent interference. It has to be noted that other radars such as the airport surveillance radars have different scanning patterns.

UWB operating on an external outer wall: The UWB device must be operating with only an external wall providing building shielding. Placement of the UWB device interior to the building where additional walls provide shielding will provide additional isolation.

UWB main beam directed at the radar: A UWB imaging device would most likely not have an omni directional antenna. The main beam of the UWB device would need to be directed at the radar. Side lobes and back lobes would provide additional isolation.

UWB device must be active: The nature of these devices is that they would not always be active. The device would transmit long enough to obtain the required image.

7.2.1.1.2 Probabilistic approach – Monte-Carlo simulation

Since the deterministic approach showed that with the correct geometry, and ignoring other mitigating factors, the UWB imaging devices could produce an interfere level in excess of the radar protection criteria, a simulation was set up to account for as many of the other mitigating factors as possible. This simulation took into account the other factors such as UWB device height, position within a building, and main beam orientation. The simulation also addressed the rotation and the changing elevation of the radar antenna.

7.2.1.1.2.1 Methodology

This analysis employs a fixed location receiver (meteorological radar) and a transmitter (UWB device) that is placed at 30 million random locations around the receiver. At each location, the power level of the UWB device, as an interferer, is calculated at the victim receiver, the meteorological radar. A level of –124 dBm represents the power at the input to the radar receiver at which the UWB device signal exceeds the interference criterion. This level is based on Recommendation ITU-R M.1464. The analysis program moves the UWB device to random locations within a radius of approximately 3 km around the meteorological radar. In addition, the UWB device operating height was randomly varied between 0 and 30 m, and the main beam azimuth of the UWB imaging device was randomly varied. For site conditions, the building penetration loss was varied between a minimum of 10 dB for an outside wall, to 30 dB for operation interior to the building.

Any points beyond 3 km were determined to not cause interference in any geometry, so the simulation only moved the device to points within 3 km of the radar. The radar antenna simulates practical meteorological radar operation by rotating 360º in azimuth, and changing antenna elevation for elevation cuts at 0.5º, 1.5 º, 2.5 º, 3.5 º and 4.5º.

The propagation models used were free space and Recommendation ITU-R P.530 (Multipath). No terrain data was considered. At ranges of 3 km or less, terrain shielding will be negligible. The radar antenna height is set to the typical height of 30 m for meteorological radars in the United States, though some deployed systems do have configurations where the antenna height could be as low as 10 m. The program automatically accounts for the on tune rejection (OTR) correction for the difference between the UWB reference bandwidth of 1 MHz and the radar receiver bandwidth of 630 kHz. The OTR in this case is –2.0 dB.

The program performing the calculations using the Monte-Carlo Method calculated the interference power at the radar in the following manner:

$$P_{RX} = e.i.r.p._{UWB} + OTR - G_{RX} - B_{LOSS} - P_{LOSS} - M_{LOSS}$$

where:

P_{RX}: power from all the UWB devices in one cell

$eirp_{UWB}$: e.i.r.p. of the UWB devices within a 1 MHz bandwidth

G_{RX}: gain of the radar antenna in the direction of the UWB device

OTR: on tune reject due receiver bandwidth narrower than UWB ref. bandwidth

B_{LOSS}: building attenuation

P_{LOSS}: path loss

M_{LOSS}: multipath loss.

7.2.1.1.2.2 Results (probabilistic approach)

The simulation showed that consideration of 30 million different points around the radar, produced no events where the protection criteria for the radar was exceeded. An additional factor that was not included in the simulation is the percentage of time that a UWB imaging device would actually operate within 3 km of a meteorological radar. This is difficult to quantify, but it is expected to be quite low given the typical location of meteorological radars and the anticipated manner in which imaging systems would be deployed. This factor lowers the probability of interference to an even smaller value.

7.2.1.2 Indoor devices and handheld indoor/outdoor devices (3.1-10.6 GHz)

7.2.1.2.1 Methodology (indoor devices and handheld indoor/outdoor devices)

The United States rules allow for two types of UWB devices that do not require licensing or coordination.

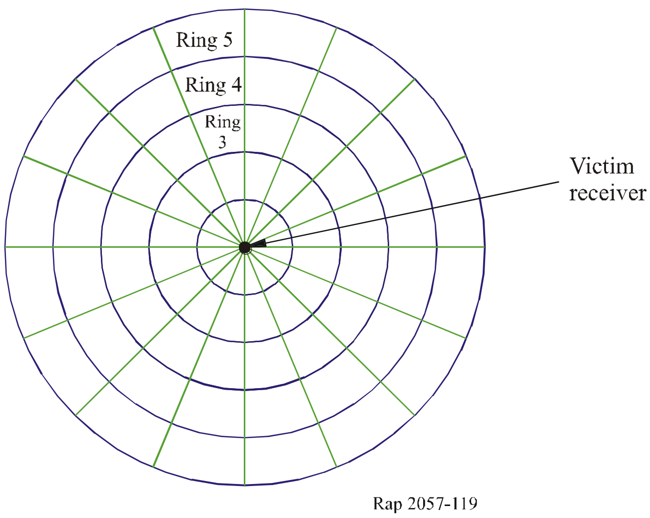
The first type are transmitters that are restricted to indoor use only, using shielding provided by buildings to allow a higher e.i.r.p. The second type of transmitter may be used indoors or outdoors, but is limited to use in devices that must be hand held. To account for the lack of structural shielding, the permitted e.i.r.p. of the hand-held devices is lower than the indoor devices. The operational bandwidth of both types of devices is 3.1-10.6 GHz, however, emissions at lower levels are permitted in the band 2 700-2 900 MHz. Table 82 provides the characteristics used in the analysis for the two types of devices.

The UWB devices of the type analysed in this section can be deployed anywhere without need for coordination, and in any density. This analysis considers a deployment of UWB devices around a radar. It is worth noting that the e.i.r.p. external to a building for an indoor device with 10 dB of structural shielding is the same as the e.i.r.p. of a UWB device that is allowed to operate outside. For this analysis the two types of devices can be treated the same for calculating aggregate interference since the e.i.r.p. external to a building, where 10 dB of attenuation is applied, is the same as the e.i.r.p. of the outdoor device.

A circular analysis area is established with the radar placed in the centre. The radar antenna height is set to 30 m. The computer program randomly places UWB devices around the radar at the user-selected density. Since little information or understanding exists that can be drawn upon for determining a realistic deployment density, a range of densities were analysed. The analysis area is broken into small cells bounded by rings and radials extending out from the radar location. Refer to Fig. 119 for a simple example. Though the example only shows five rings and 16 radials, the analysis program used much higher numbers.

FIGURE 119

Example of division of analysis area into small parts

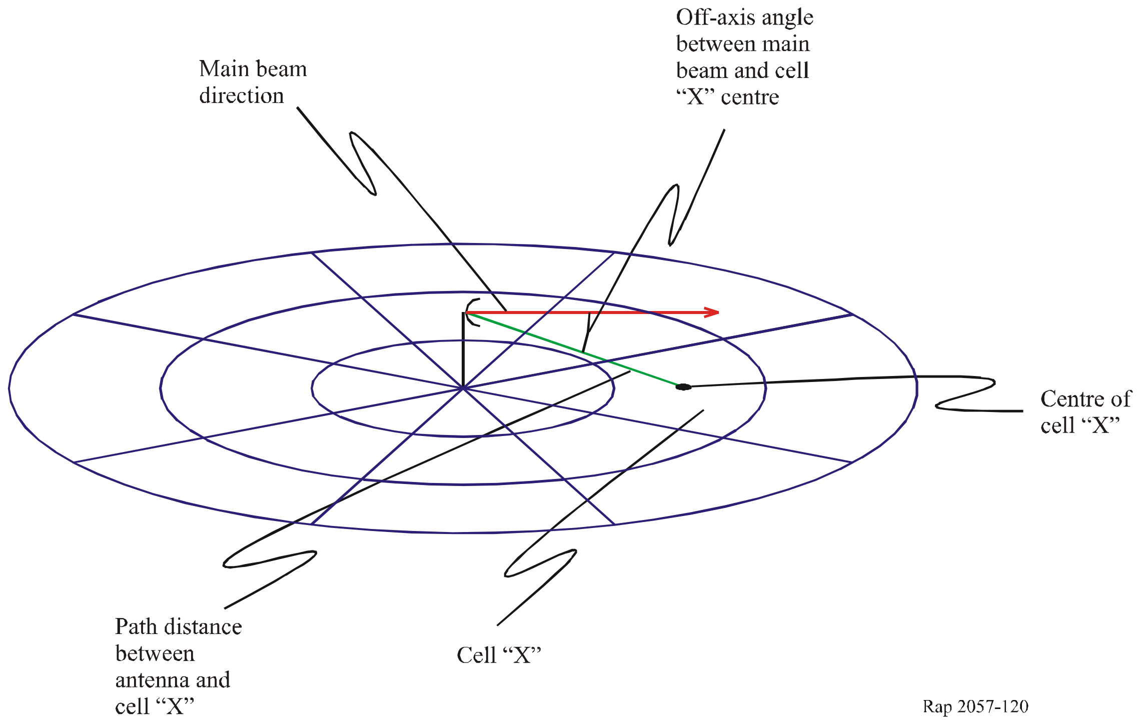


Based on the random placement of the UWB devices, the number of devices in each cell of the analysis area was determined.

To simplify the analysis, the radar antenna off-axis gain and path loss was only calculated to the centre of each cell rather than to each UWB device in each cell. This approximation will be accurate as long as the cell areas remain relatively small by keeping the ring width small and the number of radials high.

FIGURE 120

Graphic depicting geometry of the analysis for a distribution of UWB devices around a radar



The on-tune rejection of the radar also needs to be considered. The e.i.r.p. of the UWB signal is provided for a 1 MHz reference bandwidth. The radar IF bandwidth is 630 kHz.

$$OTR = 10 \log \left(\frac{BW_{RX}}{REFBW_{UWB}} \right)$$

$$OTR = -2.0 \text{ dB}$$

where:

BW_{RX}: radar receiver IF bandwidth

$REFBW_{UWB}$: reference bandwidth applied to the UWB e.i.r.p.

The power at the radar receiver input from all the UWB devices in a single cell can be calculated.

$$P_{RX} = e.i.r.p._{UWB} + G_{RX} - PL + OTR + 10 \log(N)$$

where:

P_{RX}: power from all the UWB devices in one cell

$e.i.r.p._{UWB}$: e.i.r.p. of the UWB devices within a 1 MHz bandwidth

G_{RX}: gain of the radar antenna in the direction of the centre point of the cell

OTR: on tune reject due receiver bandwidth narrower than UWB ref. bandwidth

N: number of randomly placed UWB transmitters in the cell

PL: path loss.

G_{RX} was calculated using a representative radar antenna pattern, where for any given off-axis angle, the relative gain can be calculated. In the aggregate case, multipath was not considered since some paths would experience signal fading while other paths would experience signal enhancement. The net effect of multipath was assumed to be negligible.

The aggregate interference power is then calculated from all the cells in the analysis area. For an analysis area of *i* rings and *j* radials the formula is written as follows:

$$P_{SUM} = \sum_i \sum_j P_{RX} + 10 \log (C_{DUTY})$$

where:

P_{SUM}: aggregate interference from all the UWB devices in all the *i* x *j* cells

R_{RX}: power from all the UWB devices in one cell

C_{DUTY}: correction factor for UWB devices transmitting at a duty cycle less than 100%.

It should be noted in the formula above, the fact that UWB devices in practice do not transmit for 100% of the time. However, since no specific value for duty cycle is provided within the United States rules, a 100% transmit time was assumed.

The calculations presented above provide the aggregate interference into a radar for a random distribution of UWB devices. The analysis was run for a range of device distributions from 1/km^2 to 10 000/km^2.

7.2.1.2.2 Results (indoor devices and handheld indoor/outdoor devices)

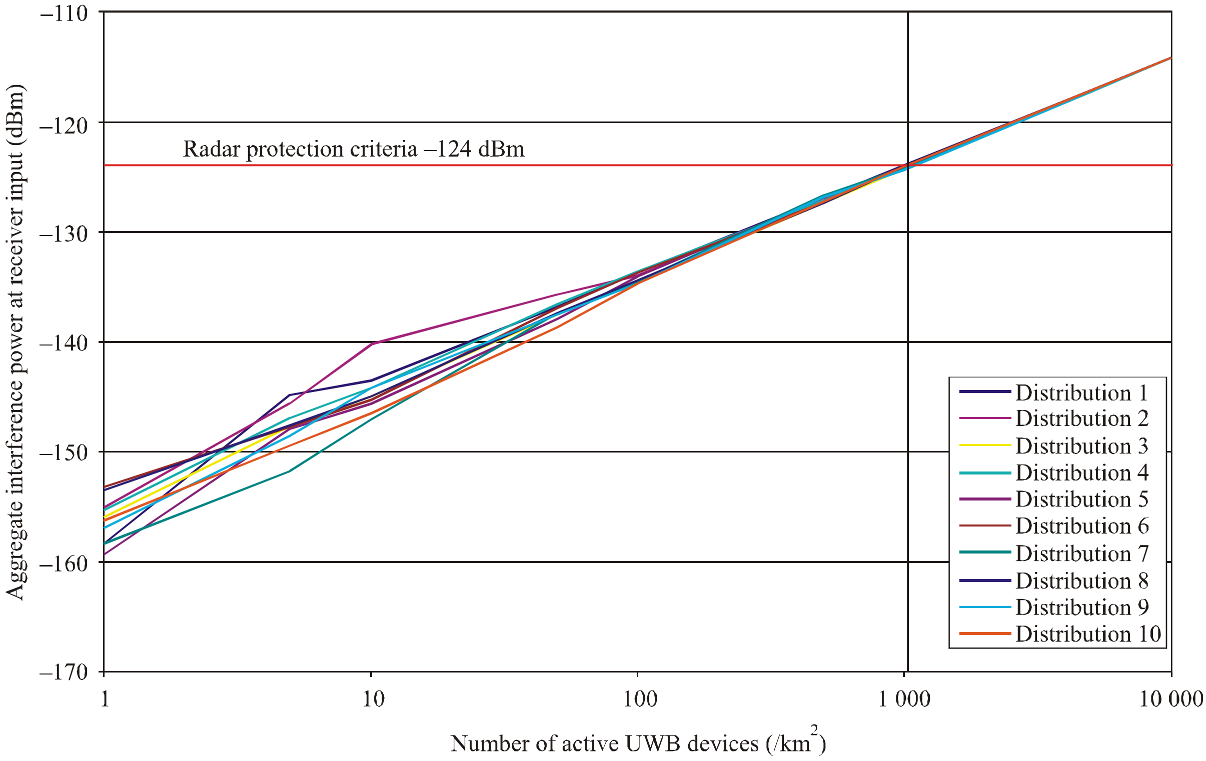
Section 3.2 outlines the analysis methodology for determining impact on meteorological radars from indoor UWB devices and handheld indoor/outdoor UWB devices.

The methodology calculates an aggregate interference level for a randomly distributed group of UWB devices around a radar. The density of the UWB devices is varied from 1 device/km^2 up to 10 000 devices/km^2.

The results of the analysis are shown on Fig. 121. For UWB densities of 1, 5, 10, 50, 100, 500, 1 000, 5 000, 10 000 and 50 000 devices/km^2, ten different random distributions were studied. The curves for all ten random distributions are shown in Fig. 121. It can be seen that at low densities, there is some variability in the results, but the results converge at higher densities. This would be expected as the higher densities provide a larger statistical sample where the placement of an individual device or several devices does not significantly impact the results.

FIGURE 121

A plot of aggregate interference power vs. active UWB device density of a random distribution of indoor or handheld indoor/outdoor UWB devices



Rap 2057-121

Figure 121 shows that a UWB device density of approximately 1 000 active UWB devices per square kilometre can potentially cause interference to a meteorological radar. Considering the locations that meteorological radars are typically installed, it does not seem realistic to expect the device density to ever exceed 1 000/km^2. Therefore, this analysis indicates the current rules established in the United States are sufficient for protection of meteorological radars typically deployed in the United States.

7.2.1.3 Conclusion for Study A

Based on typical deployment in the United States for use of 2.8 GHz meteorological radars, Study A tends to show that the potential for interference from imaging devices is small. The deterministic calculations show that certain geometries could cause interference. However, the other mitigating factors such as UWB device height variability, UWB device location within a building, UWB device activity, UWB device main beam direction, radar antenna rotation, and radar antenna elevation help to mitigate the potential for interference. It also tend to show that the indoor and indoor/outdoor handheld devices do not result in an aggregate interference level sufficient to exceed the radar protection criteria until the active UWB device density exceeds 1 000/km^2 with each device operating at an e.i.r.p. of –61.3 dBm/MHz. The United States Administration believe that this is a very high-density value when the typical meteorological radar location is considered and that, therefore, UWB imaging and handheld devices that abide by the requirements, both technical and operational, of the United States rules will not pose an interference problem to meteorological radars in the 2.7-2.9 GHz band operating within the United States of America.

7.2.2 Study B

Study B has considered both deterministic and statistical approaches for meteorological radars in the 2.8, 5.6 and 9.4 GHz bands, allowing to determine respectively single entry and aggregate interference.

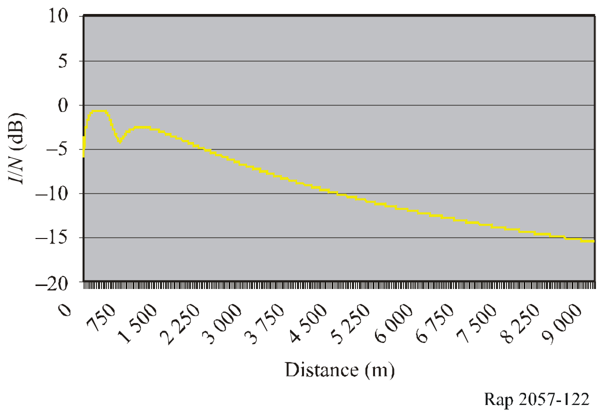
7.2.2.1 Deterministic approach

The deterministic approach allows to calculate the interference from 1 UWB device to a meteorological radar.

For a given azimuth from the radar, the interference level (in terms of I/N) is calculated for the range of distances from the radar up to 9 km from the radar and for an UWB device located on the ground, allowing to present a curve similar to that in Fig. 122.

FIGURE 122

Representation for the deterministic approach



In each frequency band, similar representation are presented for different radar parameters such as antenna gain and antenna height as well as different azimuth from the instantaneous radar pointing direction.

7.2.2.2 Statistical approach

The statistical approach allows to calculate the interference from a deployment of UWB devices to a meteorological radar.

For a given density of simultaneously active UWB density (in devices/km^2), several parameters are randomly determined:

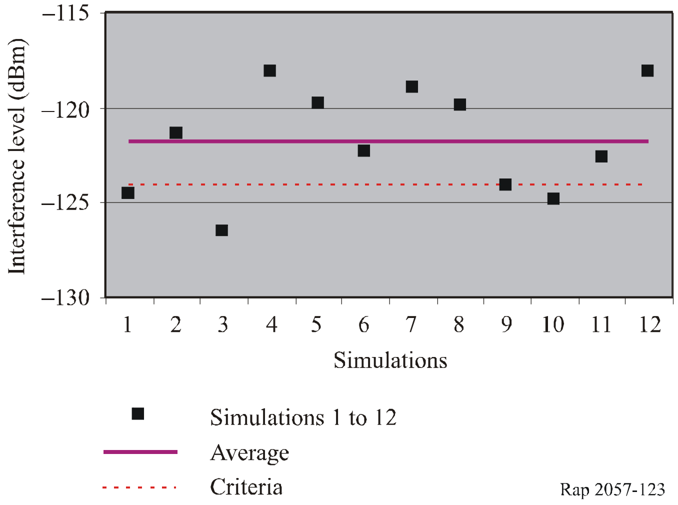
– Location of each UWB device:
  – the distance is determined for each concentric circle around the radar corresponding to an area of 1 km^2 (the maximum distance has been set to 3 km, assuming that at higher distance, the average shielding attenuation over the whole UWB population would limit the additional interference);
  – the azimuth of the UWB is random (1 to 360°).
– Height of the UWB device is randomly determined from 0 to a maximum height assumed to be 2 m below the radar antenna height.
– Indoor/outdoor location of the UWB device is randomly considered based on a given outdoor use ratio. For indoor devices, an additional attenuation of 10 dB is used.

For a given set of radar parameters, 12 simulations are performed to calculate the aggregate interference levels (dBm) presented as on Fig. 123 and compared to the interference criteria:

– the interference levels corresponding to each simulation;
– the average interference level of the 12 simulations

FIGURE 123

Representation for the statistical approach



Finally, acknowledging that meteorological radars are mainly deployed in rural and suburban environment, simulations have been performed with the following UWB density scenarios (with the associated indoor deployment ratio).

TABLE 84

Number of active UWB devices and outdoor use percentage considered in the study

Type of deployment	Density of simultaneously active UWB (N_b/km²)	Outdoor use (%)
Rural	1	50
Rural	5	50
Rural	10	50
Suburban	20	20
Suburban	50	20
Suburban	100	20
Urban	500	10

7.2.2.3 Frequency band 2 700-2 900 MHz

The parameters of the meteorological radars used for the simulations are given in Table 83.

With regards to UWB devices, different power limits are proposed in the current United States regulation, depending on the type of UWB:

– for imaging applications, assumed to be low density: –41.3 dBm/MHz

– for telecommunications applications (indoor): –51.3 dBm/MHz

– for telecommunications applications (outdoor): –61.3 dBm/MHz.

Calculations for the deterministic approach that represents single entry interference have been performed with the –41.3 dBm/MHz limit, since it corresponds to low density imaging applications and that single entry interference from telecommunications devices is assumed to be negligible compared to aggregate interference.

For the statistical approach, interference calculations have only been performed with outdoor telecommunications devices presenting a –61.3 dBm/MHz power density limit, acknowledging that corresponding indoor devices present the same interference potential (–51.3 dBm/MHz limit – 10 dB indoor/outdoor attenuation).

7.2.2.3.1 Deterministic approach results in the 2.8 GHz band

FIGURE 124

39 dBi antenna gain

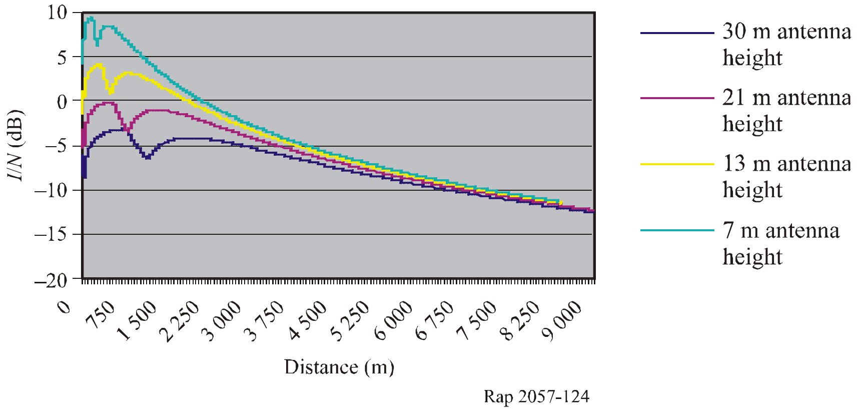


FIGURE 125

43 dBi antenna gain

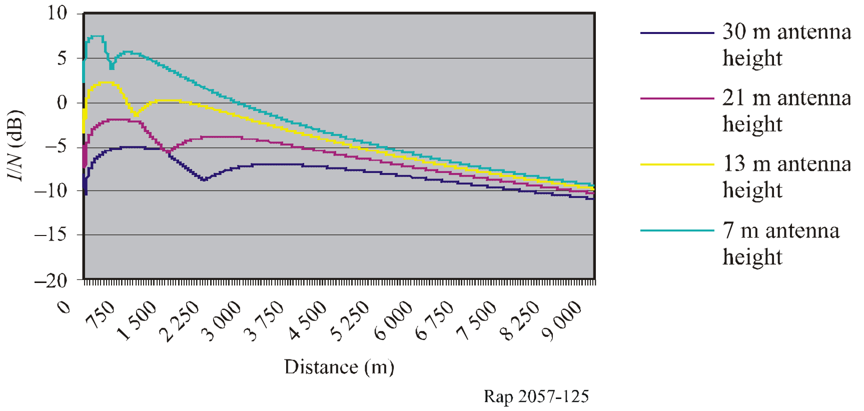
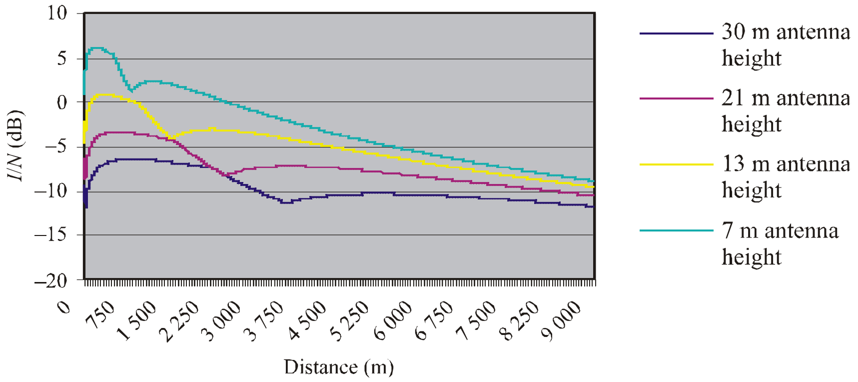


FIGURE 126

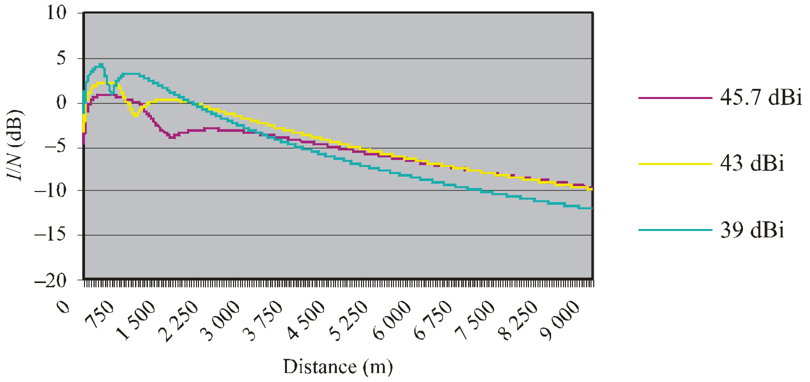
45.7 dBi antenna gain



Rap 2057-126

FIGURE 127

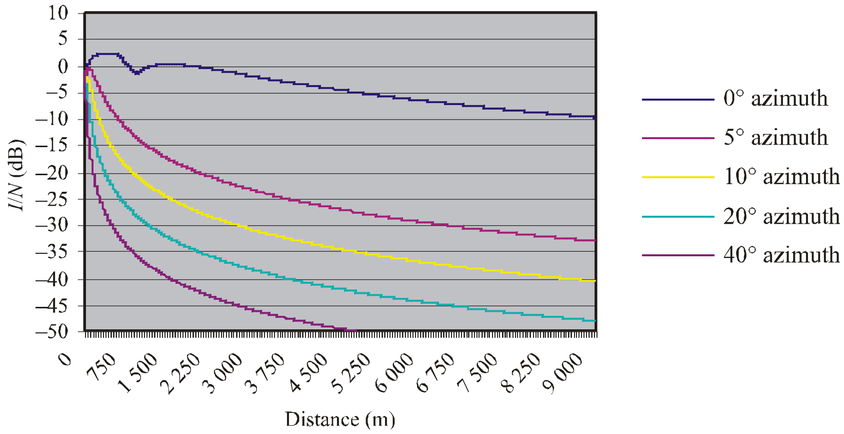
Antenna gain comparison (13 m antenna height)



Rap 2057-127

FIGURE 128

Azimuth comparison (43 dBi and 13 m)



Rap 2057-128

Figures 124 to 128 clearly show that, on a single entry basis, UWB devices operating with a –41.3 dBm/MHz power density limit are not compatible with meteorological radars in the 2.7-2.9 GHz frequency band.

The interference protection criteria are exceeded by a large amount (between 10 and 20 dB), in particular at low distance from the radar where no additional interference attenuation can be expected.

Compared to the radar parameters currently considered in Study A (45.7 dBi antenna gain and 30 m antenna height), the interference levels are widely increased by taking into account the corresponding parameters as existing in Europe (down to 39 dBi antenna gain and 7 m antenna height). Figures 124 to 126 show the impact of the antenna height whereas Fig. 127 shows the impact of the antenna gain.

In addition, as shown on Fig. 124, such high interference levels are also experienced in ranges of azimuth from the radar that are not negligible (up to ± 10° at several hundreds metres from the radar).

On the other hand, it has also to be considered that UWB imaging systems are likely to operate with maximum power directed through walls or into ground which would hence limit de facto the impact to meteorological radars. Such attenuation could be reasonably taken at 10 dB.

As a conclusion, **on a single entry basis**, it is proposed that power limits of UWB applications in the 2.7-2.9 GHz band **be limited at the maximum to –51 dBm/MHz**, whatever the considered applications.

7.2.2.3.2 Statistical approach results in the 2.8 GHz band

Statistical simulations have been performed for telecommunication UWB devices, for each of the UWB densities as given in Table 84, and with meteorological radars parameters assumed to be typical, i.e.:

– 43 dBi antenna gain;

– 13 m antenna height.

Figure 125 gives the result of the 12 simulations performed for 50 active UWB devices/km^2, consistent with suburban case.

FIGURE 129

2.8 GHz band simulations results (50 UWB/km^2)

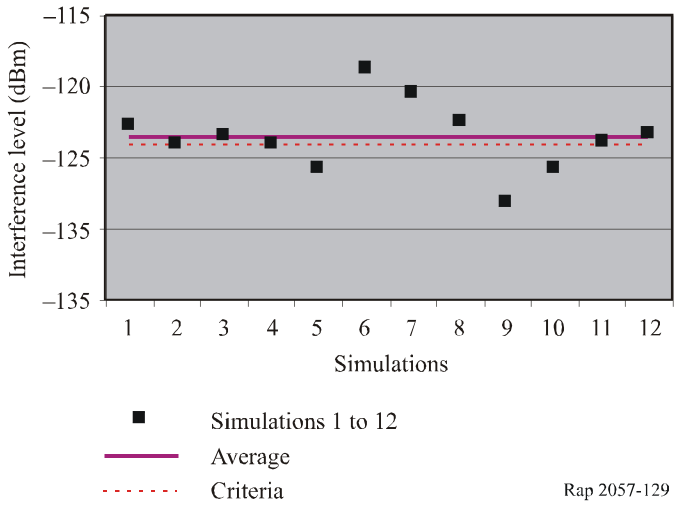


Figure 130 gives a summary of all simulations by plotting for each UWB density case, the maximum interference level among the 12 simulations, the minimum interference level and the average value of the 12 simulations.

FIGURE 130

2.8 GHz band simulations results

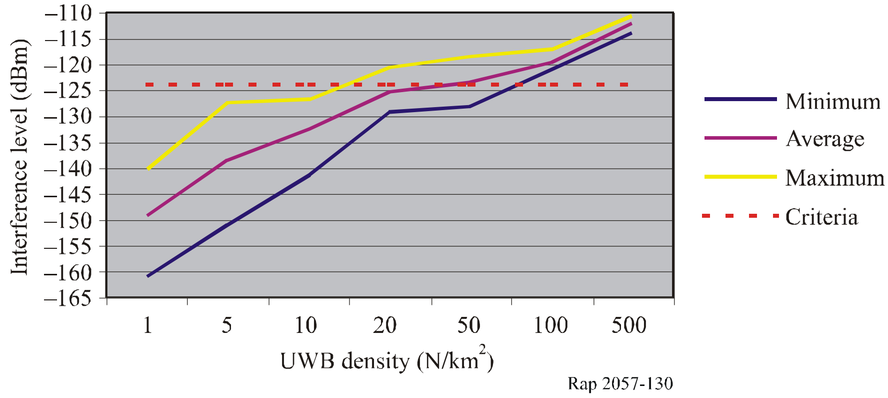


Figure 130 clearly shows that for deployment of UWB operating at –61.3 dBm/MHz, the meteorological radar protection criteria is exceeded as far as the UWB density is over 10 to 20 devices/km^2, representing a suburban deployment in which a number of meteorological radars are deployed.

For a UWB density of 100 devices/km^2, still representing a suburban deployment, the protection criteria is exceeded by up to 7 dB.

Acknowledging further that the whole interference protection criteria can not be given to a single application, the statistical simulations hence tend to demonstrate that, **on an aggregate basis**, the adequate UWB power density limit to protect meteorological radars in the 2.7-2.9 GHz band is **-71 dBm/MHz**, which correspond to a 10 dB tightening of the United States regulations limits.

7.2.2.4 Frequency band 5 600-5 650 MHz

The parameters of the meteorological radars used for the simulations are given in Table 83.

With regards to UWB devices, the same power limit (-41.3 dBm/MHz) is proposed in the current United States regulation, for all UWB applications.

For the statistical approach, interference calculations have been performed with indoor and outdoor telecommunications devices, taking into consideration a 10 dB additional attenuation for indoor devices.

7.2.2.4.1 Deterministic approach results in the 5.6 GHz band

FIGURE 131

43 dBi antenna gain

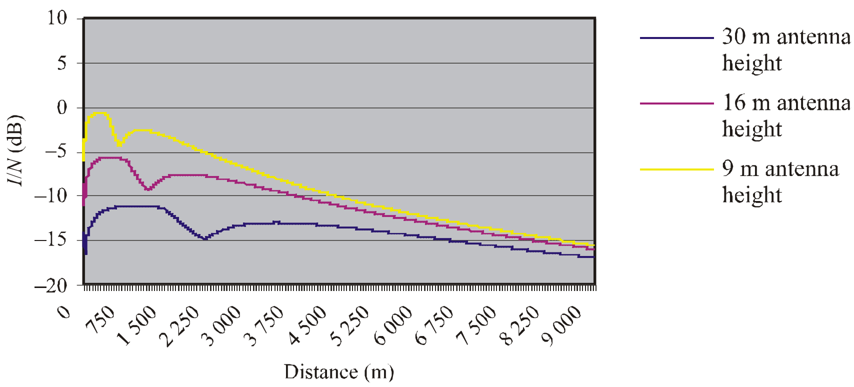
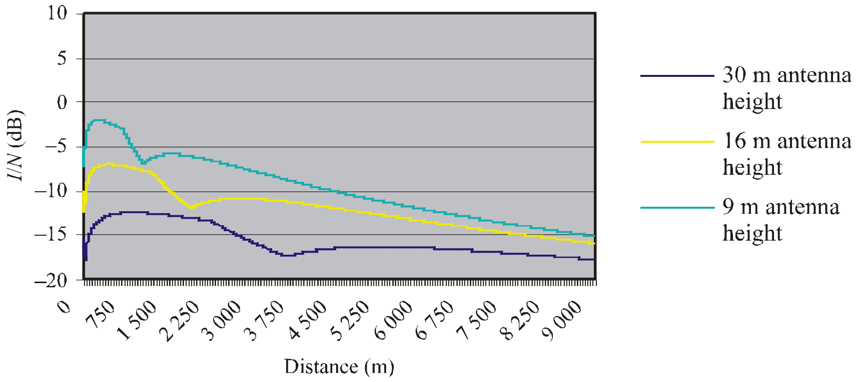


FIGURE 132

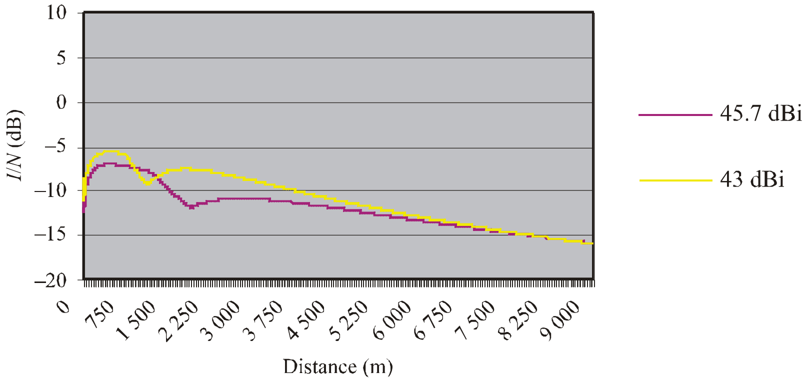
45.7 dBi antenna gain



Rap 2057-132

FIGURE 133

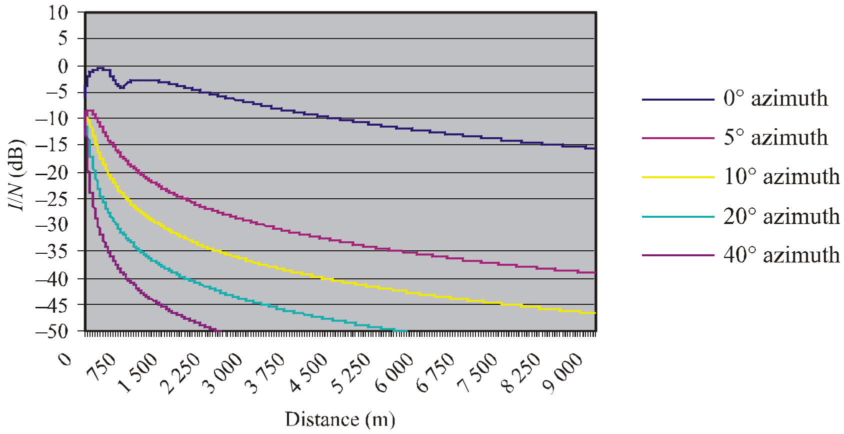
Antenna gain comparison (16 m antenna height)



Rap 2057-133

FIGURE 134

Azimuth comparison (43 dBi and 16 m)



Rap 2057-134

Figures 132 to 134 clearly shows that, on a single entry basis, UWB devices operating with a –41.3 dBm/MHz power density limit are not compatible with meteorological radars in the 5.6-5.65 GHz frequency band.

The interference protection criteria are exceeded by up to 10 dB, in particular at low distance from the radar where no additional interference attenuation can be expected.

Compared to 2.8 GHz band calculations as presented in § 3.1 above, the interference difference is mainly due to the difference in free space attenuation (6 dB) and to the different antenna gains and antenna heights.

As shown on Fig. 134, such high interference levels are also experienced in ranges of azimuth from the radar that are not negligible (up to ± 5° at several hundreds metres from the radar).

As a conclusion, **on a single entry basis**, it is proposed that power limits of UWB applications in the 5.6-5.65 GHz band **be limited at the maximum to –51 dBm/MHz**, whatever the considered applications.

7.2.2.4.2 Statistical approach results in the 5.6 GHz band

Statistical simulations have been performed for all type of UWB devices, for each of the UWB densities as given in Table 84, and with meteorological radars parameters assumed to be typical, i.e.:

– 43 dBi antenna gain;

– 16 m antenna height.

Figure 135 gives the result of the 12 simulations performed for 50 active UWB devices/km^2, consistent with suburban case.

FIGURE 135

5.6 GHz band simulations results (50 UWB/km^2)

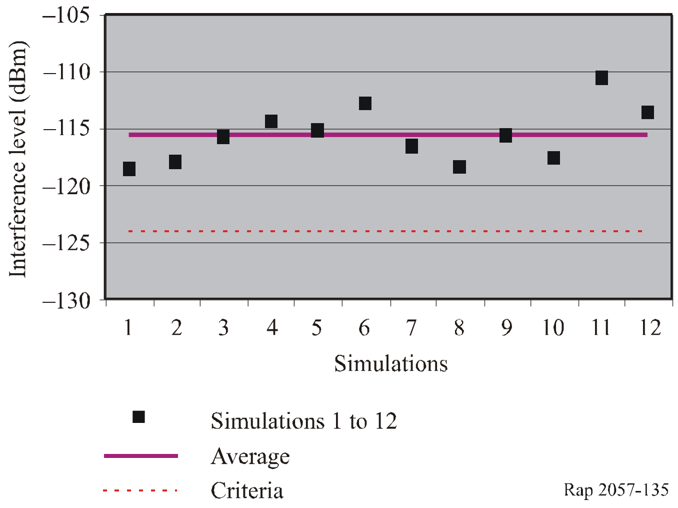


Figure 136 gives a summary of all simulations by plotting for each UWB density case, the maximum interference level among the 12 simulations, the minimum interference level and the average value of the 12 simulations.

FIGURE 136

5.6 GHz band simulations results

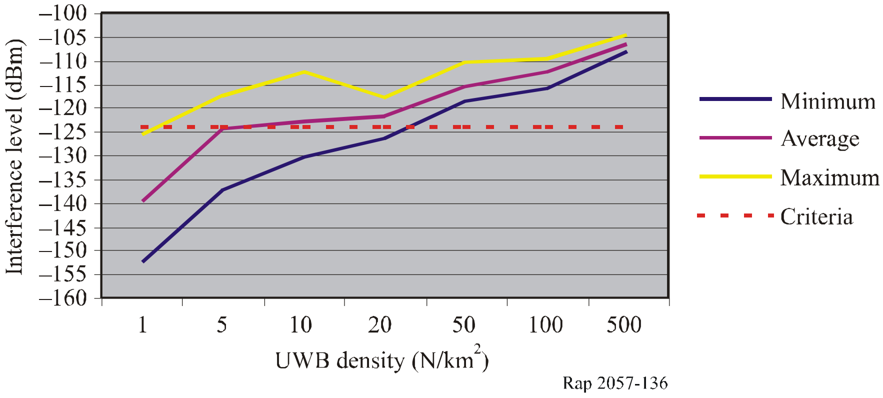


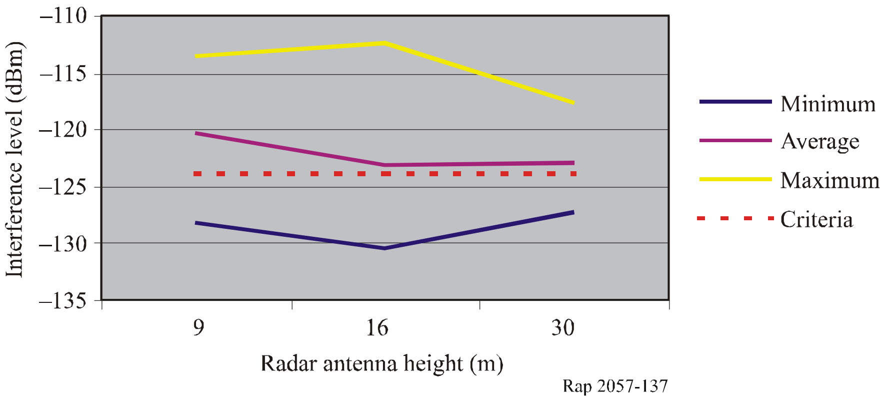
Figure 136 clearly shows that for deployment of UWB operating at –41.3 dBm/MHz, the meteorological radar protection criteria is exceeded in almost all cases, whatever is the UWB density.

For UWB density up of 100 devices/km^2, representing a suburban deployment in which meteorological radars are typically implemented, the protection criterion is exceeded by up to 15 dB.

Figure 137 also provides a comparison of similar interference levels for different antenna heights (and for 10 UWB devices/km^2) that also confirms the impact of the radar antenna height on the interference calculation, increased in average by about 5 dB when considering 9 m antenna height instead of 16 m.

FIGURE 137

5.6 GHz band simulations results (10 UWB/km^2)
Antenna height comparison



Also acknowledging that the whole interference protection criteria can not be given to a single application, the statistical simulations hence tend to demonstrate that, **on an aggregate basis**, the adequate UWB power density limit to protect meteorological radars in the 2.7-2.9 GHz band is **–65 dBm/MHz**, which correspond to a 24 dB tightening of the United States regulations limits.

7.2.2.5 Frequency band 9 300-9 500 MHz

The parameters of the meteorological radars used for the simulations are given in Table 83.

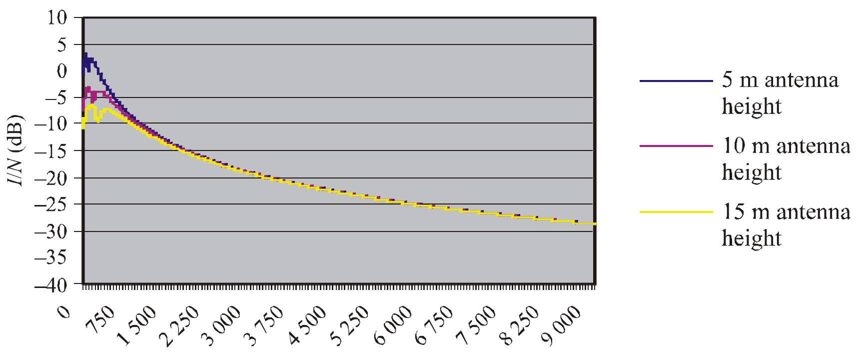
With regards to UWB devices, the same power limit (-41.3 dBm/MHz) than in the 5.6 GHz is proposed in the current United States regulation, for all UWB applications.

For the statistical approach, interference calculations have been performed with indoor and outdoor telecommunications devices, taking into consideration a 10 dB additional attenuation for indoor devices.

7.2.2.5.1 Deterministic approach results in the 9.4 GHz band

FIGURE 138

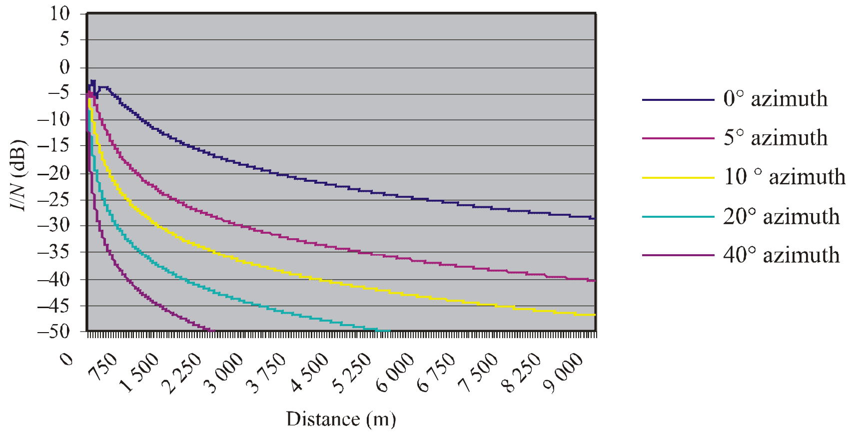
33 dBi antenna gain



Rap 2057-138

FIGURE 139

Azimuth comparison (33 dBi and 10 m)



Rap 2057-139

Figure 138 clearly shows that, on a single entry basis, UWB devices operating with a -41.3 dBm/MHz power density limit are not compatible with meteorological radars in the 9 300-9 500 MHz frequency band.

The interference protection criteria are exceeded by up to 13 dB, in particular at low distance from the radar where no additional interference attenuation can be expected.

As shown on Fig. 139, such high interference levels are also experienced in ranges of azimuth from the radar that are not negligible (up to ± 5° at several hundreds metres from the radar).

As a conclusion, **on a single entry basis**, it is proposed that power limits of UWB applications in the 9 300-9 500 MHz band **be limited at the maximum to –54 dBm/MHz**, whatever the considered applications.

7.2.2.5.2 Statistical approach results in the 9.4 GHz band

Statistical simulations have been performed for all type of UWB devices, for each of the UWB densities as given in Table 84, and with meteorological radars parameters assumed to be typical, i.e.:

– 33 dBi antenna gain;

– 10 m antenna height.

Figure 140 give the result of the 12 simulations performed for 50 active UWB devices/km^2, consistent with suburban case.

FIGURE 140

9.4 GHz band simulations results (50 UWB/km^2)

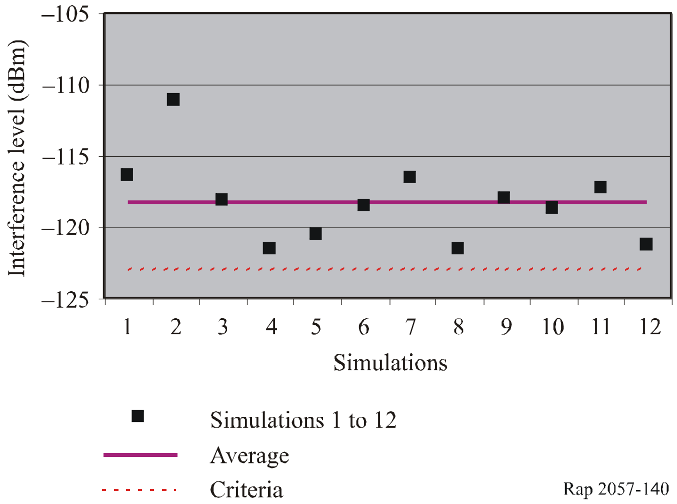


Figure 141 gives a summary of all simulations by plotting for each UWB density case, the maximum interference level among the 12 simulations, the minimum interference level and the average value of the 12 simulations.

FIGURE 141

9.4 GHz band simulations results

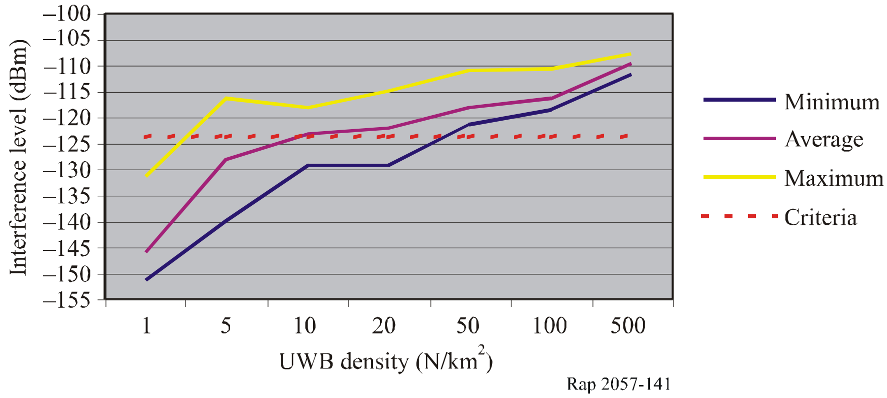


Figure 141 clearly shows that for deployment of UWB operating at –41.3 dBm/MHz, the meteorological radar protection criteria is exceeded in almost all cases, whatever is the UWB density.

For UWB density up of 100 devices/km^2, representing a suburban deployment in which meteorological radars are typically implemented, the protection criteria is exceeded by up to 13 dB.

Also acknowledging that the whole interference protection criteria can not be given to a single application, the statistical simulations hence tend to demonstrate that, **on an aggregate basis**, the adequate UWB power density limit to protect meteorological radars in the 2.7-2.9 GHz band is **-60 dBm/MHz**, which correspond to a 19 dB tightening of the United States regulations limits.

7.2.2.6 Conclusion of Study B

Study B, that considers meteorological deployment in the 2.8, 5.6 and 9.4 GHz bands shows that UWB devices operating at power density levels described in the United States regulations are not compatible with meteorological radars.

Detailed simulations presented on both deterministic (single entry) and statistical (aggregate) basis provide enough materials to determine, as given in Table 85, the adequate power density limit that would allow UWB applications to operate in the 2.8 GHz, 5.6 GHz and 9.4 GHz frequency bands without producing harmful interference to meteorological radars.

TABLE 85

Power density limit necessary to protect meteorological radars

Frequency band (GHz)	UWB application type	Current United States power density limit (dBm/MHz)	Power density limit necessary to protect meteorological radars (dBm/MHz)
2.8	Imaging (low density)	–41.3	–51
	Telecommunication (indoor)	–51.3	–61
	Telecommunication (outdoor)	–61.3	–71
5.6	Imaging (low density)	–41.3	–51
	Telecommunication (indoor and outdoor)	–41.3	–65
9.4	Imaging (low density)	–41.3	–54
	Telecommunication (indoor and outdoor)	–41.3	–60

7.3 Conclusion

Even though using similar approaches, studies A and B provide different conclusions on the impact of UWB devices on meteorological radars in the 2 700-2 900 MHz frequency band. Study B concludes on the need to tighten by 10 dB the power density limits as currently regulated in the United States whereas Study A, performed by the United States Administration, conclude on the adequacy of these limits to protect meteorological radars.

The main rationale to these different conclusions relates to the antenna height and antenna gain figures used in both studies and that are by a large amount controlling the level of interference. Indeed, lower figures for these two parameters lead to an increase of the relative antenna gain under which UWB devices are seen from the radar and hence to an increase of the interference level.

Study A considers a 30 m antenna height and a 45.7 dBi antenna gain that may be representative of meteorological radars in the United States but that are not representative of typical meteorological radars such as those deployed in Europe where antenna height down to 7 m and antenna gain down to 39 dBi are deployed.

Therefore, the current power density limits as regulated in the United States may be sufficient to protect one specific type of meteorological radar as deployed in the United States but is not sufficient to protect typical meteorological radars deployed worldwide that need a 10 dB tightening, as shown in the above table.

The bands 5 600-5 650 MHz and 9 300-9 500 MHz were not considered in Study A since these meteorological radars are not predominantly used in the United States. It can therefore be assumed that the derivation of the United States power density limits did not considered the case of meteorological radars in the 5.6 and 9.4 GHz bands.

Study B clearly shows that there is a need for a large tightening of these United States limits to ensure the protection of meteorological radars. It is important to stress that, unlike the 2 700-2 900 MHz band, these two frequency bands are in the generic band for UWB telecommunications devices (3-10.6 GHz band) in which the United States limits are 20 dB higher than the limits in the 2.8 GHz band.

Hence, the power density limits as currently regulated in the United States are not adequate to ensure protection of meteorological radars in the 2.8 GHz, 5.6 GHz and 9.4 GHz bands deployed such as those in Europe, at the exception of the specific case of radars deployed in the United States in the 2.8 GHz with 30 m antenna height and 45.7 dBi antenna gain.

Apart from this latter case, power density limit as in Table 85 are necessary to adequately protect meteorological radars.

Appendix 1
to Annex 1

(Ref: § 1.6.2)

Characterization of a mobile handset in multipath environments

Introduction

There are multiple techniques for evaluating the performance of a mobile handset under fading conditions. In this Appendix, we present results from a measurement technique based on reverberation chamber.

1 Measurement approaches

In order to reliably predict the handset's performance in any realistic environment, one must accurately account for all of the factors that affect radio propagation. Among these factors are head and body loss, radiation efficiency of the antenna and the handset's response to multipath fading.

There are different approaches for measuring the impact of each of these factors. One approach involves a measurement technique described in the CTIA standard for over-the-air performance testing of mobile phones*. Another approach involves the use of a reverberation chamber. Both of these very different approaches provide similar results. The information and results presented in this Appendix are taken from the references cited below. [Orlenius *et. al.*, 2003 and 2005].

* Cellular Telecommunication & internet Association (CTIA), Method of Measurement of Radiated RF power and receiver performance, Rev. 2.0, March 2003.

2 Reverberation chamber

The reverberation chamber has been widely used for EMC measurements for many years. Recent advances in this technology have improved the accuracy of measurements preformed in relatively small chambers, with smallest dimensions of the order of several wavelengths of the lowest frequency of interest. These developments [Rosengren *et. al.*, 2001; Hill, 1994 and 1998] coupled with the simplicity of procedures for operation of the chamber, are making the reverberation chamber the tool of choice in measuring radiation antenna efficiency, free space radiation impedance, diversity gain of antennas, the channel capacity of MIMO antenna systems, and the total radiated power and receive sensitivity of mobile phones and other wireless devices, based on different technologies (e.g. GSM, CDMA, DECT, Bluetooth, UMTS).

3 The total isotropic sensitivity (TIS) measurements of cdma2000 mobile phones

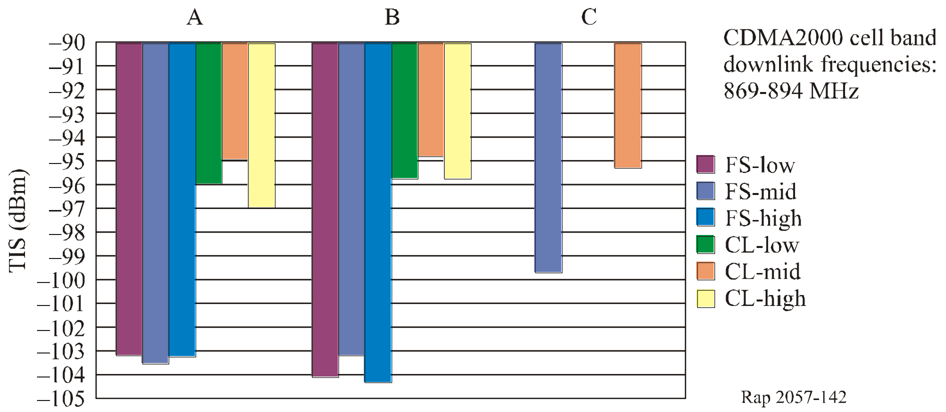
The term total isotropic sensitivity (or spherical effective radiated receive sensitivity of the phone) is a standard measure of the handset's receiver sensitivity which includes the degradation due to the radiation efficiency of the antenna. TIS is equal to the conducted receiver sensitivity of the handset, measured at the receiver port, taking into account the radiation efficiency of the phone antenna. This is presented in CTIA standard for radiation test (anechoic chamber).

These tests determine both the effect of handset antenna (when tested in free space mode), and the head and hand losses, when operated in talk mode, next to the phantom head and hand.

Consistent with the CTIA standard, TIS is measured on three channels (low, middle and high). Three cdma2000 phones were tested both in a free space position (FS), and in talk position (handset next to a phantom head) and the test results are presented in Fig. 141. The test results are also included in the summary Table 86. For additional results, information on measurement setup and test procedures related to reverberation chamber, see cited references[40].

FIGURE 142

Results of TIS measurement for three phones in both free space and talk position, next to a phantom head



4 The average fading sensitivity (AFS) measurements of cdma2000 mobile phones

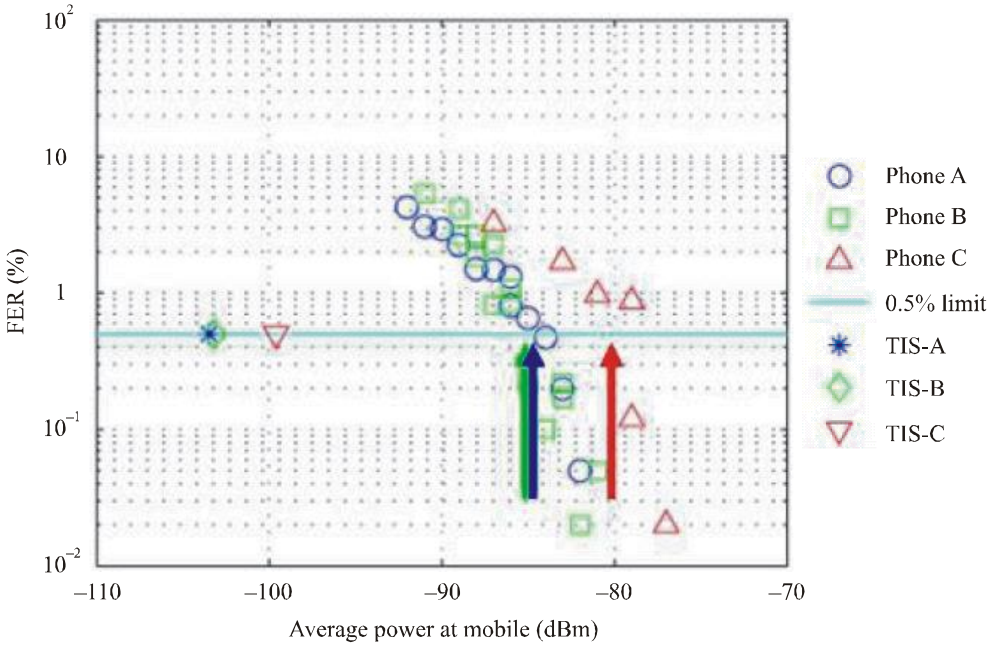
A reverberation chamber also supports a Rayleigh distribution of propagating signals which are used to simulate a real-time fading environment. It can directly measure the average FER for a handset in

[40] See footnotes 30 and 31. Additional results are provided at: http://www.bluetest.se/downloads/Bluetest-IEEEAPS2005-shortcourse-050611.pdf.

this environment. The AFS for three phones were measured and results are shown in Fig. 143 and a summary of the results is presented in Table 86. For information on measurement setup and test procedure, see cited references[41].

FIGURE 143

Average FER measured in Rayleigh fading environment of a reverberation chamber for three phones in free space position measured at the cell band. The TIS values in free space are also shown



Rap 2057-143

5 Comparison between TIS and AFS sensitivities[42]

Table 86 summarizes the data presented in the above graphs. The AFS values in the table are determined at the 0.5% FER level.

TABLE 86

TIS and AFS measured in free space position inside the reverberation chamber. Phones A and B are the same model and measured at channel 283 (cell band). Phone C is different model and measured at channel 356

	TIS (dBm)	AFS (dBm)
Phone A	–103.5	–84.8
Phone B	–103.2	–85.4
Phone C	–99.6	–80.4

[41] See footnotes 32.

[42] See footnote 30.

Appendix 2
to Annex 1

(Ref: § 1.62)

Noise figure calculation: The block diagram depicts a typical receiver front end. It is used in this Appendix to clarify a number of issues related to noise figure. Additionally, the Appendix presents a methodology for computing the noise figure. Table 87 provides an example of some of the key components used in current handsets. The following equation is used to calculate the noise figure for *Block 2*, which when applied to our example turns out to be equal to about 10 dB.

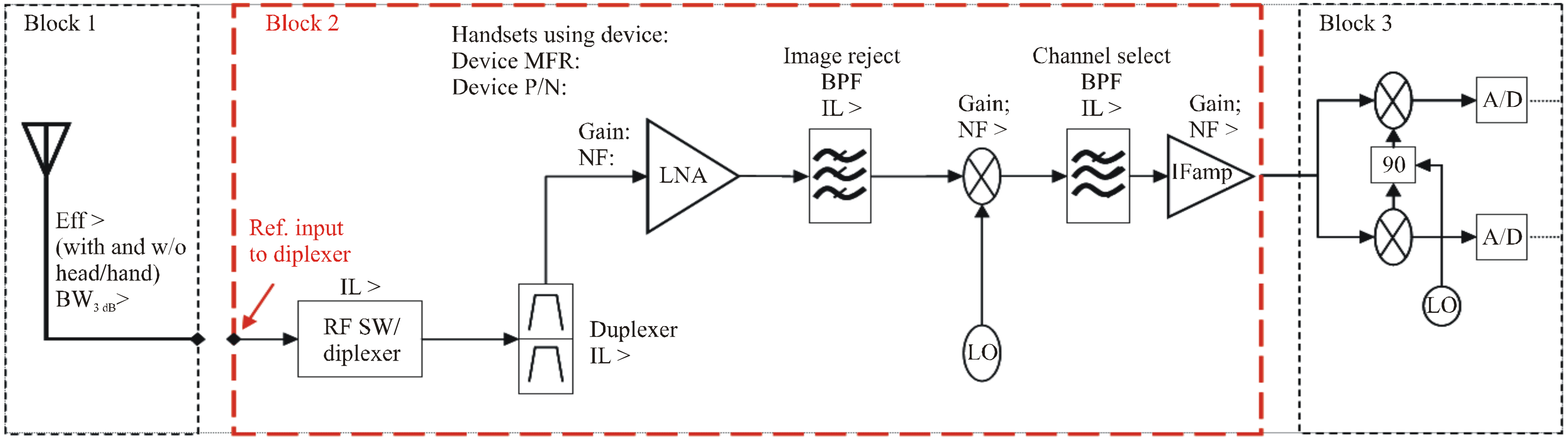
$$Noise\ \ figure_{Block\ 2} = F1 + \frac{F2-1}{G1} + \frac{F3-1}{G1G2} + \frac{F4-1}{G1G2G3} + ...$$

where:

F: noise factor (numeric)

G: gain (numeric).

FIGURE 144



Rap 2057-144

TABLE 87

Contributions to the MS handset noise figure from components in current use

	Total	Misc losses i.e. circuit board)	RF SW/diplexer	Duplexer[(1)]	LNA	Image BPF	Mixer	IF BPF
			MFR:ANADIGICS P/N: AWS5533	MFR: muRata P/N:DFYK91G88LEHAC	MFR: ST P/N:SMA640A	MFR. Eg., Fujitsu/muRata	MFR: Philips P/N: BGA2020	MFR: Eg., Fujitsu/TriQuint
Gain (dB)	10.70	–1	–0.7	–4.6	14	–3	6	–3
NF (dB)	9.92	1	0.7[(2)]	4.6[(2)]	1.6	3[(2)]	9	3[(2)]

(1) In the following FCC filing it is shown that at elevated temperatures filter response shifts by approximately 2-2.5 MHz (either direction). CDMA and GSM lose approximately 2 to 10 dB at 1 917.5 MHz as shown in slide 15 at: https://ecfsapi.fcc.gov/file/6518151338.pdf.

(2) Insertion loss.

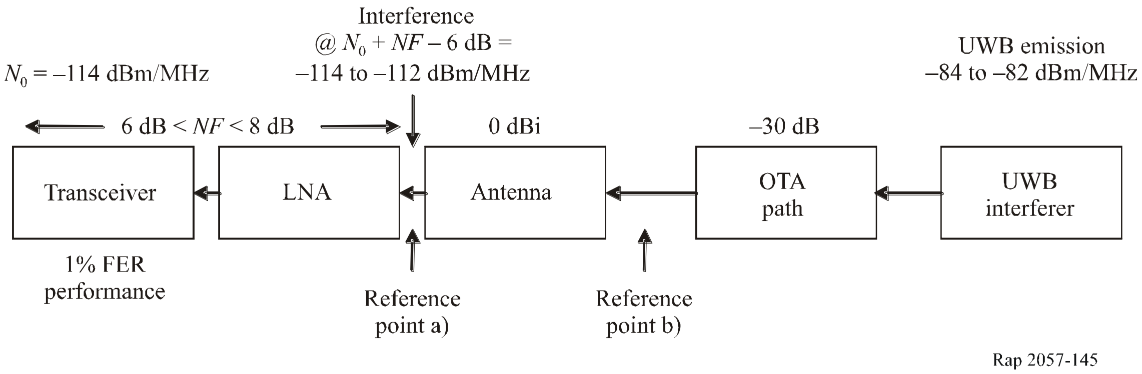
Appendix 3
to Annex 1
(Ref: § 1.6.3)

1 Input to the Correspondence Group by Sector Members

A PCS receive block diagram containing measurable reference points is shown below, for a mobile device in weak signal coverage with local wide band radio interference.

FIGURE 145

CDMA receiver model



A CDMA mobile device receiver utilizes its low radio noise figure in weak coverage conditions, such as indoors or outdoors at cell edges. The minimum useful receive radio signal level is limited by the radio noise floor, which is determined by receiver temperature, *T*, radio frequency bandwidth, *B*, and radio noise figure, *NF*. The noise floor competes with the received signal, and limits the sensitivity of the radio receiver.

$$\textit{Radio noise floor } N = k\,T\,B + NF \text{ (in units of rf power, energy/s)}$$

For digital cellular radios, we define the composite digital radio sensitivity as the minimum received desired signal power at which a predetermined FER onset occurs.

The industry standard TIA-98 specifies minimum sensitivity of –104 dBm/1.25 MHz = –105 dBm/MHz, for a worst-case 9 dB NF and 10 kbit/s voice call, measured at the antenna connector (Reference point a) in the Fig. 145). The sensitivity of a CDMA receiver is always referenced to point a) and depends on the noise figure of the receiver. The noise figure of the receiver includes all receiver artifacts and additional losses (cable and any receiver component including the LNA). The gain, *G*, is the net gain of the antenna, feeder loss and any loss due to the needed matching circuit. Dependent on NF, current CDMA mobile devices typically operate ($6 < NF < 8$ dB) in the radio noise floor spectral density ($N_0 + NF$) range of:

$$N = –106 \text{ to } –108 \text{ dBm/MHz}$$

The threshold of interference to the receiver from a nearby wide band interference source (causing say a 1 dB rise of the received radio noise signal), occurs with added noise at about 6 dB below the receive signal level. For a weak coverage signal near the sensitivity level, the threshold of interference is:

$$I_R = N – 6$$

$$= –112 \text{ to } –114 \text{ dBm/MHz}$$

At a distance of 0.4 m = 30 dB isotropic free-space path loss at 1 900 MHz, the interferer's transmit e.i.r.p. at the threshold of interference is

$$I_T = I_R + 30 \text{ dB}$$
$$= –82 \text{ to } –84 \text{ dBm/MHz}$$

Note that Recommendation ITU-R P.341 (sub-section A41), contains the "transmission loss concept" diagrammatically, which is aligned with Fig. 145 above, where the above "antenna" combines both receiving antenna gain and the receiving antenna loss and the "filters, feeder" is included within the transceiver. Due to the small separation distance (0.4 m), free-space path loss is appropriate.

Appendix 4
to Annex 1
(Ref: § 1.6.3)

1 Input to the Correspondence Group by one Administration

To clarify the statements made about the noise figure, please provide the following information. See the receiver block diagram in Appendix 2 to Annex 1.

– Complete the table.

– Calculate the corresponding noise figure, E, using the following equation:

$$Noise\ \ figure_{Block\ 2} = F1 + \frac{F2-1}{G1} + \frac{F3-1}{G1G2} + \frac{F4-1}{G1G2G3} + ...$$

– Provide couple examples of handsets (e.g. MFR, model number) currently using all of these parts.

Device	MFR	Part number	Gain/loss	Noise figure
Diplexer/RF SW				
Duplexer				
LNA				
Image reject BPF				
Mixer				
IF Filter				

Appendix 5
to Annex 1
(Ref: § 1.6.3)

1 Input to the Correspondence Group by a Sector Member

2 Mobile forward/reverse antenna gain

We understand that the mobile manufacturers tune (design) the VSWR and other factors at the mobile antenna interface to be somewhat equal at the downlink (1 930-1 990 MHz) and uplink (1 850-1 910 MHz) frequencies, and expect the gain to be approximately equal in both directions. We use no forward/reverse asymmetry for mobile antenna gain our network link budget.

We performed some antenna gain measurements on mobiles, for both receive and transmit bands, show the gains to be fairly equal, within the measurement accuracy we are able to attain. There may be a trend for 1-2 dB less gain in the receive direction, that might need to be corrected if true.

For transmit antenna gain, we use the “max power” intrinsic transmit operating point, and the “receive sensitivity level” as the intrinsic receive operating point. The uncertainty in the receive measurement is higher than the transmit measurement, because the low levels at the receive sensitivity operating point. The test data below shows the typical RX and TX antenna gain measurement data for three fairly current phones.

The antenna gain is defined here to be with respect to the conveniently measurable antenna connector, which is mainly an rf-test-connector located electrically close to the mobile antenna driving point, whose ubiquitous presence is driven by testability requirements in the 3GPP2-C.S0011 specification.

3 Transmit

In the mobile transmit direction, for PCS band 1 850-1 910 MHz, the mobile is driven to the intrinsic max power point, producing approximately +25 dBm at the antenna connector, and with for example 2 dB peak gain, yielding a measurement of +27 dBm peak e.i.r.p.

The peak reverse gain varies from –1 to +3 dBi, with some measurement error of less than a dB.

4 Receive

In the mobile receive direction, for PCS band 1 930-1 990 MHz, the mobile is presented with a receive signal near the intrinsic (thermal) sensitivity limit. At the antenna connector, this is measured to be in the range of –107 dBm to –109 dBm (depends mostly on multi-band duplexors and other front end attenuation configurations.) Receive antenna gain measurements show a range of –1 to +3 dBi, but the measurements are still thought to be error prone (due to the noisy operating point near the sensitivity limit).

Mobile 1 transmit

	Free space			**Phantom head right ear**			**Human head right ear**		
Antenna position	**Fixed**			**Fixed**			**Fixed**		
CDMA band	**PCS**			**PCS**			**PCS**		
CDMA channel	**25**	**600**	**1 175**	**25**	**600**	**1 175**	**25**	**600**	**1 175**
RF port TX power (dBm)	24.5	24.7	24.7	24.5	24.7	24.7	24.5	24.7	24.7

TRP (dBm)	21.7	21.6	21.1	19.3	20.1	19.1	14.0	15.0	14.6
Antenna efficiency (dB)	–2.8	–3.1	–3.6	–5.2	–4.6	–5.6	–10.5	–9.7	–10.1
Peak e.i.r.p. (dBm)	25.6	25.6	24.9	25.7	26.3	25.6	21.9	22.9	22.5
Min e.i.r.p. (dBm)	3.4	4.8	7.5	0.1	–1.5	–2.7	–7.7	–9.1	–8.4
Average e.i.r.p. (dBm)	21.2	21.1	20.6	17.8	18.5	17.5	11.6	12.5	12.1
Peak antenna gain (dBi)	1.1	0.9	0.2	1.2	1.6	0.9	–2.6	–1.8	–2.2
Direction of peak, θ (degrees)	195.1	195.1	180.1	315.2	240.1	240.1	345.2	345.2	345.2
Direction of peak, ψ (degrees)	111.1	111.1	111.1	100.6	74.1	68.8	111.1	105.9	105.9
NHPRP at 30° (dBm)	19.2	19.1	18.5	17.4	18.2	17.2	12.7	13.7	13.3
NHPRP at 45° (dBm)	20.6	20.5	20.0	18.5	19.2	18.3	13.5	14.5	14.1

Mobile 1 receive

Condition	**Free space**			**Phantom head right ear**		
Antenna position	**Fixed**			**Fixed**		
CDMA band	**PCS**			**PCS**		
CDMA PCS channel	**25**	**600**	**1 175**		**600**	
RF Port RX sensitivity (dBm)	–107.0	–108.0	–108.0		–108.0	
TIS (dBm)	–103.2	–104.2	–103.9		–98.8	
Antenna efficiency (dB)	–3.8	–3.8	–4.1		–9.2	
Peak EIS (dBm)	–106.3	–107.6	–107.3		–106.8	
Min EIS (dBm)	–91.0	–88.5	–88.7		–80.7	
Average EIS (dBm)	–102.1	–102.9	–102.5		–95.0	
Peak antenna gain (dBi)	–0.7	–0.4	–0.7		–1.2	
Direction of peak, θ (degrees)	120.1	30.0	30.0		60.0	
Direction of peak, ψ (degrees)	31.8	127.0	127.0		–63.5	
NHPIS at 30° (dBm)	–101.3	–102.4	–102.1		–91.6	
NHPIS at 45° (dBm)	–102.8	–103.9	–103.5		–93.1	

Mobile 2 transmit

Condition	**Free space**			**Free space**			**Human head right ear**		
Antenna position	**Fixed, standard battery**			**Fixed, extended battery**			**Fixed**		
CDMA band	**PCS**			**PCS**			**PCS**		
CDMA channel	**25**	**600**	**1 175**	**25**	**600**	**1 175**	**25**	**600**	**1 175**
RF port TX power (dBm)	23.8	23.9	24.6	23.8	23.9	24.6	23.8	23.9	24.6
TRP (dBm)	20.3	19.8	20.7	21.0	20.1	21.1	9.9	8.7	10.0
Antenna efficiency (dB)	–3.5	–4.1	–3.9	–2.8	–3.8	–3.5	–13.9	–15.2	–14.6
Peak e.i.r.p. (dBm)	23.4	23.2	24.4	23.8	22.8	23.9	17.8	16.4	17.7
Min e.i.r.p. (dBm)	5.1	3.1	3.0	7.1	4.8	6.2	–11.4	–11.2	–7.0

Average e.i.r.p. (dBm)	19.7	19.2	20.1	20.3	19.4	20.4	8.5	7.3	8.7
Peak antenna gain (dBi)	–0.4	–0.7	–0.2	0.0	–1.1	–0.7	–6.0	–7.5	–6.9
Direction of peak, θ (degrees)	180.1	150.1	150.1	225.1	225.1	225.1	105.1	105.1	105.1
Direction of peak, ψ (degrees)	37.0	42.3	42.3	90.0	95.3	95.3	137.6	137.6	137.6
NHPIS at 30º (dBm)	18.1	17.5	18.3	18.8	17.8	18.7	7.5	6.1	7.4
NHPIS at 45º (dBm)	19.2	18.7	19.5	20.0	18.9	19.9	8.9	7.6	8.9

Mobile 2 receive

Condition	**Free space**			**Phantom head right ear**		
Antenna position	**Fixed**			**Fixed**		
CDMA band	**PCS**			**PCS**		
CDMA PCS channel	**25**	**600**	**1 175**	**25**	**600**	**1 175**
RF port RX sensitivity (dBm)	–108.5	–109.0	–108.0	–108.5	–109.0	–108.0
TIS (dBm)	–103.6	–104.9	–103.9	–100.9	–101.9	–100.6
Antenna efficiency (dB)	–4.9	–4.1	–4.1	–7.6	–7.1	–7.4
Peak EIS (dBm)	–108.1	–108.3	–107.4	–107.5	–108.8	–106.7
Min EIS (dBm)	–90.2	–92.8	–90.5	–89.3	–88.4	–88.1
Average EIS (dBm)	–102.5	–103.8	–102.9	–99.2	–100.0	–98.8
Peak antenna gain (dBi)	–0.4	–0.7	–0.6	–1.0	–0.2	–1.3
Direction of peak, θ (degrees)	150.1	0.0	120.1	150.1	150.1	150.1
Direction of peak, ψ (degrees)	31.8	95.3	31.8	0.0	–127.0	–127.0
NHPIS at 30º (dBm)	–101.3	–102.8	–101.6	–94.8	–95.8	–94.1
NHPIS at 45º (dBm)	–102.9	–104.2	–103.2	–96.6	–97.5	–95.9

Mobile 3 transmit

Condition	**Free space**			**Phantom head right ear**		
Antenna position	**Retracted**			**Retracted**		
CDMA band	**PCS**			**PCS**		
CDMA channel	**25**	**600**	**1 175**	**25**	**600**	**1 175**
RF port TX power (dBm)	23.6	23.7	23.6	23.6	23.7	23.6
TRP (dBm)	20.8	20.6	19.6	20.5	20.3	19.0
Antenna efficiency (dB)	–2.8	–3.1	–4.0	–3.1	–3.4	–4.6
Peak e.i.r.p. (dBm)	26.8	27.0	26.0	29.7	29.6	28.3
Min e.i.r.p. (dBm)	6.8	3.2	1.6	–1.0	1.2	0.3
Average e.i.r.p. (dBm)	18.8	18.7	17.7	17.3	17.2	16.2
Peak antenna gain (dBi)	3.2	3.3	2.4	6.1	5.9	4.7
Direction of peak, θ (degrees)	165.1	165.1	165.1	285.1	285.1	285.1
Direction of peak, ψ (degrees)	116.4	116.4	121.7	116.4	121.7	121.7

NHPIS at 30º (dBm)	18.9	18.6	17.5	18.1	17.8	16.5
NHPIS at 45º (dBm)	20.0	19.8	18.7	19.6	19.3	18.0

Mobile 3 receive

Free space		
Extended		
PCS		
25	600	1 175
–107.0	–108.0	–106.5
–100.5	–103.7	–101.3
–6.5 –107.5	–4.3 –112.3	–5.2 –108.6
–91.7	–94.5	–93.9
–98.0 0.5	–101.3 4.3	–99.3 2.1
0.0	150.1	150.1
–95.3 –97.9	95.3 –101.9	95.3 –98.9
–98.8	–102.8	–99.9

Annex 2

Studies related to the impact of devices using ultra-wideband technology on systems operating within the fixed service

1 Summary

The mixture of indoor/outdoor UWB percentage for Scenarios 1a, 1b and 1c (bands below 11.6 GHz) has been here unified to a 20% for all rural and urban scenarios.

In this Annex, the possible implementation of some UWB applications in the FS bands is explored on few representative cases of expected worst-case scenarios. The FS performance criteria, receiver characteristics are defined and numerical evaluations are carried on. Finally, some limits for UWB devices are proposed in parametric form depending on UWB deployment characteristics (e.g., device density, peak power factors).

This Annex is focused on studies on bands allocated to FS between 3 and 26 GHz. For frequency bands lower than 3 GHz, where lower bandwidth are expected for FS systems (FWA and P-P typically do not exceed 7/14 MHz), qualitative considerations leading to very close objectives and e.i.r.p. spectral density (SD) requirements for FS protection are presented.

Another UWB application intended for deployment in bands between 22 to 26.5 GHz (e.g. vehicular anti-collision devices that present different interference scenarios) are proposed.

Based on protection criteria and FS system characteristics are those in Recommendation ITU-R SM.1757, the UWB interference objectives are summarized in Tables 88 and 89.

The potential interference scenarios associated with this kind of generic analysis depends on many different parameters, which highly affect the aggregated interference power. The choice of the appropriate set of parameters for building up a reasonable "worst case" could vary from administration to administration.

This is due to a number of reasons such as:

– The search for the reasonable parameters for building up a "worst-case" scenario also depend on a number of mitigation factors that, being mostly of unpredictable and uncertain nature, cannot be definite with a unique value or their presence can not be guaranteed in all cases; also for them the "subjective" perception of administration may vary for local, historical, national policy, geographical or other reasons.

– In selecting this reasonable set of parameters for "worst-case" evaluation, also the "degree of risk" that administrations wish to take for balancing the protection of the FS primary service and the attractive use of SRR emerging technology, depends on the above-mentioned factors.

Therefore, while maintaining the same general interference scenarios, the study, when aggregate interference is concerned, will derive two different numerical conclusions based on two different FS case studies:

Case 1: This case represents the potential interference from "generic" UWB devices which could be used for any possible unknown applications, with safeguard for high activity (up to 5% and up to 20% for hot-spots). Also any additional mitigation factors which are of unpredictable and uncertain in nature will not be taken into account so that the risk of potential interference from SRR to the FS is maintained low in any circumstances.

Case 2: This case uses a different set of parameters that takes into account other specific factors associated with WPAN applications, with current foreseen average activity over a large population (up to 1%) and average mitigation factors which normally might assure UWB operation free from giving harmful interference to FS links, but may exceed the FS protection objectives by some dB in extreme situations. In addition, it is assumed that the higher impact of "single entry" UWB interference cases are avoided through specific provisions (i.e. mitigation techniques, such as DAA, to protect indoor fixed wireless access terminal stations (FWA TS) on the same desk and banning UWB devices deployed on fixed outdoor locations to protect outdoor FS station from LoS situations within their boresight angle footprint).

Values in Table 88 are referenced to the antenna input and take into account feeder losses, when applicable, between the antenna and the receiver input. They are based on an I/N (r.m.s. in 1 MHz) = –20 dB protection criteria for the average (r.m.s.) objective and on a preliminary $I_{Peak}/N_{r.m.s.}$(in 50 MHz) = +5 dB for the peak objectives. This value has been derived from practical interference tests at 23 GHz reported in Appendix 1 to this Annex, also assuming that the FS receiver behaviour and the emission characteristics of UWB devices are similar in any frequency band.

TABLE 88

Summary of UWB aggregate interference objectives for protection of FS

		Average power density of aggregate interference (dBm/MHz)				Peak power wide-band density of aggregate interference (dBm/50 MHz)			
		Bands 3 to 6 GHz	**Bands 7 and 8 GHz**	**Band 10.5 GHz**	**Bands 23 and 26 GHz**	**Bands 3 to 6 GHz**	**Bands 7 and 8 GHz**	**Band 10.5 GHz**	**Bands 23 and 26 GHz**
FWA CS and TS (wide-band BW = 50 MHz)	CS and outdoor TS	≤ – 129	N/A	≤ – 127	≤ – 128	≤ – 87	N/A	≤ – 85	≤ – 86
	Indoor TS	≤ – 121.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A
High capacity P-P (BW = 50 MHz)		≤ – 127	≤ – 128	≤ – 127	≤ – 128	≤ – 85	≤ – 86	≤ – 85	≤ – 86

N/A: Not available.

The expected aggregate interference level, evaluated in this Report, is compared with these objectives defining maximum level for any single UWB source, relative to its emission characteristic, expected penetration on the territory (e.g. expected density/km^2 in the reference UWB deployment scenarios defined in the main body of this ITU-R Report) and the applicable mitigation factors.

Indoor FWA TS applications are also considered on the bases of a minimum distance from an UWB device.

In addition, for an exhaustive check on any possible severe situation, less restrictive objectives for FWA TS, closer to the CS (but also to the UWB interference source) and not affected by deep fading, are defined in Table 89.

TABLE 89

UWB aggregate interference objectives for protection of FWA TS that are close to the CS

	Average power density of aggregate interference (dBm/MHz)		Peak power wide-band density of aggregate interference (dBm/50 MHz)	
	3.5 GHz band	**10.5 GHz band**	**3.5 GHz**	**10.5 GHz**
FWA TS (wideband BW = 50 MHz)	≤ –104	≤ –102	≤ –74	≤ –72

For the 23 and 26 GHz bands this case is not relevant due to the different protection scenario between FWA TS and UWB vehicular radar applications.

A number of typical scenarios (summarized in the main body of this Report as 1a), 1b), 1c) and 3a) for aggregation of multiple UWB devices, as well as specific single UWB interference evaluation, have been carried on.

The study shows that impact of UWB applications to FS systems might be acceptable with the UWB e.i.r.p. density limits (both r.m.s. and wide-band peak) set in Table 90.

TABLE 90

Limits for FS protection of UWB applications

Scenarios evaluated in this Annex ↓		**Acceptable UWB e.i.r.p. density**	
3.1 GHz to 10.6 GHz band "Case 1: Generic UWB deployment"		**r.m.s. (dBm/MHz)**	**Wide-band peak (dBm/50 MHz)**
Single UWB entry at 1 m distance from indoor FWA TS (1-4.2 GHz only)		–76.5	–34.5
Single outdoor UWB entry in adverse position to an outdoor FS station		–57	–15
Aggregate Scenario 1c: (10.000 UWB/km^2 – 5% activity – 80% indoor)		–59.7	–17.7
Aggregate Scenario 3a: (hot-spot building 1 UWB/10 m^2 – 20% activity)		–60	–18
Single limit for FS protection for all the above scenarios (3.1 GHz to 10.6 GHz)		–76.5 (1)	–34.5(1)
3.1 GHz to 10.6 GHz band "Case 2: Deployment based on WPAN UWB indoor applications"		**Acceptable UWB e.i.r.p. density**	
		r.m.s. (dBm/MHz)	**Wide-band peak (dBm/50 MHz)**
Single UWB entry at 1 m distance from indoor FWA TS (1-4.2 GHz only)		(2)	(2)
Single outdoor UWB entry in adverse position to an outdoor FS station		(2)	(2)
Aggregate Scenario 1c: (10.000 UWB/km^2 – 1% activity – 100% indoor)		–40 to –48(3)	+2 to –6(3)

TABLE 90 (*end*)

Aggregate Scenario 3a: (hot-spot building 1 UWB/10 m^2 – 1% activity with WPAN model)		–38	+4
Single limit for FS protection for all the above scenarios (3.1 GHz to 10.6 GHz)		– 40 to –48 or –76.5(3)	+2 to –6 or –34.5(3)
22 GHz to 29 GHz band		**Acceptable UWB e.i.r.p. density**	
		r.m.s. (dBm/MHz)	**Wide-band peak (dBm/50 MHz)**
Single car entry		See § 1.2.5	See § 1.2.5
Aggregated Highway	Deployment 1	See § 1.2.5	See § 1.2.5
	Deployment 2	See § 2.2.5	See § 2.2.5

(1) This value is driven by the single UWB entry for indoor FWA TS applications that would be limited to bands below 4.2 GHz. Above 4.2 GHz, the limit would be driven by the value for aggregate Scenario 1c to bands up to 7.125 GHz; according to the study, there might be a further relaxation of 2.5 dB up to 8.5 GHz and of further 2.5 dB for the 10.5 GHz band. Also note that the single interferer scenarios do not consider possible mitigation techniques which could significantly limit the presence of outdoor devices as well as allow UWB devices to use adaptive mitigation techniques (e.g. DAA) below 4.2 GHz.

(2) Range depending on variants in the model actual implementation, the consideration of multiple scenario aggregation and the possibility or not of an additional 20% population of handheld UWB devices.

(3) The Case 2 analysis does not, in general, consider the single interferer scenarios (i.e. single outdoor interferer or single indoor interferer) that would significantly adversely affect the impact on the FS applications. Therefore, it should be noted that, if this approach is used, administrations should significant limit outdoor usage of UWB devices by prohibiting outdoor infrastructure and other applications which might be used outdoors. This would result in a very low probability occurrence of an outdoor UWB device operating in close proximity to an outdoor FS antenna. Even when this event does occur, the activity of the UWB device will likely be very small due to the application usage model. In addition, administrations should require UWB devices to use adaptive mitigation techniques to avoid interference to near-by FS systems, typically FWA indoor terminals and related CS. No specific calculation has been made for Case 2 in bands above 4 GHz; however it is assumed that results are considered at least 6 dB more favourable up to 8.5 GHz and 9 dB up to ~11 GHz.

1.1 Fixed service objectives and characteristics

1.1.1 Fixed service protection objectives

The common ITU-R rule for interference from unwanted emissions from sources other than FS or services, sharing the same band on primary bases, is reported in Recommendation ITU-R F.1094. Recommendation ITU-R F.1094 provides the apportionment of the total degradation of an FS link as:

– 89% for the intra service interference;

– 10% for the co-primary services interference;

– 1% for the aggregation of the following interferences:
  a) emissions from radio services which share frequency allocations on a non-primary basis;
  b) unwanted emissions (i.e. out-of-band and spurious emissions such as energy spread from radio systems, etc.) in non-shared bands;
  c) unwanted radiations (e.g. ISM applications).

These percentages[43] are not related to the total time of operation but apply to the performance objectives such as given in Recommendations ITU-R F.1397 and ITU-R F.1491. In addition, this degradation allowance is not given to a single transmitter but to the aggregation of the whole secondary services transmitters and unwanted signals.

Moreover, Recommendation ITU-R F.1094 recommends that no impairment, due to interference, on system availability (generally requested less than 0.01% of the time) be allowed (i.e. propagation attenuation only is to be considered).

This criterion is considered applicable also for the UWB emissions interference (that can be considered among in-between cases a) and b) above).

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43 Actually the above percentages have been set as “provisional” since 1994 first release of Recommendation ITU-R F.1094 and kept unchanged until now. They are then considered stable values.

1.1.1.1 Long-term criteria

Long-term objectives for bands where multipath is the dominant aspect of adverse propagation

From the above principle, ITU-R has defined interference criteria described in the following paragraphs, based on the conclusion of the Radiocommunication WP 9A (stated in specific liaisons) that concluded that an I/N = –20 dB is considered valid as interference protection criteria for all bands used by FS.

An interference criterion of I/N = –20 dB for the aggregate r.m.s. interference is consistent with the objectives for interference power used in most frequency bands.

The rationale is an expected linear relationship between degradation objectives and the percentage of allowed performance degradation. On a general basis, Recommendation ITU-R F.758 sets I/N = –10 dB for co-primary services, which are assigned the 10% portion of error performance degradation in Recommendation ITU-R F.1094. Hence the I/N = –20 dB might be assumed as representative for the 1% error performance degradation for all not co-primary services and other sources.

It can also be noted that, depending on the interference scenario, this criterion could also be applied to time averaged interference power by using the fractional degradation of performance (FDP) criterion of 1% (see Recommendation ITU-R F.1108 for rationale on FDP concept).

The interference criterion I/N = –20 dB is valid for bands up to about 15 GHz.

Finally, due to the multipath nature of fading in these frequency bands, it should be considered that the propagation-induced attenuations of the FS link path and the interfering path are un-correlated. In these bands, the time averaged interference power has been used in developing interference criteria when the interferer power varies in time (see Recommendation ITU-R F.1108).

It is also interesting to note that Radiocommunication WP 9A raised the point that, due to the multipath nature of fading in these frequency bands, it should be considered that the propagation induced attenuations of the FS link path and the interfering path are uncorrelated.

It is also worth noting that a previous meeting of Radiocommunication WP 9A (April 2002) had to address the definition of interference criteria to protect the fixed service from aeronautical mobile satellite stations operating on a secondary basis and agreed that, for such secondary service, an I/N = –20 dB for 20% of the time is the adequate criteria.

Finally, it should be considered that this is a generic objective assuming that the interference will have similar spectral emission characteristic of the noise. In UWB case, due to the pulsed characteristic of most applications, additional considerations would be needed for peak (within FS receiver bandwidth) interference objectives recognizing that it clearly depends on the type of UWB and scenario considered.

Long-term objectives for bands where precipitation is the dominant fade mechanism

Radiocommunication WP 9A considered a specific analysis in the 23 and 26 GHz bands, demonstrating that the interference criteria I/N = –20 dB, when considering an apportioning of the 1% permitted performance degradation into a 0.5% for UWB SRR interference and 0.5% left for all other source of interference foreseen by Recommendation ITU-R F.1094 (i.e. secondary services interference, the unwanted emissions and the unwanted radiations) is appropriate for studies of their impact on FS in these frequency bands where fading is controlled by rain.

This figure was derived from the evaluation of various situation of link length and rain rates that are considered significant for the FS applications. Radiocommunication WP 9A concluded that although the nominal fade margins for all different cases are different, the fade-margin degradation values depend, to a high extent, neither on the required availability nor on the rain zone. There is a small variability of the results due to the hop length.

Radiocommunication WP 9A calculated a fade margin degradation values range from 0.03 dB to 0.12 dB which corresponds to respectively I/N = –21.6 and I/N = –15.5 dB, which justify and support the long-term criterion of –20 dB of I/N.

Radiocommunication WP 9A considers that this I/N figure may be used for all bands above 15 GHz.

In addition, it has to be noted that, since the above FS protection criterion is justified in rainy conditions, some levels of correlation between the attenuations of the FS link path and the interfering path should be considered in the interference studies. It was not possible for Radiocommunication WP 9A to draw any figure for this correlation impact, mainly dependent on the assumed scenarios, but it was noted that the order of magnitude of the FS hop length (several km) is assumed to be much higher than the interfering path.

1.1.1.2 Short-term criteria

Short-term criteria, also reported by Recommendation ITU-R F.758, is an additional criteria that gives allowance, for very short percentage of time (e.g. in the order of 0.0001% of the time), for a positive I/N ratio to happen. This could be related to possible coherent sum of many UWB devices of the same kind; the statistical behaviour of the aggregate power (referred as amplitude probability distribution (APD) in NTIA studies) depends on the actual characteristic of the UWB emission or mixture of different emissions.

Being this study generic and not focused to a specific UWB emission, this criterion will not be considered at this stage and would need a case by case consideration.

1.1.1.3 Additional considerations on objectives for FWA

In bands below 10.6 GHz, FWA TS, have also to be specifically considered in some cases. Objectives for TSs are different according to their distance from the CS.

The ITU-R objectives of Table 88 are generally set for TS at cell coverage borderline, while closest TS do generally experience less fading and operate at a higher nominal receiver signal level (RSL) depending on the actual power transmitted by CS (selected, according proprietary algorithm, by the manufacturer for reducing the dynamic range required to TS closer to the CS). ITU-R Recommendations do not specifically deal with this case but it can be assumed that the interference level for long-term protection might be higher.

1.1.1.3.1 Example in conventional outdoor applications

As an example, in the likely event that the CS would deliver to closest TSs lower transmit power (e.g. on a burst-by-burst or sub-carrier bases according the access methods) they might be kept at an RSL producing a similar FM of the border TSs. Being not limited by fading generated S/N ratio, those TSs would be more affected by the UWB peaks that might produce errors burst.

In this case the long-term objective could be possibly kept higher (of a FM dB factor), than the objective for noise limited receivers set in previous sections.

On this basis, it has been assumed that those terminals would be able to accept an average interference corresponding to an I/N = +5 dB that corresponds to a fade margin referenced to a 10^{-13} BER, typically assumed 7 dB lower than a 12 dB fade margin (referenced to 10^{-6} BER), which is considered typical in these FWA application in these frequency bands.

Based on the consideration of § 1.1.1.5, the peak interference for those TS can be evaluated using equation (68):

$$I_{P50} = N_{A50} + 5 + FM \tag{68}$$

where:

I_{P50}: peak interference power (dBm) in 50 MHz

N_{A50}: average (r.m.s.) FS noise power (dBm) in 50 MHz

FM: FS fade margin.

1.1.1.3.2 Example in indoor applications

Foreseen applications for ETSI HIPERMAN (under development in ETSI EP-BRAN) and IEEE 802.16 include indoor terminals with omnidirectional antennas in bands below 6 GHz. UWB devices may be among the types of handheld device used in the same room; therefore, this application would require studies based on a "minimum distance" rather than the aggregate interference from a large area or from a "hot-spot building" where UWB are deployed, as currently done for other outdoor applications.

Indoor applications in bands (here studied in bands ~ 3.5 GHz) are likely to be more affected by multipath distortion rather than by pure link budget reduction. Nevertheless a link budget reduction due to UWB device close by will reduce the coverage in term of useable locations within a building.

Therefore instead of the I/N = – 20 dB objective currently used for all "outdoor" FS stations, Radiocommunication WP 9A, taking also into account the operating environment and the likely low fade margin that these indoor applications will experience, defined an objective degradation of 0.2 dB of the link budget that could be translated in term of I/N assuming:

$$I/N = -13 \text{ dB}$$

Regarding the peak limitation, still dealing with a margin degradation, the approach described in the § 1.1.1.4 should be used.

1.1.1.4 Consideration of peak interference objectives

When wide-band peak power is concerned, the sum of noise and aggregate interference power has a probabilistic distribution. This would imply that the actual statistic of all UWB emission is fully determined. However, for a generic preliminary approach, the $10 \log(-\ln(p))$ distribution for the band-limited Rayleigh receiver noise peak around its average level, as a function of its probability "p" of being exceeded, is compared to the peak interference.

For not affecting the BER characteristic of the receiver, it is necessary that the added UWB interference does not change, at any relevant probability level, the distribution function of noise peak power around and above its average value (e.g. for p < ~4% with the an assumed $I_{P50}/N_{A50} \leq +5$ dB).

Therefore it seems reasonable to establish that the aggregate peak of all UWB devices should be maintained lower than the widest-band average value of the noise (e.g. $I_{P50}/N_{A50} \leq +5$ dB within 50 MHz band) or, in other terms, the I_{P50} aggregate objective is separately kept 42 dB above the I_A density objective (i.e. $I_{P50} \leq I_A + 20 + 10 \log 50 + 5$). This assumption is still conservative and based on some practical tests made under another study between FS and UWB SRR at 24 GHz (see Appendix 1 to this Annex).

In addition, the aggregation function of the peaks of large number of uncorrelated UWB is assumed to follow a 10 log adding law. The rationale is that, from one side, the peak aggregation should follow the sum in voltage (i.e. with 20 log law), but from another side the probability that all UWB and noise aggregate interference voltage peaks are contemporary and in phase might be very low.

Regarding peak interference it should be noted that, even if the UWB peak power might occur for a percentage of time (due to devices duty-cycle and/or activity factor) less than the 20%, it will still affect the "long term" objectives due to the different physical speed of propagation variation and UWB emission variation since performance objectives are set on propagation variation speed (i.e. on a second's time base) while UWB peak power occurs at "milliseconds" speed or less (i.e. could generally affect each second).

Based on the above, the aggregate peak power objective $I_{P50}/N_{A50} \leq +\ 5$ dB is assumed to be sufficient to protect the fixed service. It can be noted that it is equivalent to:

$$I_{P50}\ (\text{dBm/50 MHz}) \leq I_A\ (\text{dBm/MHz}) + 42\ \text{dB} \tag{69}$$

where:

I_{P50}: peak interference power (dBm) in 50 MHz

I_A: average (r.m.s.) interference power (dBm) in 1 MHz

N_{A50}: average (r.m.s.) FS noise power (dBm) in 50 MHz.

1.1.2 Fixed service characteristics

1.1.2.1 Introduction

Digital FS links are designed according to ITU-R Recommendations that require certain error performance and availability objectives derived from the integrated telecommunications rules established by the ITU-T.

They result in "link budgets" (i.e. S/N ratios), function of the hop-length P-P (point-to-point applications) or cells radius (multipoint FWA applications) and the expected statistical distribution of attenuation depth in that geographical area, in order to satisfy those objectives.

The error generation in digital receivers is affected by the overall noise, N, coming to the "decision point", which is defined by equivalent noise bandwidth, assumed to be the 3 dB receiver bandwidth, RX_{BW}. The following noise calculations are considered:

N (r.m.s. density in dBm/MHz) = –114 + noise figure

N (total r.m.s. power in dBm) = –114 + 10 log (RX_{BW}) + noise figure

N (total peak power in dBm) = N (total r.m.s. power) + 10 log(–ln(p)).

NOTE 1 – The noise figure, in FS applications, is considered at the input of the receiver, including radio frequency duplexer filters losses.

The 10 log(–ln(p)) term represents the peak factor of band-limited thermal noise (Rayleigh noise) exceeded with a probability "p" (e.g. 9.64 dB for p = 0.01%). This peak factor is not commonly used for digital FS link planning (even if the actual error rate is physically linked to noise peak phenomena rather than to mean values). This is due to the fact that, being the thermal noise "Gaussian" in nature, its peak to r.m.s. ratio, at same probability, is constant with the receiver bandwidth. However, it is needed here as reference for evaluating the objective value of the peak of interference.

The FS characteristics that are necessary to the study with UWB are mainly:

– antenna gain
– antenna pattern
– noise figure
– feeder losses
– bandwidth.

FS antennas are relevant for this study, from one side their high directional characteristics (in both azimuth and elevation) restrict the area where interference might be significant, but from the other side the high gain enhance the potential interference of those UWB within the covered area.

With regard to the bandwidth which is necessary to determine the peak noise power, the most critical and representative application is those with the largest bandwidth. Since 30/40 MHz are currently used in band below 10.6 GHz and that in higher frequency bands a 50 MHz bandwidth is now considered more representative, in particular for FWA access, 50 MHz bandwidth has been used as a future trend for all systems below 10.6 GHz, in particular FWA systems.

Other FS system characteristics (e.g. receiver sensitivity and modulation formats) are not relevant for the assessment of the interference, *I*, since the analysis is done only evaluating the *I*/*N* ratio.

Finally, the FS systems that are typical in the range 3 to 10.6 GHz are:

– FWA systems, quite common in 3.41-3.6 GHz and 10.15-10.68 GHz bands.

– High capacity links for trunk, regional and mobile networks infrastructures applications in 3.6-4.2 GHz, and 4.4-5.0 GHz, 5.9-8.5 GHz (made-up by several adjacent FS bands) and 10.15-10.68 GHz.

– FWA indoor TS, as foreseen by ETSI HIPERMAN (HM) and IEEE 802.16 projects. Even if those standards will be applicable to any FS band from 1 to 11 GHz, the indoor application are suitable only where propagation behaviour allows NLoS connections with reasonable average attenuation towards the outdoor located CS.

  Therefore only the 3.5 GHz band is here studied.

– For bands 23 and 26 GHz see § 1.5.7.

1.1.2.2 Interference objective calculation (bands below 11.6 GHz)

The interference objective for all cases is given by equation (70):

$$I = N + FL + I / N_{criteria} \tag{70}$$

where:

N: total r.m.s. noise density (as described in § 1.1.2.1).

FL: feeder losses (dB).

I/*N*: criteria is the FS protection criteria.

Table 91 gives, for all bands and FS applications the relevant values of noise figure and feeder losses.

TABLE 91

Noise figures and feeder losses

FS applications	Frequency band (GHz)	Noise figure (dB)	Feeder losses (dB)
P-P	4, 5 and 6	4	3(1)
	7 and 8	6	None(2)
	10.5	7	None(2)
FWA (conventional outdoor applications)	3.5	5	None(2)
	10.5	7	None(2)
FWA TS (indoor applications)	3.5	5.5	None

(1) Common practice, for these applications, is to have indoor deployment with feeders connections that generally give additional attenuation.

FS applications	Frequency band (GHz)	Noise figure (dB)	Feeder losses (dB)

(2) For these applications it become more and more common (in particular for mobile networks infrastructures) to deploy equipments that have the RF part close to the antenna. Therefore no additional feeder losses have to be taken into account.

On this basis, Table 92 gives the interference objectives for the corresponding FS applications.

TABLE 92

Interference objectives

FS applications	Frequency band (GHz)	N_A (dBm/MHz)	I_A (dBm/MHz)	I_{P50} (dBm/50 MHz)
P-P	4, 5 and 6	–110	–127	–85
	7 and 8	–108	–128	–86
	10.5	–107	–127	–85
FWA (outdoor)	3.5	–109	–129	–87
	10.5	–107	–127	–85
Indoor FWA TS	3,5	–108.5	–121.5	–79.5

Finally, Table 93 give the interference objectives for FWA TS that are close to their CS, based on the additional consideration as in § 1.1.1.3. Recognizing that those receiver are less sensitive to interference, this objectives have been established for a typical cell size of 9 km and 12 dB fade margin.

TABLE 93

Interference objectives for FWA outdoor TS that are close to their CS

Application	Frequency band (GHz)	N_A (dBm/MHz)	I_A (dBm/MHz)	I_{P50} (dBm/50 MHz)
Outdoor TS	3.5	–109	–104	–74
	10.5	–107	–102	–72

1.1.2.3 FS antenna characteristics for FWA systems

For 23 and 26 GHz bands see § 1.5.8.

Table 94 summarizes the FWA antenna parameters used in the present Report.

TABLE 94

FWA CS and TS typical antennas

CS omnidirectional(1)	**CS sectorial 90º**(2)	**Directional (for low gain outdoor TS antennas in 3.5 GHz band)**(3)	**TS (indoor) omni-directional**	**Directional (high gain TS antennas in 10.5 GHz band)**(4)
Gain = 8 dBi	Gain = 16 dBi	Gain = 16 dBi	Gain = 0 dBi(5)	Gain = 40 dB
Azimuth RPE = not applicable	Azimuth RPE = Fig. 146 (Rec. ITU-R F.1336)	Azimuth and elevation Fig. 148 (Rec. ITU-R F.1336)	Azimuth RPE = not applicable	Azimuth and elevation Fig. 149 (Rec. ITU-R F.699)
Elevation RPE = Fig. 147 (Rec. ITU-R F.1336)	Elevation RPE = Fig. 147 (Rec. ITU-R F.1336)	–	Not used for the minimum distance evaluation	–
Elevation tilt-down = 2º	Elevation tilt-down = 2º	–	–	–

(1) The gain reflects an average "simple" application.

(2) The gain reflects a "best practice" application.

(3) The gain reflects an average "simple" TS application. It is not excluded that some TS at cell edge may use high gain antennas. However this is not considered a common practice and will not be taken into account.

(4) For TS at cells edge a maximum dish size of 1.2 m is assumed.

(5) This value is the one indicated by Radiocommunication WP 9D as typical, however it is recognized that depending on the design (e.g. for direct ICT integration or when separate antennas are used) the gain might also be negative or slightly positive.

The above FWA TS antenna types, when used for interference studies, may be considered the practical boundaries, from which the behaviour of all other types of antennas may be extrapolated.

Figures 146, 147, and 148 give the radiation pattern envelopes (RPE) of the antennas to be used for this study.

FIGURE 146

90º sectorial antennas azimuth RPE

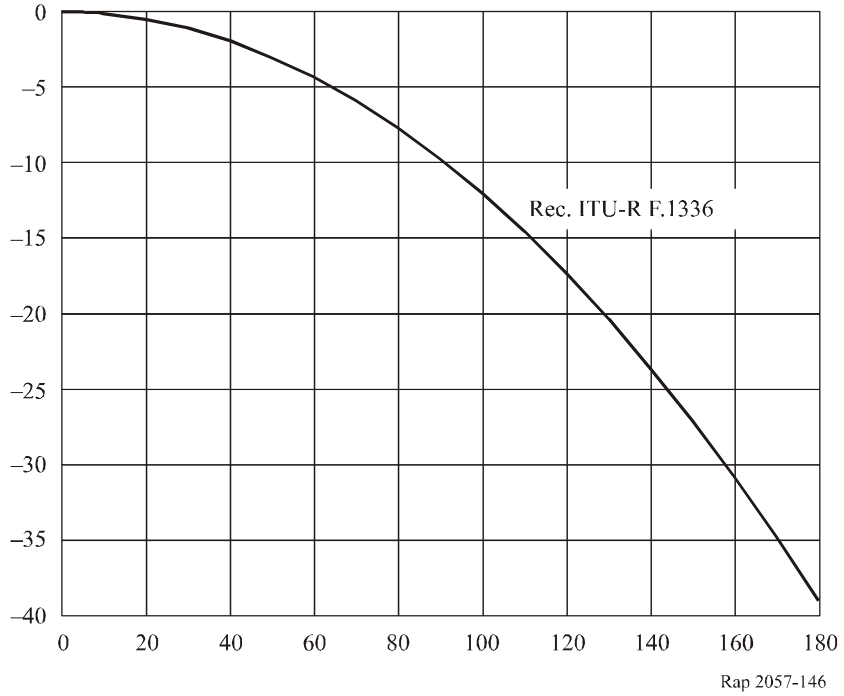


FIGURE 147

Omnidirectional and 90º sectorial antennas elevation RPE

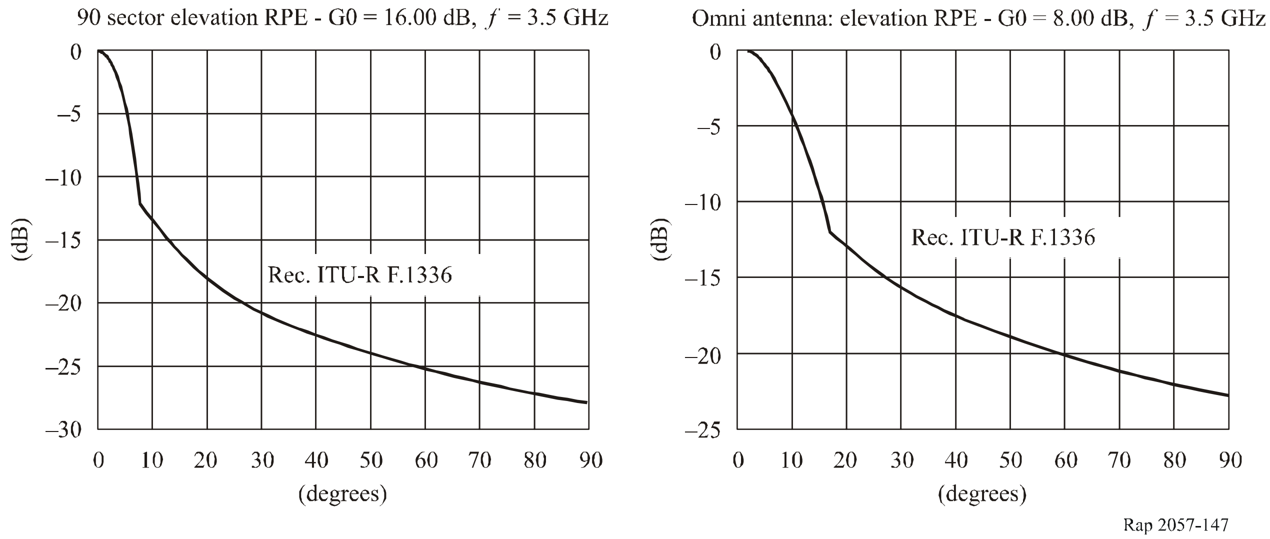
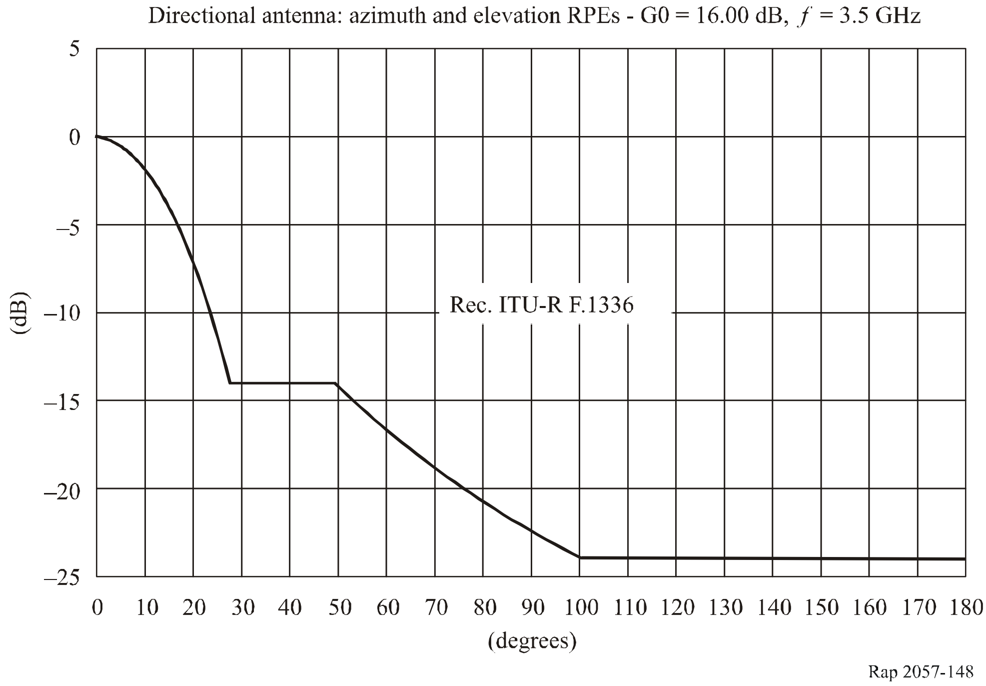


FIGURE 148

FWA-TS reference antenna pattern used in the study



1.1.2.4 FS antenna characteristics for P-P systems below ~11 GHz

Table 95 summarizes the P-P antenna parameters used in the present Report.

TABLE 95

P-P antennas

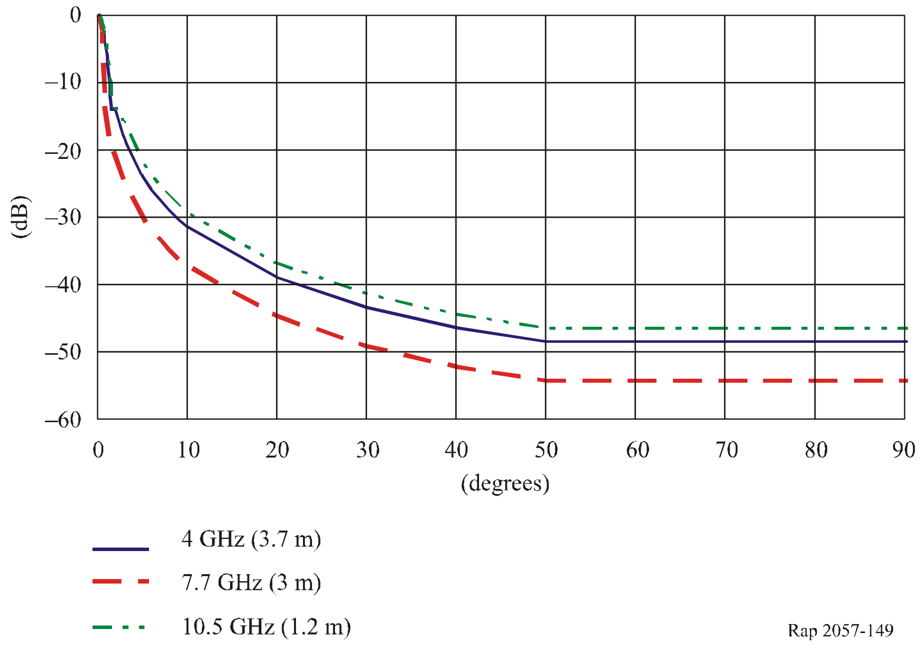
High performance dish in 4, 5 and 6 GHz bands (trunk applications)	**High performance dish in 7 and 8 GHz bands (regional and mobile infrastructures applications)**	**High performance dish in 7, 8 and 10.5 GHz bands (local and mobile infrastructures applications)[(1)]**
Diameter = 3.7 m	Diameter = 3 m	Diameter = 1.2 m
Gain ≅ 41 dB	Gain ≅ 40 dB	Gain ≅ 40 dB
Azimuth and elevation RPE = Fig. 149	Azimuth and elevation RPE = Fig. 149	Azimuth and elevation RPE = Fig. 149
Elevation tilt-down = 0º	Elevation tilt-down = 0º	Elevation tilt-down = 0º

(1) This antenna is also common for FWA TS at borderline of medium size P-MP cells.

Figure 149 gives the RPE of the antennas to be used for this study.

FIGURE 149

P-P antennas (also applicable to 10.5 GHz FWA TS) azimuth and elevation RPE



1.2 Representative scenarios for bands below 11 GHz

FS systems for their "fixed" nature and being often deployed in urban/suburban areas are affected by UWB devices according their actual positioning and density distribution defined by the specific UWB application. Therefore a number of scenarios should be assessed for evaluating the impact of UWB systems.

FS systems are characterized by high gain antennas for P-P systems and most of the TS of FWA systems, but omnidirectional or sectorial antennas are used for the CS and some indoor TS of FWA systems.

With regard to UWB, four different scenarios have been studied in bands between 3.1 and 10.6 GHz:

– Single entry outdoor UWB to an outdoor FS station.

– Uniformly distributed UWB (Scenarios 1).

– Hot spots UWB (Scenario 3a)).

– Minimum distance between an UWB device and an indoor TS.

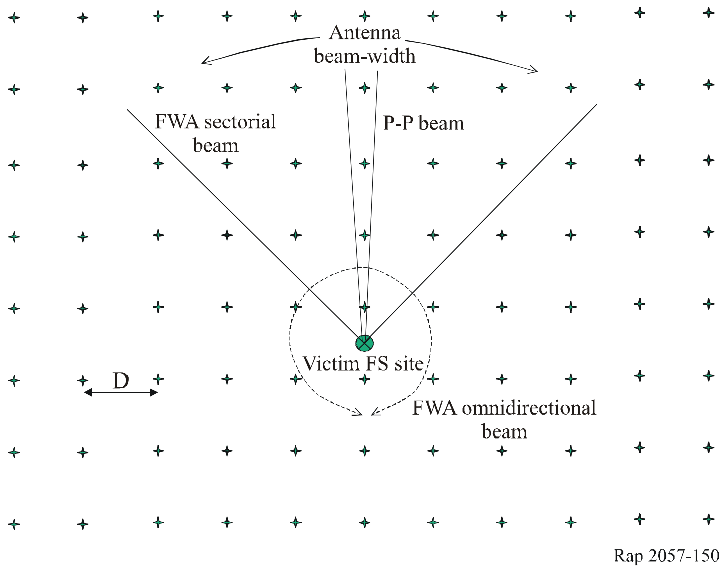
1.2.1 Scenario 1 – Uniformly or randomly distributed UWB emissions

1.2.1.1 Case 1 – Uniform distribution

The general scenario for uniformly[44] distributed UWB systems interfering FS is shown in Fig. 150.

FIGURE 150

Generic scenario for uniformly distributed UWB systems affecting a FS receiver



The UWB systems are considered uniformly distributed on the territory, according a certain density in "devices/km^2"; the distance D between adjacent UWB given by:

$$D\ (km) = 1 \Big/ \sqrt{UWB\ density / km^2}$$

Those UWB systems are "illuminated" by the FS antenna and, in the case of directional antennas, each UWB system will contribute to the aggregate after being weighted by the relevant antenna Gain/RPE decoupling.

It should be noted that UWB devices might be either indoor or outdoor; some of them will be in LoS of the FS station, while others will be shadowed by surrounding buildings. Additional attenuation factors should then be taken into account, possibly according to ITU-R available data and Recommendations.

---

[44] In this study a "uniform" distribution is used in place of a more physically realistic "random" one. The use of a random distribution, while complicating the evaluation, would not offer much more information, in particular when the density is great. The aggregate level obtained with "uniform distribution" gives a unique value; if random distribution would actually be used, the logical resulting aggregate level, of a number of trials, should have a "Gaussian distribution" (as narrower as the devices density is larger) centred around the value obtained with the uniform distribution. Thus the uniform distribution would not represent the "absolute worst case" (in particular when the density is low) but it is still considered a good and fair simplification for this study, also considering the large variance of a number of other factors (i.e. the "*K*" factors). It should also be considered that a random distribution approach is useful when both victim and interferer is MOBILE (for taking into account the "mutual probability" of interference); in our case FS is fixed by definition and the "generic UWB devices" are not specifically considered fixed or mobile.

In § 1.3.3, Figs. 157 and 158 give numerical evaluation of the aggregate interference for the representative FS systems described in Recommendation ITU-R SM.1757, they do not consider any indoor to outdoor attenuation and assume all UWB devices in LoS.

For indoor applications, mitigation due to indoor propagation, indoor-to-outdoor walls trespassing will be considered separately (see K_B factor in § 1.4).

Regarding the additional mitigation due to the non LoS situation (which still does not consider the possible additional indoor situation) of most of the UWB devices, their aggregate power should be evaluated with proper propagation methods (e.g. Recommendation ITU-R P.1411 or the Erceg model adopted for developing IEEE 802.16 standard); however, this would result in very complex methodology with additional variables depending on territory, different urban situation etc.

Therefore, as simplified conservative approach, this mitigation factor will be considered assuming a budgetary contribution from the NLoS devices, derived from a statistically estimation over the percentage of LoS devices (see K_{LoS} factor in § 1.4 and Appendix 1 to this Annex).

1.2.1.2 Case 2 – Random distribution example

For this detailed study, the UWB distribution is assumed to be:

– Only indoor WPAN applications of given density randomly spread among households and offices in a typical western Europe city.

– No UWB outdoor fixed infrastructure or antennas.

– Separate evaluation of contribution a UWB density of 20% handheld outdoor devices (then assumed at ground level only).

The model for the scenario is based on data taken from aerial pictures elaboration of the city of Milan in northern Italy.

Data on buildings height on a great 21 × 21 km area and on a more restricted 8 × 8 km urban area (see Fig. 151 encompassing more or less urban and suburban areas) were evaluated over ~ 184 000 building entries, ~ 80 000 of which in the narrower urban area; by difference, the distribution on the suburban frame area is derived.

Building density is ~ 1 200/km^2 in the urban area and ~ 280/km^2 in the suburban frame area.

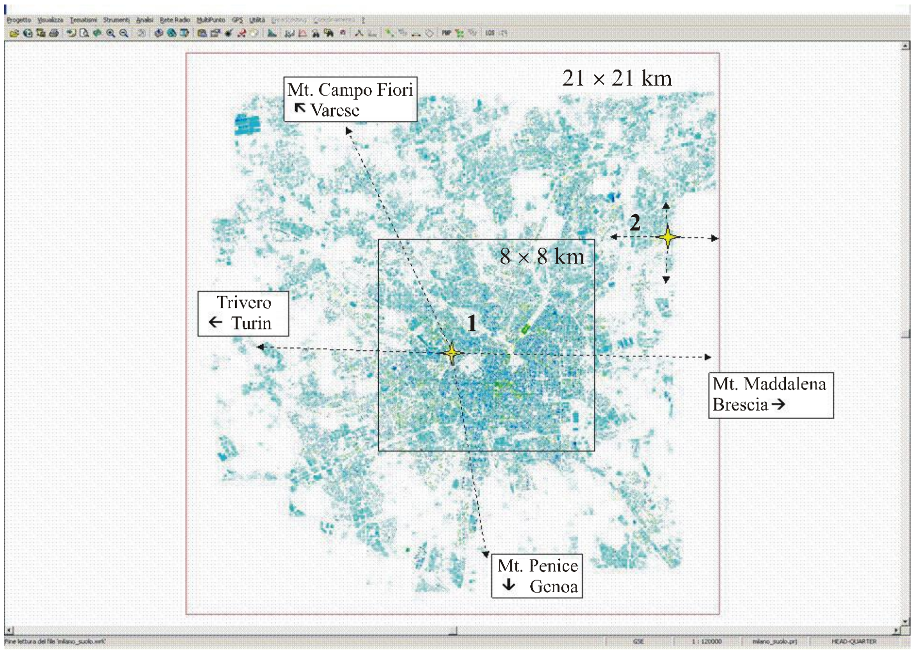
The cumulative probability distribution of building height is shown in Fig. 152.

The probability distribution of floor number and its cumulative probability (assuming them, for convenience, equal to the data granularity of ~ 3 m height each) has been derived from the total number of buildings and the related ~ 790 000 floors (see Fig. 153).

In such a way we could define through simple Monte-Carlo trials an elevation for each UWB entry, assigning to it the appropriate propagation model.

FIGURE 151

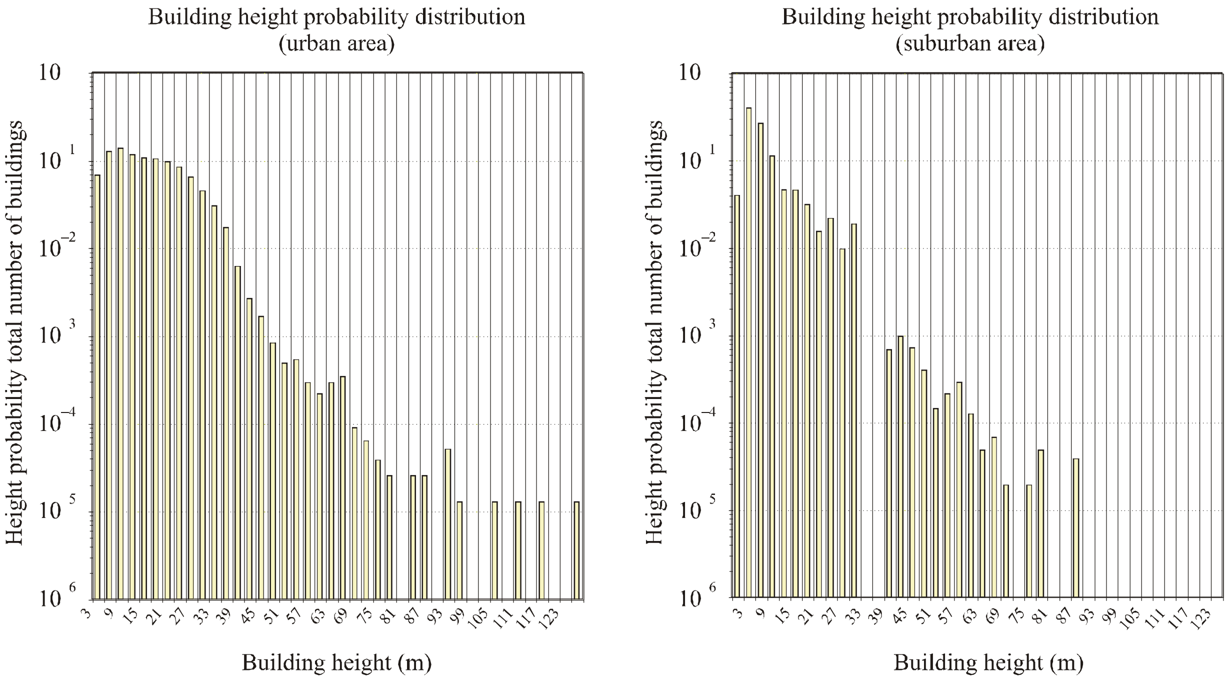
Example of urban/suburban (Milan-North Italy) distribution and typical location of FS P-P station and links



Rap 2057-151

FIGURE 152

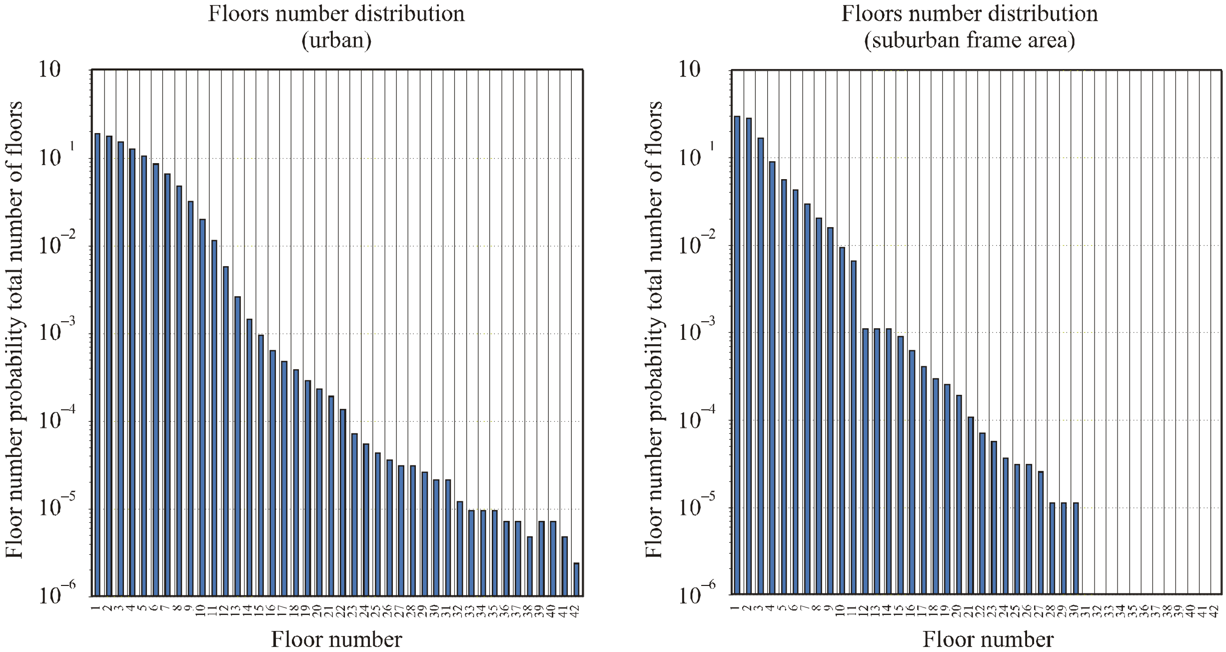
Probability distribution of building heights within the areas of Fig. 151



Rap 2057-152

FIGURE 153

Probability distribution of floor number within the areas of Fig. 151



Note 1 – Floor number 1 means ground floor.

Rap 2057-153

The new scenario takes into consideration also the fact that FS P-P stations, in general, for visibility clearance, do not point toward the centre of major cities; links are deployed at city borders, pointing towards suburban areas, possibly "grazing" the areas of higher urban density; however examples of link (even with quite high antenna) passing over the whole city are also present.

An example is shown in Fig. 154 were the location of some well known FS towers, belonging to TV operators, utilities and other users; they generally include several links at various direction bordering the centre of the city. Several other similar towers (of lower height if in the urban perimeter) might be found and other data are being collected.

Initial focus will be given on the more central one shown in Fig. 151 (location 1); for which four links directions, using 2, 4 and 6 GHz, are identified and shown in Fig. 154; antenna height ranging from ~ 45 m to ~ 110 m; in particular the link crossing Milan eastwards has the highest antennas from ~ 75 m (4 GHz) to 110 m (2 GHz). A second analysis will be done for a similar station in suburban area also shown in Fig. 151 (location 2).

With these assumptions, the scenario might be summarised as in Figs. 155a) and 155b), described as semicircles areas around FS stations, where three different areas are identified:

1 The dense urban area "grazed" by the link from FS location 2, or passed over (with due clearance from the higher buildings) by the link from FS location 1. This might be the area with topmost UWB density (e.g. 10 000/km^2) and free building height.

2 The "path clearance" sector where buildings are assumed to be suitably lower than the FS path passing over them (e.g. at least 25 m clearance). In this area the UWB density is assumed to be in a "transition" zone between urban and suburban (e.g. ~ 3 000/km^2) where links from FS location 2 are "grazing" the urban area or, for links from FS location 1 maintaining, for ~ 6 km with a slight limitation in building height, the ~10 000/km^2.

3 For links from suburban location 2, the other side of the path constituted by a suburban area; therefore UWB density is maintained at 3 000/km^2.

Assuming the FS antenna height ~ 45 m (as actually are the lower ones in the FS tower mentioned in the example), for boresight areas the floors density is derived from the general one, truncating the distribution at maximum height of 21 m (7 floors). For the higher antennas at ~ 80 m height, the building heights might reach ~ 55 m (18 floors) and the distribution will be truncated at that level.

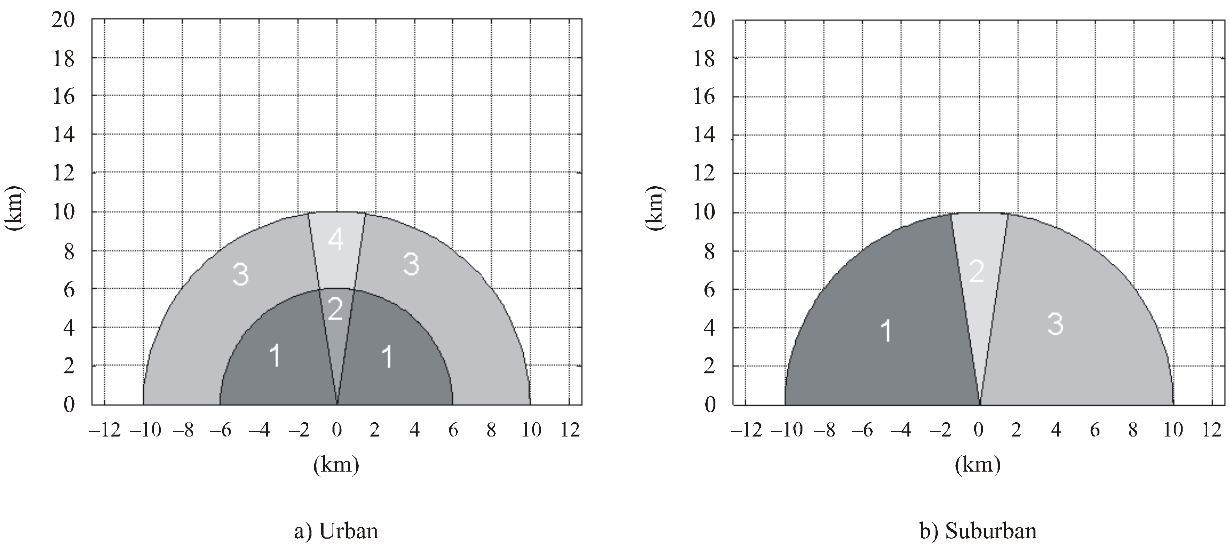
FIGURE 154

Example of FS tower (Corso Sempione, Milan-North Italy)

Rap 2057-154

FIGURE 155

Description of different UWB distribution areas in the model



Rap 2057-155

Each scenario is represented by a 180° semi-circular area; each one is subdivided in sectors where UWB deployment is different i.e.:

Scenario A:

Sector 1: Urban portion outside the main-beam Fresnel zone (10,000 UWB/km spread random over the urban building/floor height distribution).

Sector 2: Urban portion inside the main-beam Fresnel zone (10,000 UWB/km spread random over the urban building/floor height distribution, limited to height 25 m below the FS antenna).

Sector 3: Suburban portion outside the main-beam Fresnel zone (3,000 UWB/km spread random over the suburban building/floor height distribution).

Sector 4: Suburban portion inside the main-beam Fresnel zone (10,000 UWB/km spread random over the suburban building/floor height distribution, limited to height 25 m below the FS antenna).

Scenario B:

Sector 1: Urban portion grazing the main-beam Fresnel zone (10,000 UWB/km spread random over the urban building/floor height distribution).

Sector 2: Suburban portion inside the main-beam Fresnel zone (3,000 UWB/km spread random over the suburban building/floor height distribution, limited to height 25 m below the FS antenna).

Sector 3: Suburban portion outside the main-beam Fresnel zone (3,000 UWB/km spread random over the suburban building/floor height distribution).

1.2.2 Scenario 3a – Hot spots UWB emissions

For the second case of UWB category, generating "hot-spots" interference, the scenarios are a function of the UWB and FS application; the mentioned examples high speed data communication for LAN in commercial/industrial indoor applications interfering the FWA P-MP or P-P systems (described as FS "representative cases" in the relevant FS section of Recommendation ITU-R SM.1757) are reported below.

It is assumed that in suburban areas (where 3.5 GHz FWA and 4 GHz PP are generally deployed) a medium-large commercial centre building (e.g. ~10 floor) is deployed with a big company offices.

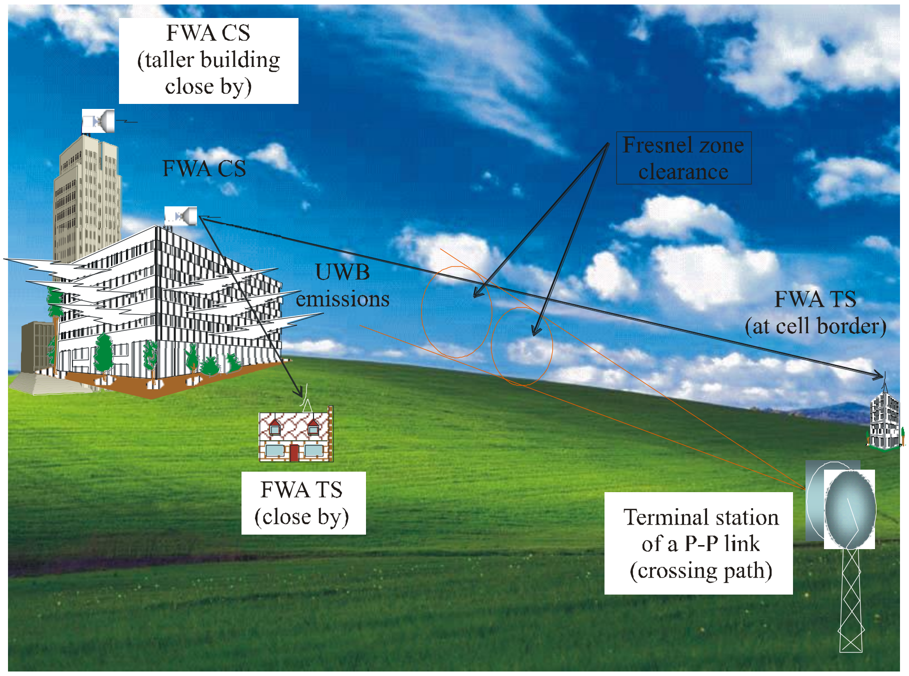
It might be likely that the same building is selected by a service provider as location for a FWA CS and a number of TS is pointing to it (see Fig. 156).

It is also possible that a P-P connection path passes nearby still maintaining the necessary clearance for LoS propagation (i.e. > ~2 times the radius of first Fresnel zone).

Another potential scenario is that where a FWA CS is positioned on a nearby building, covering an area sector that includes the one generating UWB signals. In this case the CS building, for practical visibility purpose, should be higher than the one generating UWB emissions; or better, being the study focused on suburban area, it would be more likely that the ~10 floor height is assigned to the CS building, while UWB one is lower and we would consider, in this case, ~5 floor for the UWB building (see Fig. 156).

FIGURE 156

Generic "hot-spot scenario" for UWB to FS interference



Rap 2057-156

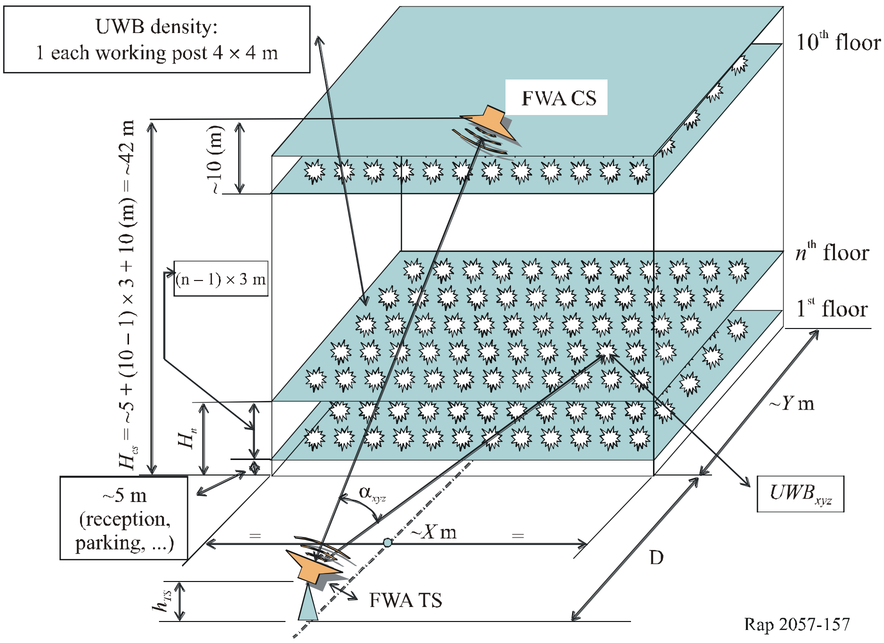
In all work places where an UWB communication device is placed, the UWB emissions may potentially affect CS, TS and P-P receivers nearby.

The geometrical scheme for the two different scenarios (FWA and P-P) might be described as in Figs. 157, 158 and 159.

It should be noted that not all the units may be visible due to the various internal building constructions.

FIGURE 157

Schematic for FWA TS interference aggregation



Rap 2057-157

FIGURE 158

Schematic for FWA CS interference aggregation

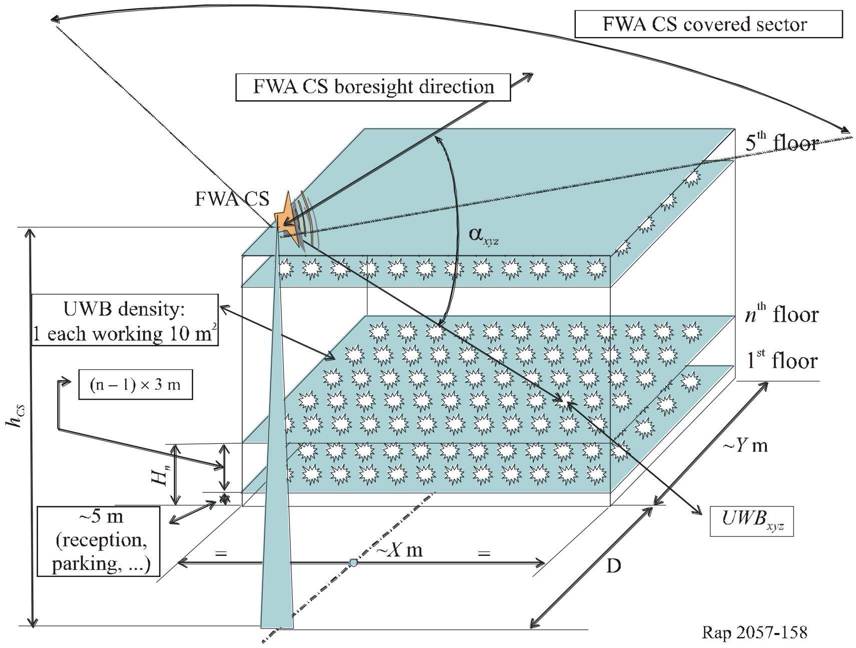
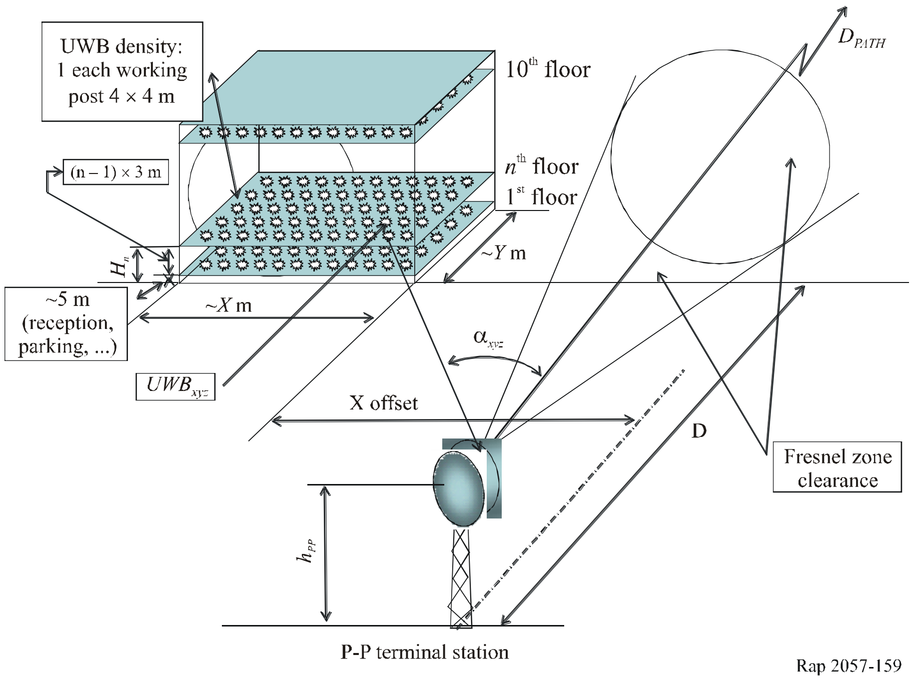


FIGURE 159

Schematic for P-P interference aggregation



For evaluating the aggregate scenarios the following assumptions have been made:

1 Size of the building: ~120 m front (*X* m in Figs 157, 158 and 159) by ~60 m depth (*Y* m in the same figures) with 10 offices floors (for FWA TS and P-P scenarios) or 5 offices floors (for FWA CS scenario).

2 UWB deployment in any workplace ~3.2 x 3.2 m^2 (1 UWB/10 m^2 according reference Scenario 3a).

3 Typical modern architecture glass-walled building with open-space work-places (limited wall attenuation potential).

4 Each UWB device will emit a reference e.i.r.p. (r.m.s.) density = –41 dBm/MHz[3].

5 FWA TS antenna height (h_{TS} in Fig. 157) ~15 m (average value).

6 FWA CS antenna height (h_{CS} in Fig. 158) ranging from 30 to 50 m (i.e. ~10 to 30 m above the roof of 5 floors UWB building).

7 P-P antenna height (h_{PP} in Fig. 159) is assumed to be:
h_{PP} > 50 m for 4/5/6 GHz links (typical for flat-land LoS links up to ~ 50 km)
h_{PP} > 35 m for 7/8 GHz links (typical for flat-land LoS links up to ~ 35 km)
h_{PP} > 20 m for 10.5 GHz links (typical for flat-land LoS links up to ~ 25 km).

8 Minimum P-P path X offset (Fig. 159) is defined as the clearance of the first Fresnel ellipsoid radius (F_{1st}) given by:

$$Xoffset(\text{m}) = F_{1st}(\text{m}) = \sqrt{\frac{300 * D_{(\text{km})} * (D_{path(\text{km})} - D_{(\text{km})})}{f_{(\text{GHz})} * D_{path(\text{km})}}}$$

where:

D_{path}: total path length (km) (here assumed as in the above bullet) and D is the distance in km shown in Fig. 159. It should be noted that at 4 GHz F_{1st} will range from 0 to ~ 30 m only.

For the purpose of this study we will assume some clearance (~ 2 times F_{1st}) and use the following X offset values:

4/5/6 GHz = 50 m

7/8 GHz = 35 m

10.5 GHz = 20 m.

For the FWA systems, the minimum distance between the CS or the TS and the "hot-spot" building has been assumed to be 100 m. For P-P receiver the aggregate interference of the "hot-spot" building has been evaluated considering the minimum required off-set path as described in Fig. 159.

In addition, for P-P systems, FWA CS and FWA TS close to the cell border for which the performance are dominated by the FM, the nominal I/N = – 20 dB is requested for meeting FS long term objectives defined in Recommendation ITU-R SM.1757.

For FWA TS that are closer to the CS and which have less FM requirement, higher interference might be accepted (depending on the actual power transmitted by CS according proprietary algorithm for reducing the dynamic range required to those closest TS),. In these cases it is expected that peak interference would become predominant.

The single entry and the aggregate interference levels, as function of the FWA-TS or P-P receiver distance D from the UWB hot-spot are given in Figs. 182, 183 and 184. It should be noted that these levels do not consider any indoor/outdoor attenuation, which will be evaluated separately.

1.2.3 Single entry outdoor UWB to an outdoor FS station

When UWB are randomly and densely deployed on the territory it is likely that one ore more outdoor devices (e.g. video surveillance on the fence of a factory) happen to be in LoS along the boresight, within the main lobe of the antenna, of a FS link passing over by.

1.2.4 Minimum distance of an UWB device to indoor FWA TS

In this scenario an indoor TS is placed physically in the same office where UWB devices are also used.

The minimum separation distance between them for suitable operation should be evaluated with an objective of ~ 1 m.

Considering that we are looking for an acceptable short distance in the order 1-3 m, we will use the dual slope Siwiak propagation model with exponents 2 (free space) and γ = 3 (multipath dispersion) given by the formula:

$$I = e.i.r.p. - 32.5 - [20 \log D_{(m)} - 10 \log(1 - 10^{-\frac{D_\gamma}{D}})] - 20 \log F_{(GHz)}$$

where:

D_γ: transition break point between exponent 2 and exponent 3

D_γ: at 1 m or 3 m will be used.

The single entry interference levels, as function of the FWA-TS receiver distance D from the UWB device are given in Figs. 185 and 186 in form of minimum distance versus UWB e.i.r.p. and expected margin degradation versus e.i.r.p. and distance.

1.2.5 Vertical plane decoupling scenario and FS antenna heights

In all cases, when FS are concerned, the antenna is generally placed as high as possible on the ground in order to enhance cell-coverage or avoid Fresnel zone incursion.

Due to the directional nature of antennas, the vertical plane decoupling plays also a fundamental role. Consequently the numerical value of the aggregate interference will also vary sensibly with the FS antenna height. Hence, different FS antenna heights have been considered in numerical evaluations in § 1.3.

1.3 Initial evaluations of upper-bounds of UWB interference to FWA and P-P systems in the selected scenarios below ~11 GHz

1.3.1 Introduction

Numerical evaluations are reported on the proposed representative examples of:

– FWA in 3.5 GHz band with omnidirectional or 90º sectorial antenna; described in Recommendation ITU-R SM.1757;

– P-P high capacity link in 4/5/6 GHz, 7/8 GHz and 10.5 GHz bands; described in Recommendation ITU-R SM.1757;

– FS antenna height, *h*, ranging from 20 to 60 m, considered as typical in flatlands, where the more severe interference scenarios are expected.

These systems will be evaluated from the point of view of expected aggregate interference from UWB systems in the most representative scenarios described in § 1.2.

The results will be compared with the acceptable interference for meeting the FS objectives given in Recommendation ITU-R SM.1757 and summarized in Tables 88 and 89.

All the numerical evaluations given in this section are made with the following constant reference power parameters for any UWB emission:

– reference isotropic r.m.s. e.i.r.p. density = –41 dBm/MHz[45];

– reference isotropic peak e.i.r.p. density = –0 dBm/50 MHz[45].

All the results would then be parametric to those values and actual systems results should be linearly normalized according actual e.i.r.p. density and with the methodology for peak to r.m.s. wide-band evaluation.

1.3.2 Single entry outdoor UWB emission r.m.s. interference

1.3.2.1 Numerical evaluation

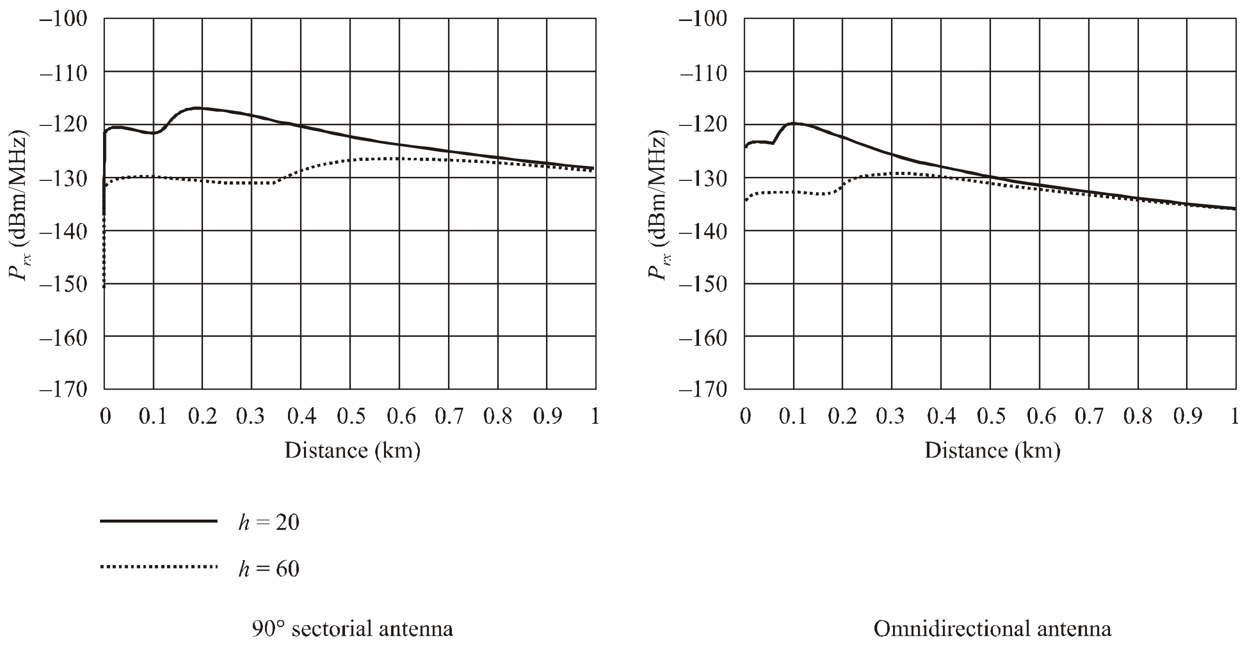
Prior to calculating any aggregate interference it might be interesting to study the variation of the interference power density produced by a single outdoor UWB emission (e.g. a surveillance device) as far as its distance increases, with pure LoS, free-space propagation, from the victim FS antenna along the bore-sight plane; the variation will be governed only by the vertical FS antenna decoupling and the free space attenuation.

The UWB device is assumed to be at ground level, even if its placement at a certain height (e.g. on a roof or a fence) with the understanding that in this case the antenna height is intended as the relative height difference between victim antenna and UWB source.

Figures 160 and 161 describe the received power behaviour with the distance.

FIGURE 160

3.5 GHz FWA



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The formulas used are:

$$\text{Power emitted (linear units): } p_{TX} = 10^{e.i.r.p./10} \quad (71)$$

---

[45] These are values that reflect e.i.r.p. limits currently adopted by one Administration.

Interfering power from a transmitter at a distance *x*, in the horizontal plane, from the victim receiver:

$$p_{RX}(x) = p_{TX} \cdot A_{fs}(h,x) \cdot G_{RX} \cdot g_{RX}(\vartheta) = 10^{e.i.r.p./10} \cdot A_{fs}(h,x) \cdot G_{RX} \cdot g_{RX}(\vartheta) \quad (72)$$

where:

A_{fs}: free-space attenuation

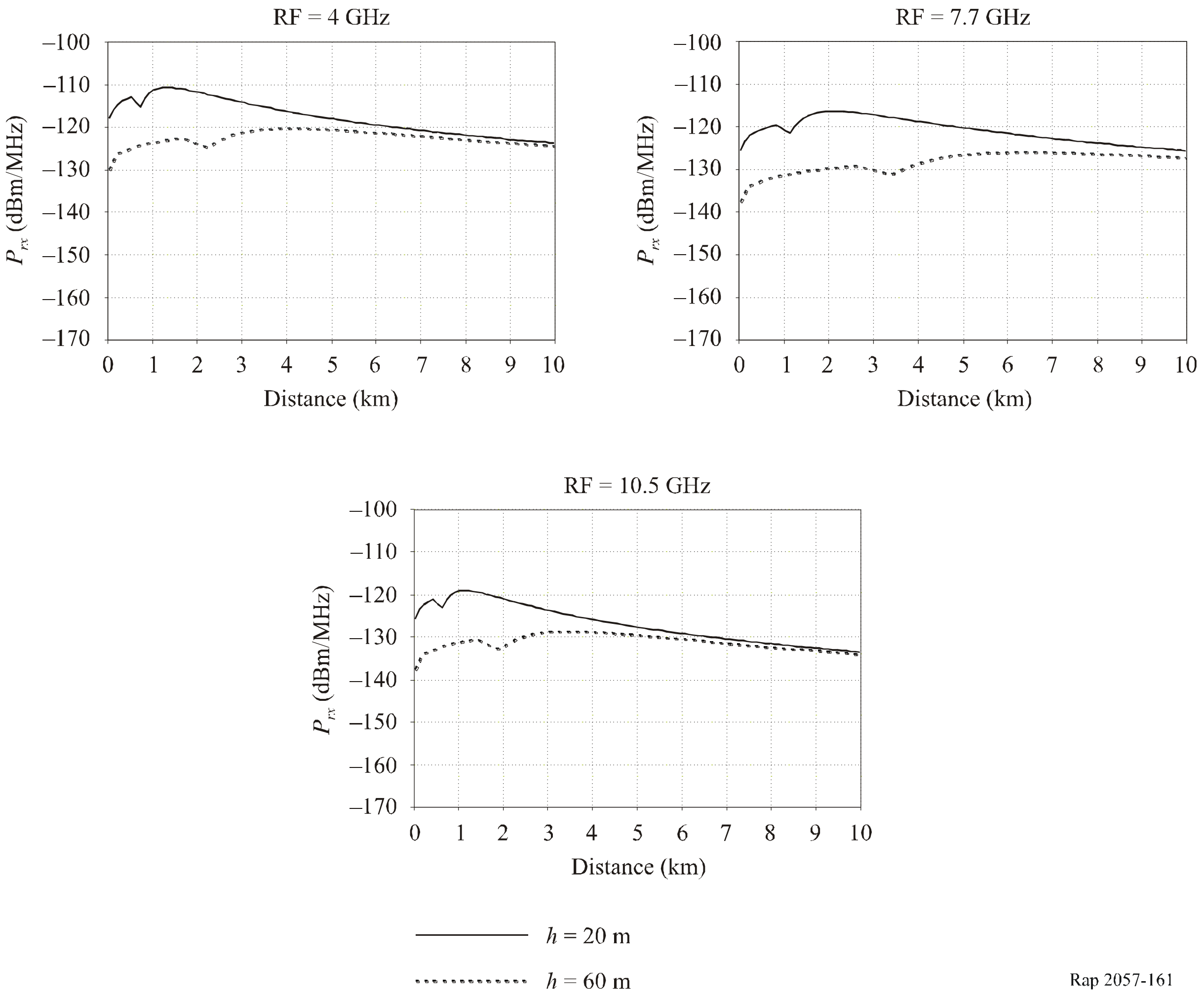
G_{RX}: antenna gain (bore-sight)

g_{RX}: vertical decoupling given by the FS antenna

ϑ: current angle between antenna bore-sight and LoS towards the UWB device expressed by $\vartheta = \arctan\frac{h}{x} - tilt$.

FIGURE 161

4 GHz, 7.7 GHz and 10.5 GHz P-P (with high directional antenna)



1.3.2.2 Conclusions on single UWB element interference

Regarding the r.m.s. interference level, from the graphs in Figs. 160 and 161, considering that the r.m.s. interference power objective is ~ –127/129 dBm/MHz (see Tables 88 and 89), a single UWB device, with e.i.r.p. density = –41 dBm /MHz, placed in LoS of a FS receiver and without any indoor-outdoor additional attenuation, would already exceed the objective by up to ~20 dB.

1.3.3 Uniformly and randomly distributed UWB emission aggregate r.m.s. interference (Scenario 1)

1.3.3.1 Case 1 – Generic UWB applications – Numerical evaluation of a uniform distribution

In the scenario described in § 1.2.1 the results in Figs. 157 and 158 are obtained.

These figures show the increase of aggregate r.m.s. interference as far as the radius of the area affected by scattered UWB increases.

With the intent of exploring the upper bound of the possible aggregation and for having a set of data that could be used for further elaboration, applying separately different mitigation assumptions for both propagation and UWB characteristics, the propagation is assumed to be LoS, free space loss (spherical diffraction is not yet effective on distances below 10 km) and the UWB devices activity at 100%. However it should be noted that these kinds of UWB applications are likely to be of lower activity and indoor, therefore building attenuation and activity factors should be taken into account when necessary in actual evaluations; in § 1.4.1.1 these various mitigations are defined and elaborated for final evaluation of the real expected aggregate interference in the reference Scenarios (1a), (1b) and (1c).

The formulas used in this case are:

– Power emitted by an elementary section of area $dx \cdot d\varphi$ (linear units):

$$p_{TX} = 10^{e.i.r.p.D_{sq}/10} \cdot dx \cdot d\varphi \tag{73}$$

where $e.i.r.p.D_{sq}$ denotes the e.i.r.p. two dimension density (dBm/MHz/m^2).

– Interfering power from an elementary section of area $dx \cdot d\varphi$ at a distance x from the victim receiver:

$$p_{RX}(x) = p_{TX} \cdot A_{fs}(h,x) \cdot G_{RX} \cdot g_{RX}(\vartheta,\varphi) = 10^{e.i.r.p.D_{sq}/10} \cdot A_{fs}(h,x) \cdot G_{RX} \cdot g_{RX}(\vartheta,\varphi) \cdot dx \cdot d\varphi \tag{74}$$

– Total interfering power from a circle with radius R:

$$p_{RX} = \int_0^{2\pi} \int_0^R 10^{e.i.r.p.D_{sq}/10} \cdot A_{fs}(h,x) \cdot G_{RX} \cdot g_{RX}(\vartheta,\varphi) \cdot dx \cdot d\varphi \tag{75}$$

In the above formulas A_{fs} is the free space attenuation, depending on the distance and receiver height h, g_{RX} is the off-axis attenuation of the antenna RPE. It depends on the elevation angle ϑ and the azimuth angle φ (not applicable for omni antenna) of the propagation path with the antenna boresight axis. These in turn depend on x and h and should take into account any possible antenna tilt.

Where both azimuth and elevation are involved, g_{rx} is calculated according to formula (76):

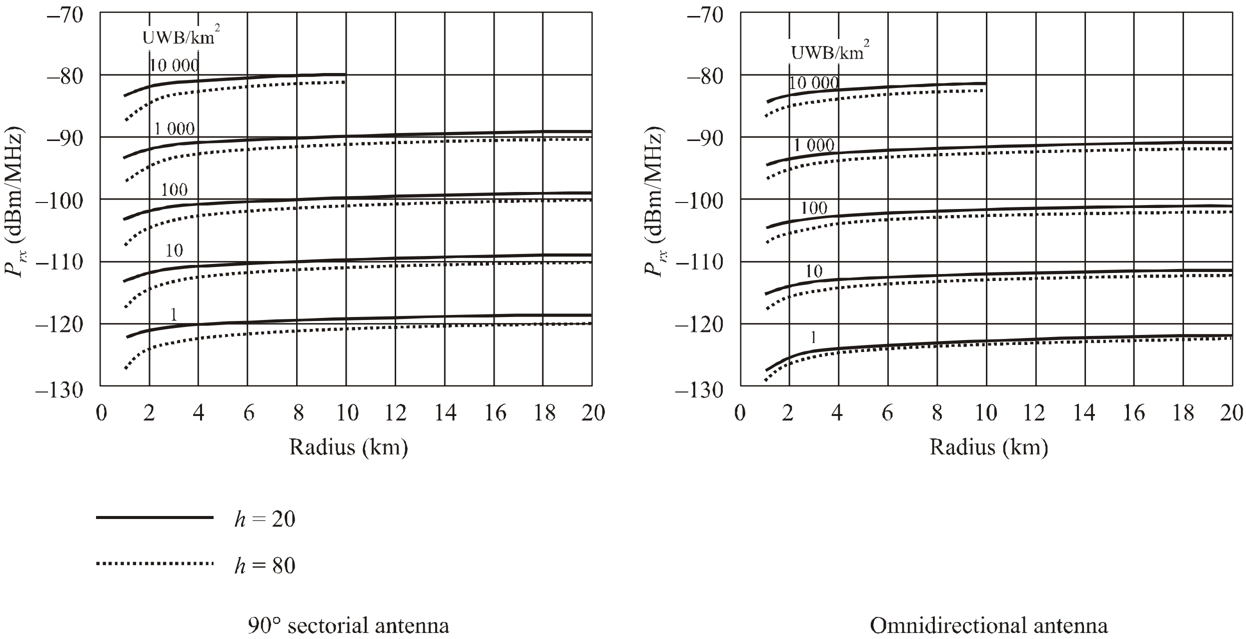
$$g_{rx}(\vartheta,\varphi) = g_{\varphi}(\varphi) + g_{\vartheta}(\arcsin(\cos\varphi \cdot \sin\vartheta)) \tag{76}$$

where g_{φ} and g_{θ} are the standard azimuth and elevation RPE decoupling.

Figures 162 and 163 show the numerical results for UWB system density ranging from 1 to 10.000 devices/km^2 (assumed all 100% active for further elaboration).

FIGURE 162

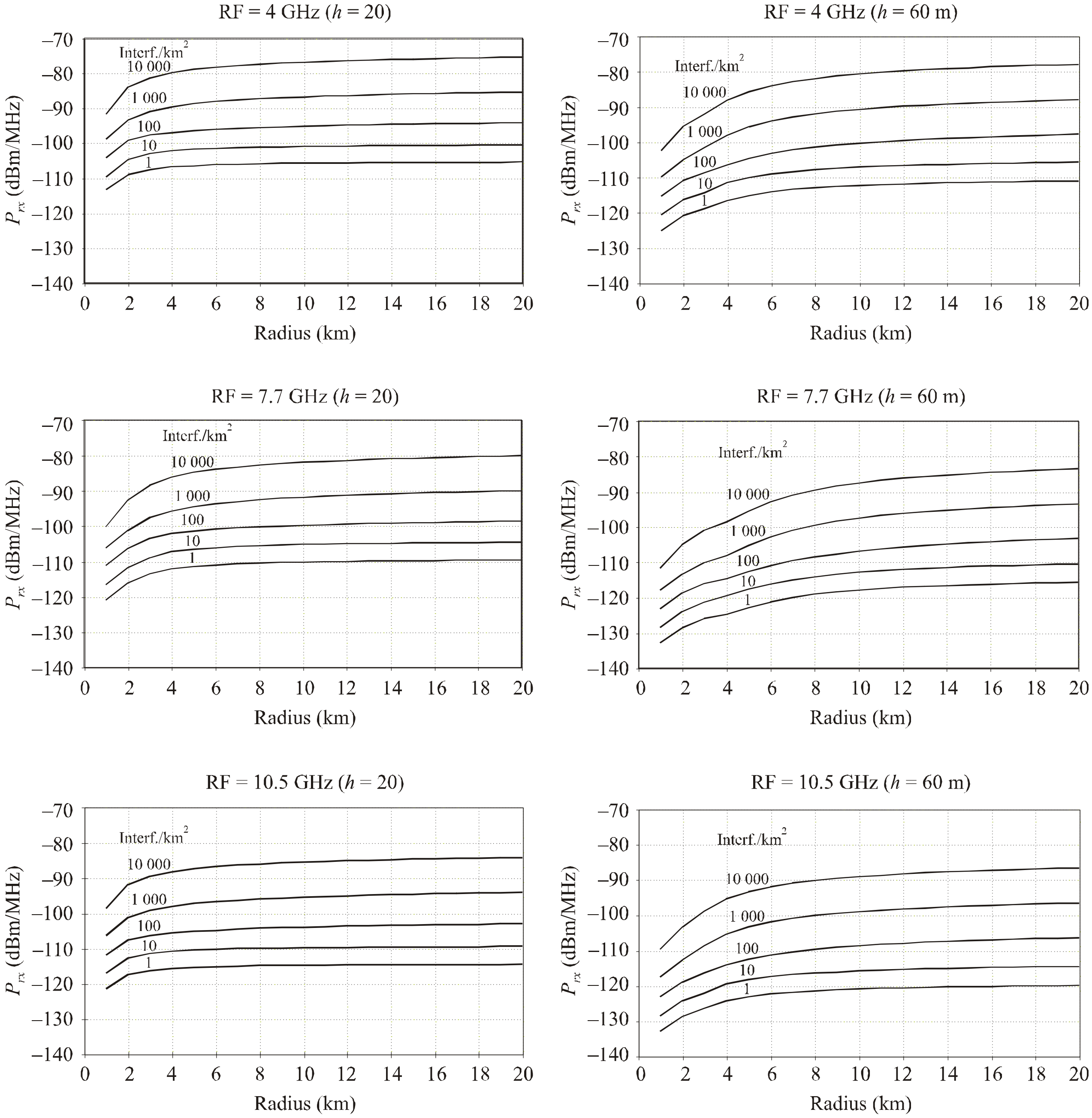
3.5 GHz FWA, aggregate interference of uniform UWB distribution (full LoS case)



Rap 2057-162

FIGURE 163

4 GHz, 7.7 GHz and 10.5 GHz P-P with high directional antenna, aggregate interference of uniform UWB distribution (full LoS case)



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These “upper bound cases” results also show that irrespective of the device density considered, UWB devices have the potential to produce an interference that exceeds the FS interference criteria (–127/–129 dBm/MHz) by an amount between ~10 to 50 dB, and then mitigation factors would play a fundamental role.

1.3.3.2 Case 1 – Generic UWB applications – General comments and parametric relationship with UWB e.i.r.p. density

From the graphs in Figs. 162 and 163, still derived assuming that all UWB devices are in LoS to the FS receiver and without any indoor/outdoor additional attenuation (i.e. representing a virtual upper bound for any aggregate interference), besides noting that all cases are obviously largely out from the objectives, all graphs show:

– an asymptotic behaviour of the aggregate value when the radius of the area exceed ~15 km;
– a difference in that aggregate value of about 10 dB per decade of UWB density; this is more evident, as expected, for omni/sectorial antennas, but also true for the larger UWB density in P-P application.

This latter point may be used for practical estimation of an asymptotic upper-bound aggregation with 1000 UWB/km^2:

– FWA at 3.5 GHz (90º sectorial antenna) ≅ –89/–90 dBm/MHz (for antenna h = 20/60 m).
– FWA at 3.5 GHz (omni antenna) ≅ –91/–92 dBm/MHz (for antenna h = 20/60 m).
– P-P at 4 GHz (high gain antenna) ≅ –85/–88 dBm/MHz (for antenna h = 20/60 m).
– P-P at 7.7 GHz (high gain antenna) ≅ –90/–92 dBm/MHz (for antenna h = 20/60 m).
– P-P at 10.5 GHz (high gain antenna) ≅ –93/–96 dBm/MHz (for antenna h = 20/60 m).

From the above graphs, made with a reference e.i.r.p. density of –41 dBm/MHz per UWB device, the relationship between the worst-case asymptotic value of aggregate interference mean power and the actual e.i.r.p. of the UWB devices could be extracted as:

– for FWA systems:

$$Aggregate\ \text{interf.}(rms\ power)\ (\text{dBm/MHz}) \approx -89 + 10\log\frac{UWB/\text{km}^2}{1\,000} + (e.i.r.p.(\text{dBm/MHz}) + 41) \quad (77)$$

– for 4 GHz P-P systems:

$$Aggregate\ \text{interf.}(average\ power)\ (\text{dBm/MHz}) \approx -85 + 10\log\frac{UWB/\text{km}^2}{1\,000} + (e.i.r.p.(\text{dBm/MHz}) + 41)$$

(78)

Summary for the "uniform distribution" scenario

The above elements show that, even if its objective is 2 dB more relaxed, the worst case is reached for 4 GHz P-P and hence will be the only one considered in deriving the suitable e.i.r.p. density limits for protection of FS from UWB, that will be based on equation (78).

We should note that "uniform distribution" is considered also representative of the average contribution of a "random distribution" see footnote in § 1.2.1

1.3.3.3 Case 2 – WPAN UWB applications – Numerical evaluation of a random distribution

The studies for this case 2 are carried over only in the most critical band of 3 to 5 GHz bands; higher frequency bands might be easily estimated from results in these bands.

1.3.3.3.1 Case 2 – Scenario

Actual urban scenario within a western Europe city (see § 1.2.1.2).

1.3.3.3.2 Case 2 – Method A

In the following sections the expected interference levels, with UWB reference e.i.r.p. density of –41 dBm/MHz, are used as reference.

This case uses a different set of UWB parameters for the aggregation scenarios that take into account other specific factors associated with WPAN applications and average mitigation factors which normally might assure SRR operation free from giving harmful interference to FS links, but may exceed the FS protection objectives by some dB in extreme situations.

1.3.3.3.2.1 Mitigation factors for the aggregate interference evaluation

For an overall aggregation evaluation, the mitigation factors, defined in § 1.4.1.1, have been directly included in the study with the following values:

– K_B factor: possible building attenuation experienced by any indoor UWB application:

The 10 dB value (i.e. difference between indoor and outdoor limits for GPS and other sensitive services protection) has been taken from the regulation of one administration as well as from the SEAMCAT handbook that also suggest the same 10 dB default value for indoor/outdoor attenuation.

However, for better reflecting the random characteristic of this parameter, the aggregate scenario 1c below, a random indoor-to-outdoor path loss model is used as follows:

– 15% devices with 12 dB attenuation.

– 15% – 40 dB attenuation.

– 70% – linear from 12 to 40 dB.

– K_{LoS} factor: this factor is not explicitly used since both LoS and NLoS channels are considered in the path loss models.

$K_{outdoor}$ factor: this factor is not explicitly used since both LoS and NLoS channels are considered in the path loss models.

– K_{pol} factor: using FS mostly either vertical or horizontal polarization, this will result in a 3 dB mitigation.

– $K_{\%}$ factor: depends on the actual utilization rate over a fixed period of time ($K_{\%} = 10\log(P_U\%/100)$ of the devices (idle gating periods); this factor might range from 100% (industrial applications) to few percent for some communication devices. The activity factor, for WPAN-based applications has been defined as:

– 1% average in peak utilization hours for Scenarios 1 (generic distribution of UWB on the territory with mixture of industrial, business and home applications);

– 0.3% average in peak utilization hours for Scenario 3a (corporate building with UWB high speed communication systems).

– As additional important mitigation, no UWB fixed outdoor implementations are considered (unless possibly under specific license procedure) eliminating the possibility of worst case "single entries" that would by themselves undermine coexistence with FS.

1.3.3.3.2.2 Propagation conditions

In order to provide physically consistent power calculation method, a study of propagation conditions in urban and suburban scenarios was performed. The goal of the study was to obtain probability of LoS/NLoS propagation conditions in the developed areas described above.

Propagation conditions for the revised scenario are obtained through Monte-Carlo simulations. In the simulations, buildings are randomly distributed with the given density as shown in Fig. 164. Buildings are assumed to have the same floor plan with 20 × 20 m footprint. Heights of the buildings satisfy distributions shown in Fig. 152.

FIGURE 164

Building distribution for simulation of propagation conditions

In each Monte-Carlo trial, devices are randomly distributed inside houses and the LoS propagation is checked with respect to walls of the building where the device is located and to other buildings, separately. Average values of indoor-to-outdoor LoS propagation probability and outdoor LoS propagation probability are calculated after large number of trials.

Simulations show that indoor-to-outdoor LoS probability is approximately 0.3 for victim height 45-60 m except 100-200 m area close to the victim where it is 0.1-0.3 due to blockage by ceilings. Outdoor LoS probabilities for 45 m and 60 m victim heights are presented in Figs. 165 and 166, respectively, for height interval up to 21 m and distance up to 7 km.

Note that for heights above 10th floor LoS probability is set to 1.

FIGURE 165

Outdoor LoS probability for urban scenario with victim height 45 m

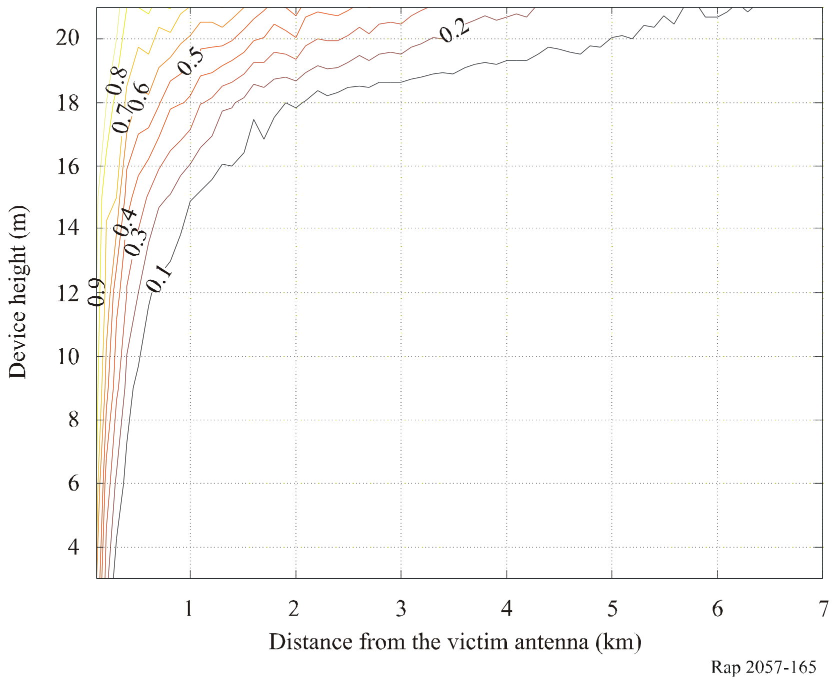
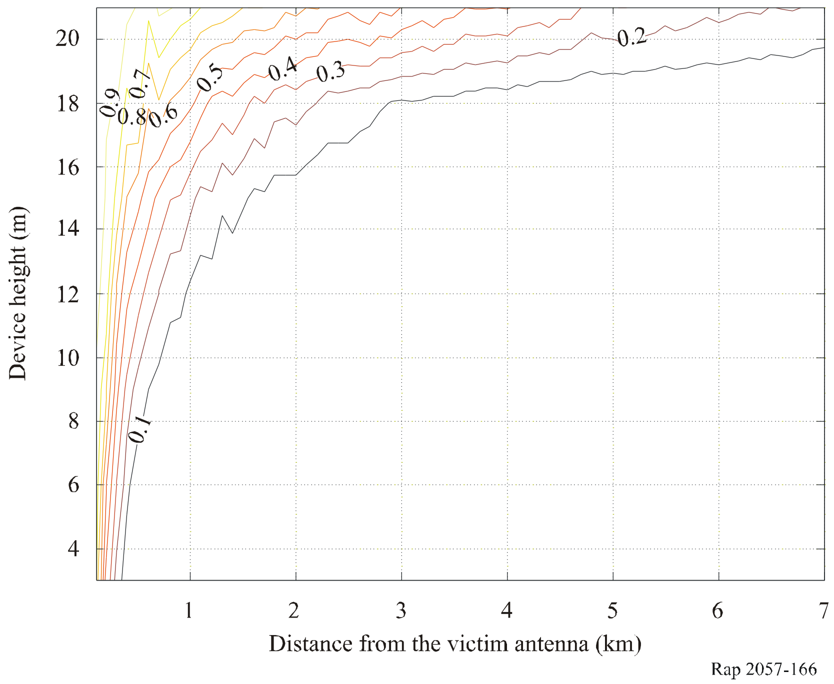


FIGURE 166

Outdoor LoS probability for urban scenario with victim height 60 m



1.3.3.3.2.3 Path loss models

For each device, it is randomly chosen if it is LoS or NLoS to the victim, according to probability presented in the previous section. Then, outdoor path loss is calculated:

– Indoor to outdoor path:
  – Random attenuation with a given probability distribution (see K_B definition in § 1.4.1.1).
– Outdoor path for LoS – free space.
– Outdoor path for NLoS:
  – Low height floors (<10 m): IEEE 802.16 Category B – NloS.
  – Medium and high height floors (>10 m): IEEE 802.16 Category C: NLoS.

The activity factor is used to determine the number of transmitting devices at the given point of time. Therefore, for 10 000 devs/km^2 and 1% AF, the number of transmitting devices is 100/km^2. Interference power is computed using power of randomly distributed devices with density of 100 devs/km^2. Thus, deviation of aggregate interference in cases with low AF is larger (summation of less number of terms) which makes less sloppy curves for less AFs.

The 9 dB Gaussian shadowing term is included as proposed in the Erceg's model: it should not exceed 2 times the standard deviation ($2\sigma = 18$ dB) to both sides. Moreover, for NLoS path loss considering that IEEE 802.16 propagation model with random shadowing may sometimes give too optimistic (low attenuation) results, a free-space lower attenuation bound is inserted, so that path loss is always chosen to be maximum of Erceg and free space.

1.3.3.3.2.4 Results of aggregate analysis for urban and suburban area model (1 000-10 000 devices/km^2)

In this section, we present results of interference evaluation for urban and suburban scenarios. Maximum house height is assumed to be 60 m (20 floors), since higher buildings are of very low probability and give no noticeable impact. Results are presented in the form of I/N preservation probability.

Figures 167 and 168 present interference levels for urban scenario 1c, without and with lognormal shadowing term (9 dB), respectively.

FIGURE 167

Probability of *I*/*N* level preservation in Scenario 1c; path loss model without the shadowing term

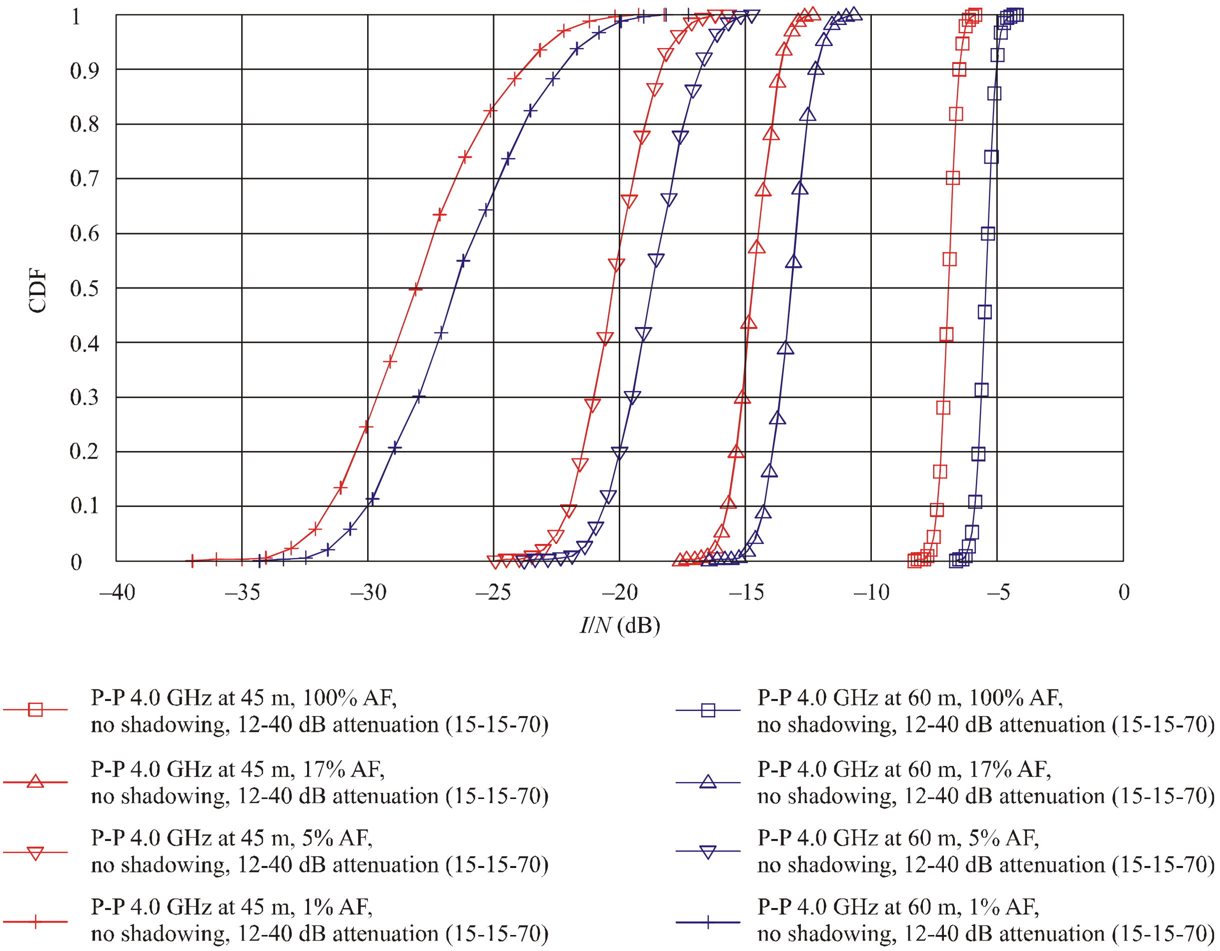


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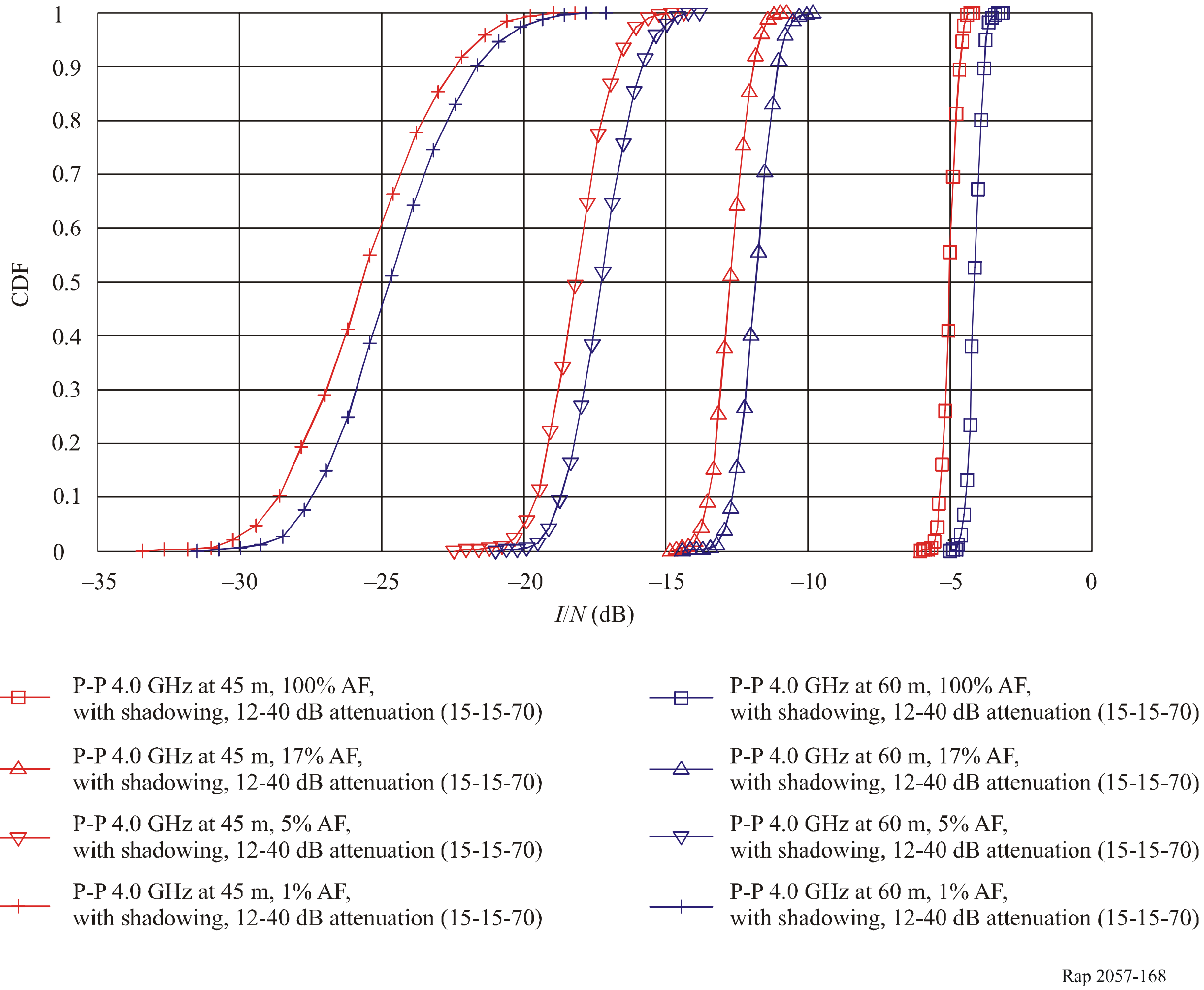
FIGURE 168

Probability of *I*/*N* level preservation in Scenario 1c; path loss model incorporates the 9 dB shadowing term



Figures 169 and Fig. 170 present interference levels for urban scenario 1b, without and with lognormal shadowing term (9 dB), respectively.

FIGURE 169

Probability of *I*/*N* level preservation in Scenario 1b; path loss model without the shadowing term

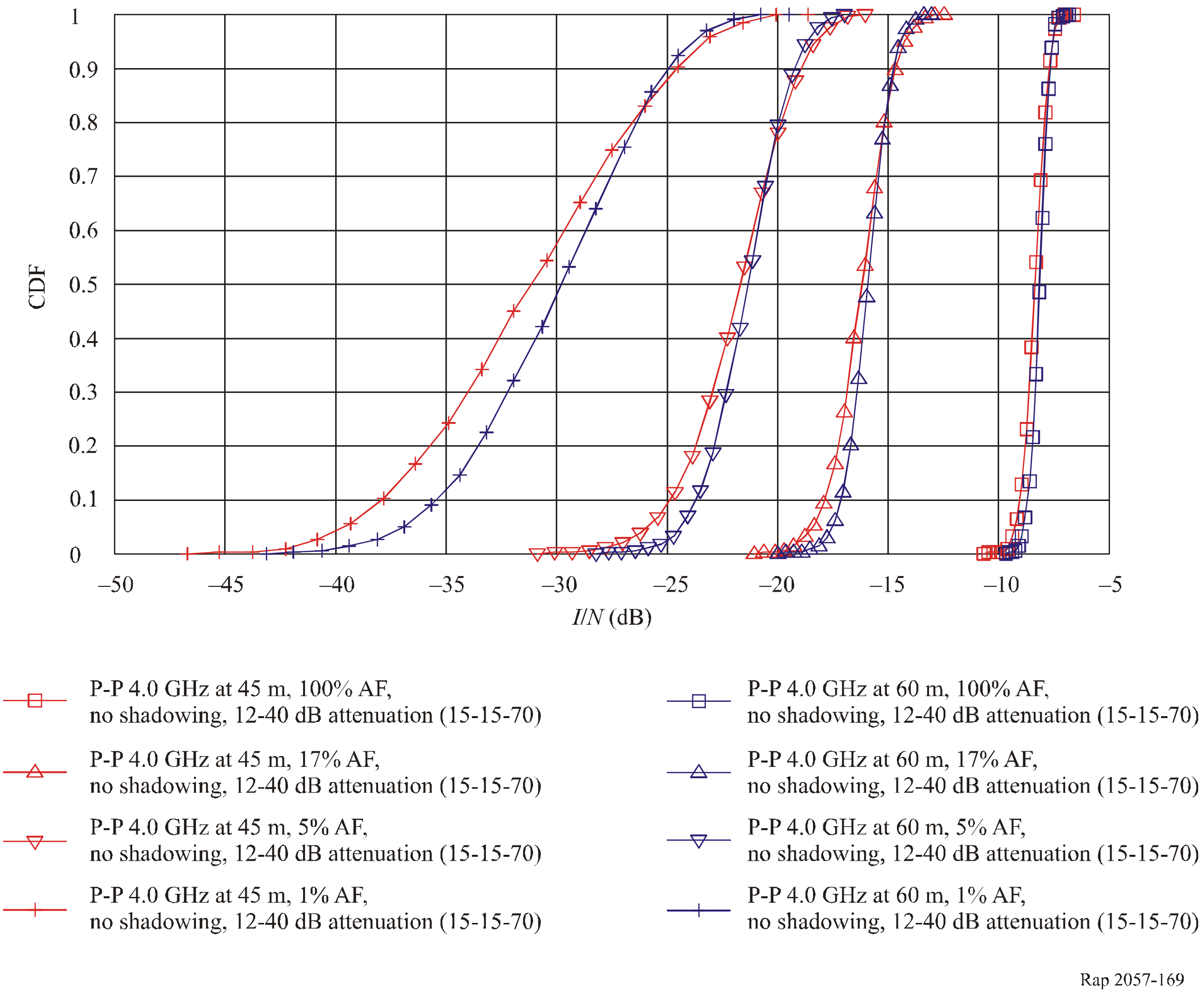


FIGURE 170

Probability of *I*/*N* level preservation in Scenario 1b; path loss model incorporate the 9 dB shadowing term

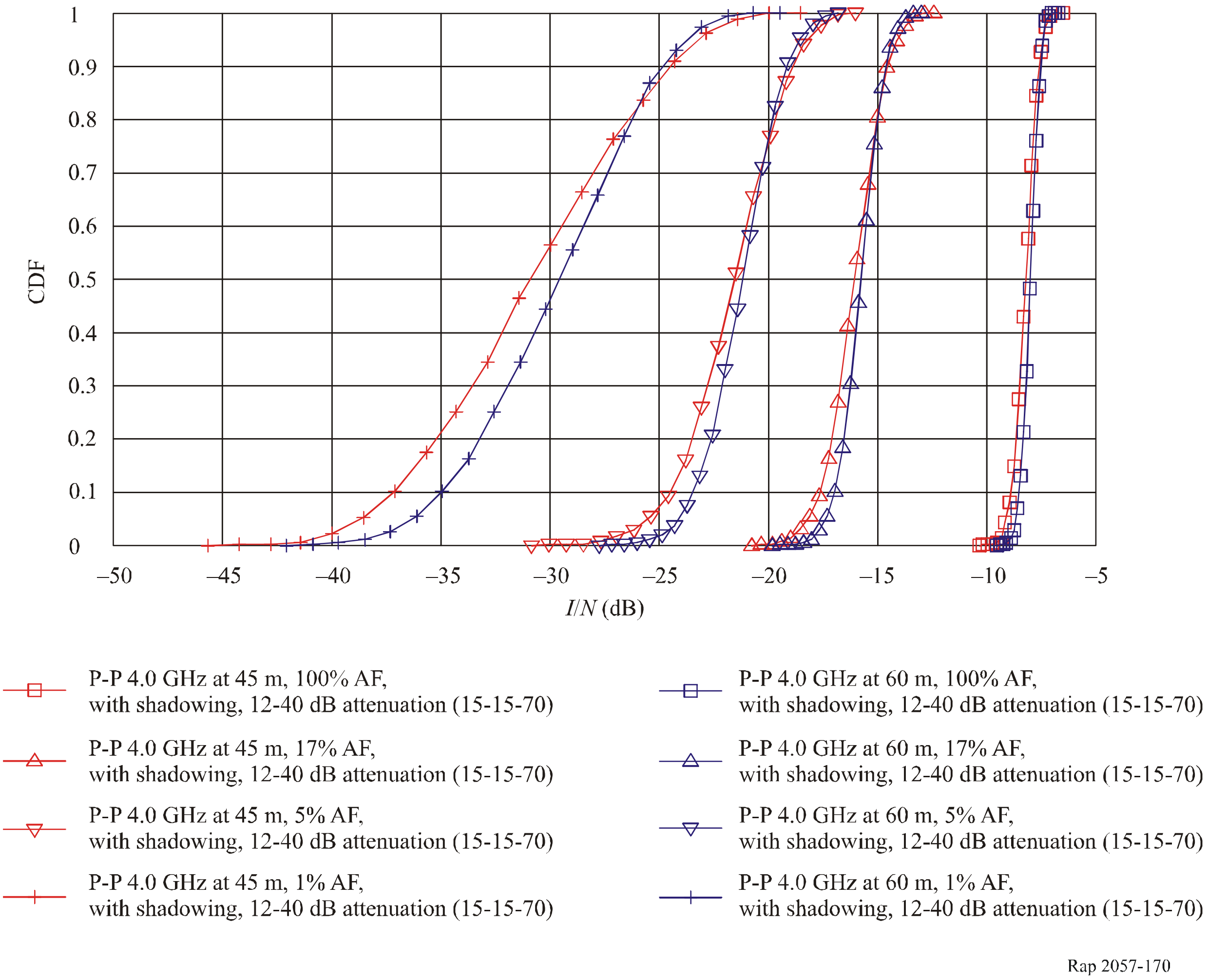
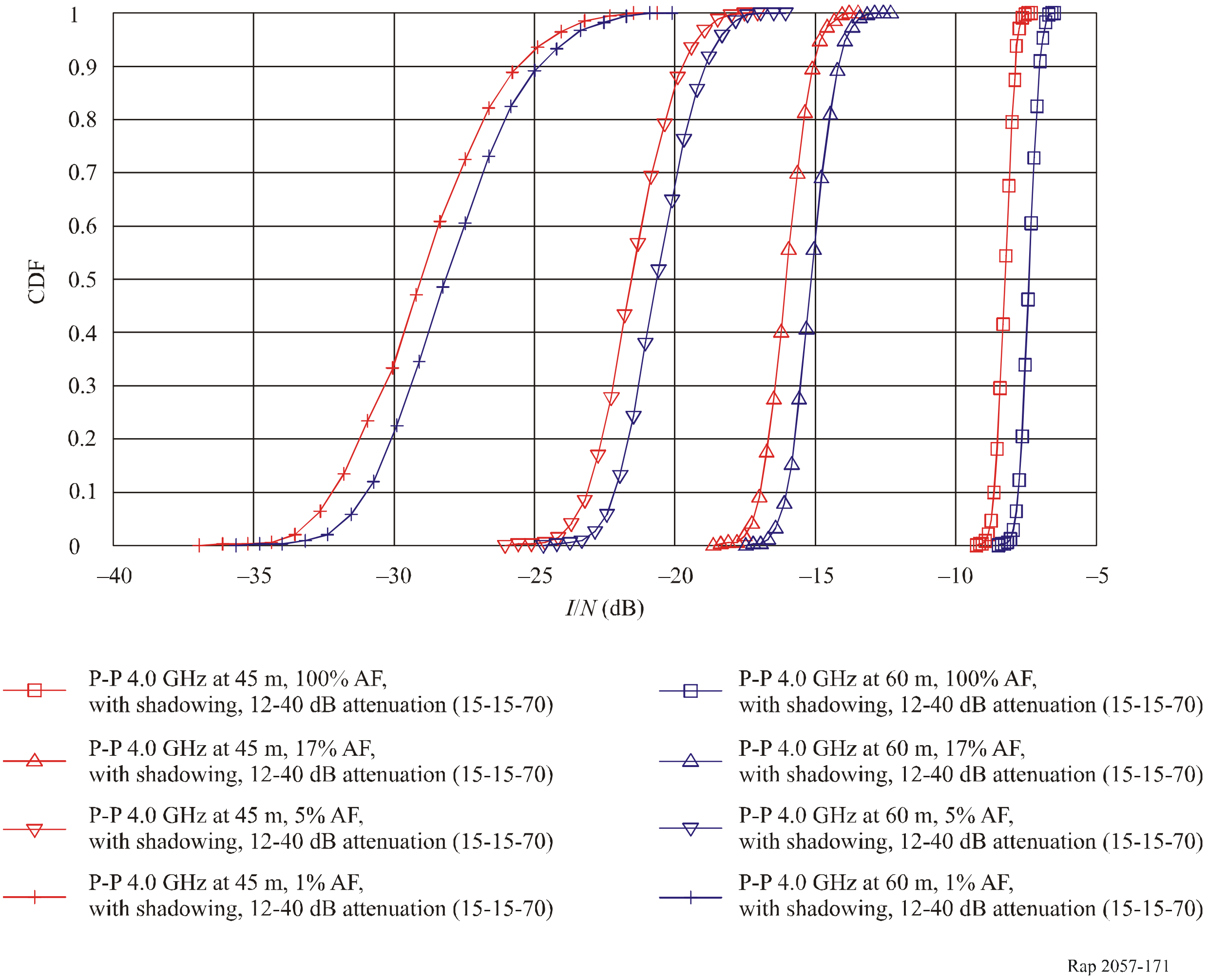


Figure 171 presents *I*/*N* confidence probabilities in the same case as in Figs. 151 and 152, with power control option enabled in all UWB devices. It is assumed that all devices can reduce emission power up to 8 dB with 1 dB step, and all power control attenuations are equiprobable.

FIGURE 171

Probability of *I*/*N* level preservation in Scenario 1c; path loss model incorporate the 9 dB shadowing term and power control option is enabled



1.3.3.3.3 Case 2 – Method B

This second method is based on the same real urban scenario (see § 1.2.1.2).

It should be noted that the methodology of evaluating LoS/NLoS probability for each floor at a certain distance from the FS location (used in previous method A) was not included in this method B model for the considerable additional implementation burden and also because it would add uncertainty to the results. Rationale is that actually, the LoS/NLoS statistical distribution has been derived using a complete random orientation of single buildings (20 × 20 m area), not connected each other; the Milan reality is far different: buildings are in blocks of 5/10 aligned along streets that have a rough radial/concentric pattern. It was furthermore estimated that differences should not be too much.

1.3.3.3.3.1 Propagation models

1.3.3.3.3.1.1 Outdoor path portion

As in method A, it is here used, as far as possible, the IEEE 802.16 adopted NLoS propagation model developed in cooperation with Stanford University for the purpose of FWA system planning in the frequency bands of interest (i.e. below ~ 6 GHz) also for UWB aggregation study.

Therefore, a more pragmatic approach as been used decreasing obstruction models as far as the UWB random height location increases.

The building height distribution exhibits a mean value of ~ 16 m (between 5 and 6 floors) in the urban area and ~ 10 m (between 3 and 4 floors) in the suburban frame area; therefore, for a three-dimensional evaluation, different propagation models should be used according the height of UWB (assigned by the Monte-Carlo random distribution). The following proposal details the propagation models for each case.

– *outdoor (20% of density as hand-held devices)*: NOTE 1 – We assume that, like FCC R&O, only hand-held outdoor devices would be allowed through regulatory provision. being at ground floor, a relatively high blocking situation might be described by IEEE 802.16 models, typically Erceg B category. UWB height = 2 m.

– *UWB distributed below the mean building height*: Erceg B with UWB height = actual randomly assigned.

– *UWB distributed from mean building height and height corresponding to ~ 5% probability*: the lightest category "C" model will be used. Standing that Erceg model are not defined for terminal heights more than 10/15 m (attenuation becoming unreasonably low), a modification has been introduced resetting all height (UWB and FS antenna) to a new virtual ground plane at the building average height (~ 15 m urban and ~ 12 m suburban). A separate run is also presented using free-space only as upper-bound check for the modification made.

– *UWB distributed on height above that ~ 5% probability*: will be considered LoS free-space. FS and UWB actual height will be used.

The height exceeding the 5% probability is ~ 30 m (10 floors) in the urban area and ~ 24 m (8 floors) in the suburban frame area.

Slight variation will happen in the "truncated height" area sector along the FS clearance path.

1.3.3.3.3.1.2 IEEE 802.16 shadowing evaluation

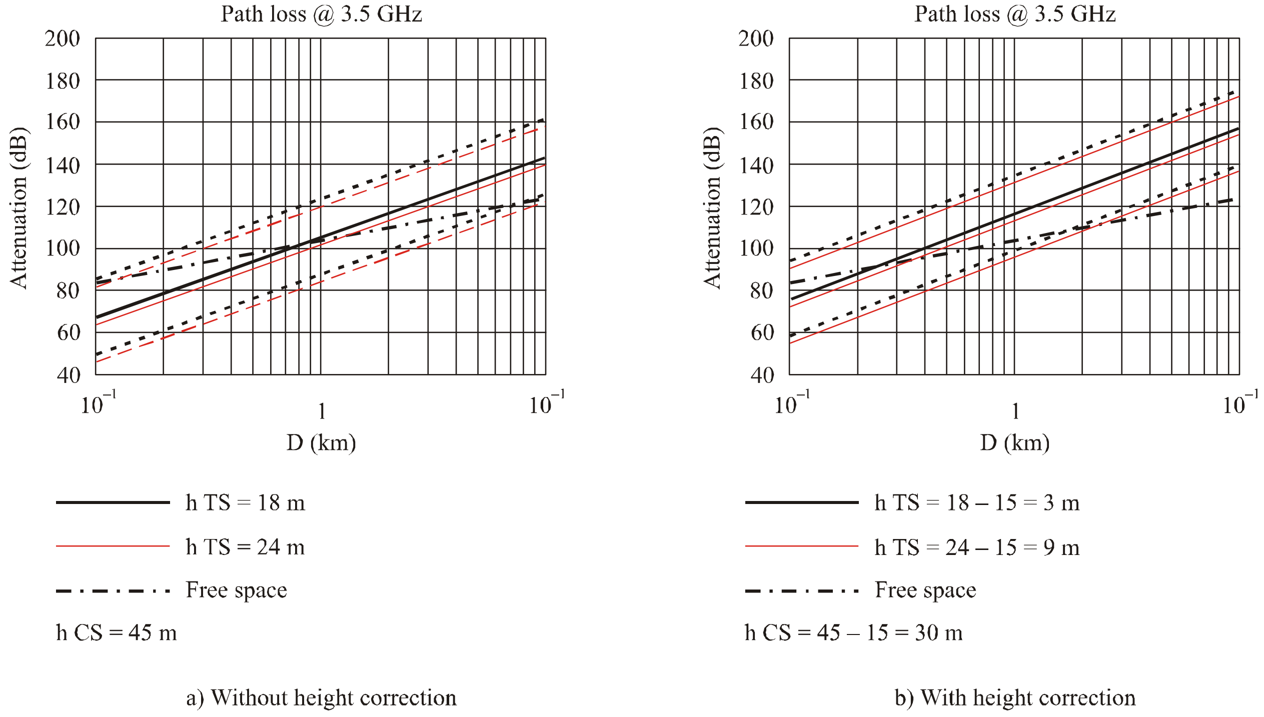
The 802.16 models (as most of the NLoS models) are based on statistic Gaussian distribution of the attenuations. They are generally described through an average attenuation (A_{50}) (dB) and an associated standard deviation ($\sigma \cong 8 \div 10$ dB).

Figure 172 shows the shadowing distribution examples of the Erceg C models used for the evaluation of higher floors contribution with $\sigma \cong 9$ dB; solid lines are mean values, dotted lines are the Gaussian variance at 95% confidence.

Figure 172a) shows the attenuations without the height correction for bringing the values within the model validity range, while Fig. 172b) show values corrected as described above.

FIGURE 172

IEEE 802.16 Erceg C path attenuation distribution used for higher floors (solid lines: mean value; dotted lines: 95% confidence range)



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1.3.3.3.3.1.3 Indoor to outdoor path portion

For the 80% of UWB devices, deployed in indoor locations, we should define the additional attenuation of the indoor and trough walls/windows attenuation.

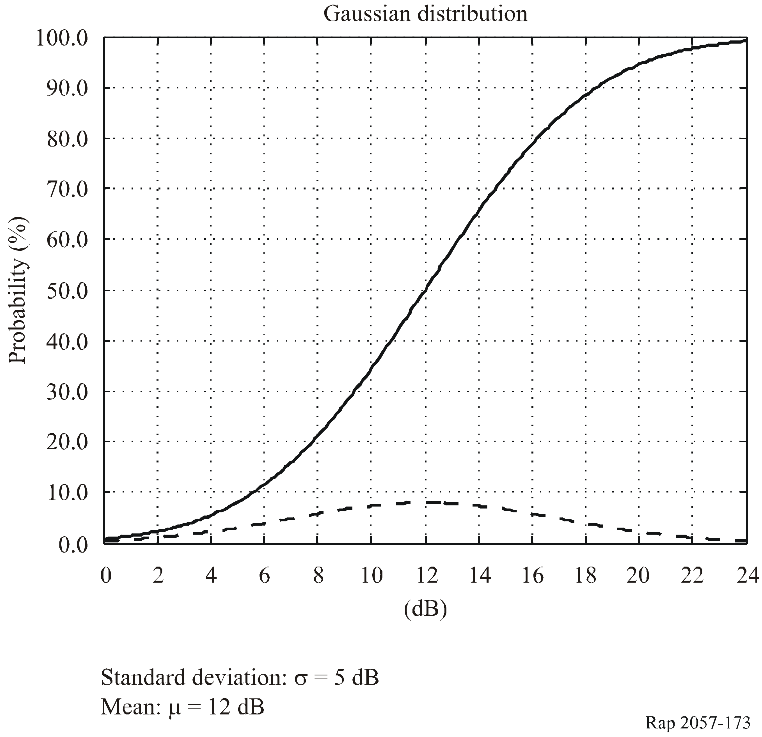
For this purpose we prefer to use as much as possible ITU-R assumptions adapted for the scope; therefore, a building footprint area of 20 × 20 m area subdivided in ~ 4 flats, with some services (stairs, elevators, etc.) in the centre.

The indoor to outdoor attenuation, will range form a lower value (for UWB closer to the building side close to the FS antenna) to a maximum for those that would be on the opposite side (neglecting, for simplicity, any possible reflection backwards by buildings behind).

We will derive a continuous distribution through the convolution (representing the joint probability) of building through wall attenuation Gaussian distribution given in Recommendation ITU-R P.1411 (Fig. 173) and the indoor attenuation, additional to free space, given by the two slope Siwiak model (with d_t = 3 m) used within Radiocommunication TG 1/8 documents for UWB indoor propagation, extended over the floors area. An additional step of 10 dB, representing the additional attenuation of internal elevators and stairs areas, is introduced in the middle of the building as shown in Fig. 174.

FIGURE 173

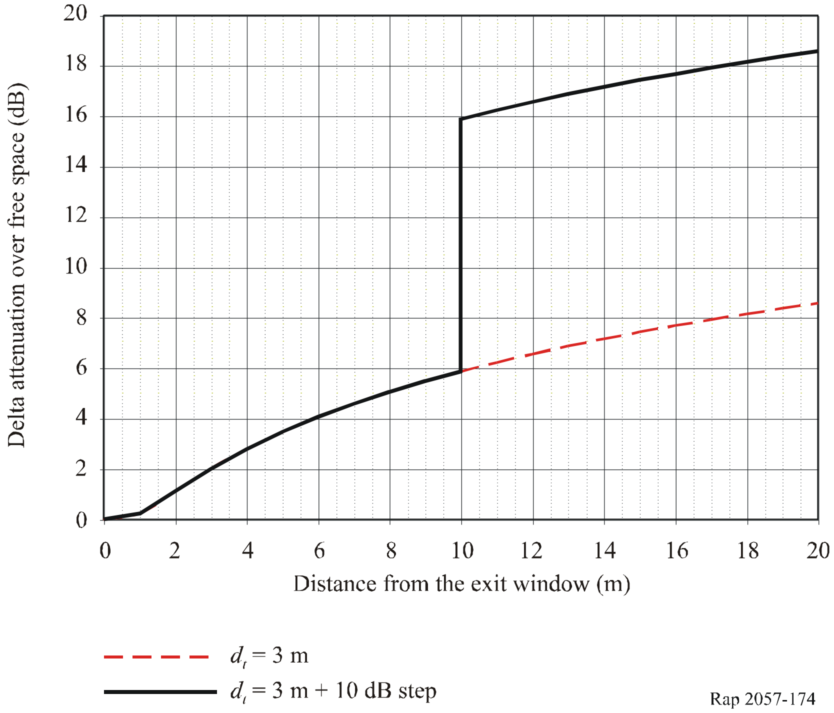
Probability density and cumulative probability of the Recommendation ITU-R P.1411 penetration distribution



Rap 2057-173

FIGURE 174

Attenuation of the indoor path additional to free-space (each value assumed to have equal probability)

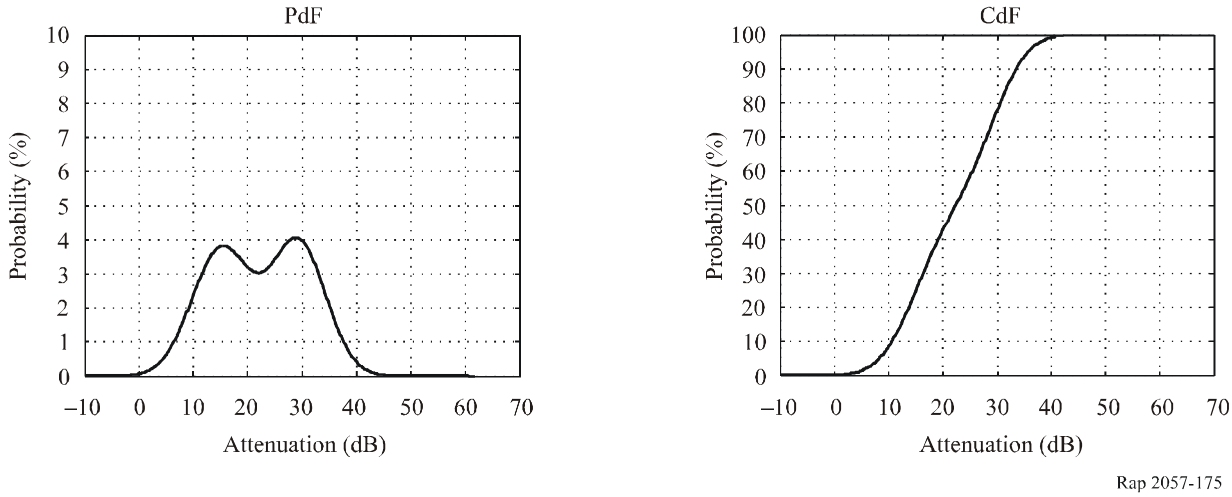


Rap 2057-174

The joint probability obtained from convolution of the two distributions is shown in Fig. 175 as probability density and cumulative probability

FIGURE 175

Probability density and cumulative probability of the joint attenuation functions



1.3.3.3.3.2 Activity factor and other mitigations

These are not FS specific; they are also linearly affecting the aggregate interference results and could be managed of-line at the conclusion of the study.

Therefore, they are included as additional "K factors" as:

– 3 dB K_{pol};

– fixed minimum activity factor of 1% (20 dB) as K%.

1.3.3.3.3.3 Monte-Carlo Snap-shots description

Step 1

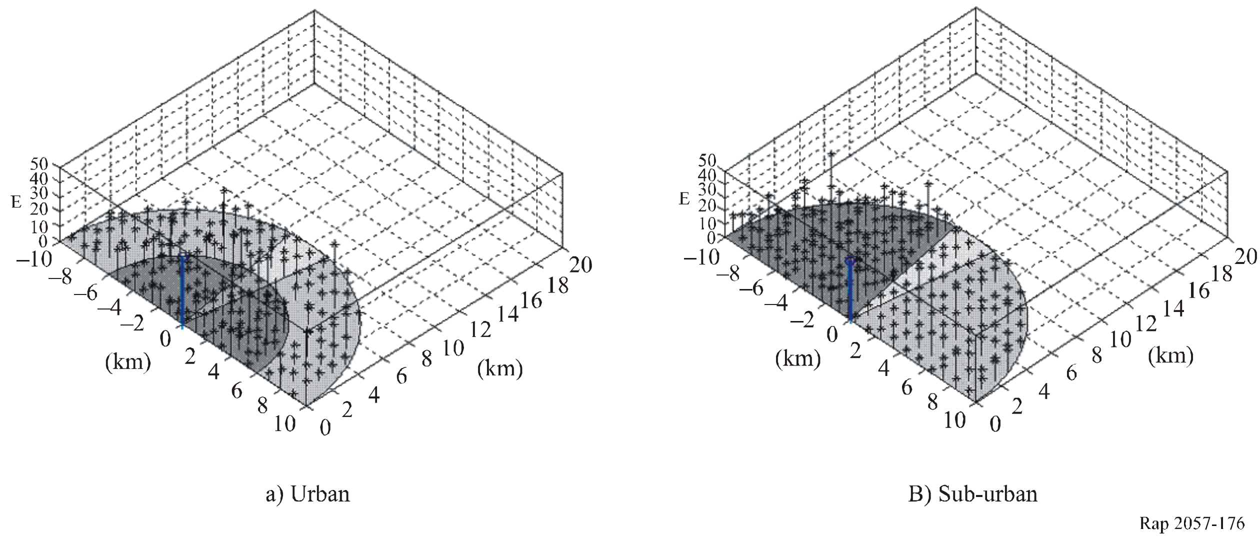
Each UWB device is given with an elevation randomly derived from the relevant building/floor distribution.

When sectors inside the Fresnel clearance of main beam are concerned, whenever a height higher than the needed clearance is picked-up, it is discarded and a new pick-up is made until it is lower that the required clearance.

Figure 176 pictorially shows the random height assignment.

FIGURE 176

Visual example of UWB height distribution over model areas



Step 2

Each UWB now allocated in the space will be given a propagation model depending on its height (i.e. Erceg B, Erceg C or free-space); arrival angle and distance is calculated and path loss, including relevant antenna RPE contribution is calculated.

Step 3

For each UWB, an indoor + building exit additional attenuation is picked up from the random distribution described in § 1.3.3.3.3.1.

Step 4

Using the attenuation of each UWB device, evaluated in previous Steps 1 to 3, the received power density of each UWB (assumed at −41.3 dBm/MHz e.i.r.p. density) is evaluated and cumulated for all UWB population within the same snapshot subdivided into the different sectors and into the overall aggregation.

Step 5

After concluding the first snap-shot, described in the previous steps, other 14 999 similar snapshots are conducted and a probability density and cumulative probability function of the aggregate e.i.r.p. SD is calculated.

For better understanding of the major source of interference, separate evaluations are made for the mean power density value (see Note 1) and cumulative distributions in each sector and in the whole area.

NOTE 1 – The mean power density values are obtained as the power sum of all snapshots results divided by 15 000 (number of snapshots). It roughly corresponds to the value not exceeded for 90% of the snapshots.

1.3.3.3.3.4 Results – Point to point (Siemens 396)

Figures 177, 178, 179 and 180 show the probability density and the cumulative probability of the aggregate power density evaluated over the 15 000 snap-shots for each aggregation; subdivision of contributions from various sectors are also shown.

The aggregate power density presented does not include any further mitigation such as average activity factor or polarization decoupling or average ATPC mitigation, which will be added separately in the conclusions.

1.3.3.3.3.4.1 Scenario A – Urban FS station

Input data summary:

UWB e.i.r.p. density	:	−41.3 dBm/MHz
UWB densities:		
Sectors 1 and 2 (urban)	:	10 000/km^2
Sectors 3 and 4 (suburban transition):		3 000/km^2
Sectors 2 and 4 opening angle	:	0.3 radians/17.19° (~twice Fresnel)
Sectors 2 and 4 limited buildings height	:	20 m (FS ant. 45 m) or 35m (FS antenna 60 m)
Sectors 1 and 2 radius	:	6 km
Sectors 3 and 4 radius	:	10 km
Erceg models variance	:	σ = 9 dB (truncated at ±2σ)

NOTE 1 – Standing the limited applicability of Erceg model for terminals heights higher than 10/15 m and attenuation for distances less that 100 m, the following variance have been considered: above the building mean height (~ 15 m urban and ~ 12 m suburban) the height of both UWB and victim FS have been reset to a new virtual ground plane coincident with the mean height. The attenuation below 100 m distance has been maintained constant at the 100 m value.

Building height distribution	:	Figure 152
Floors distribution	:	Figure 153
Indoor to outdoor additional attenuation		Convolution – Fig. 175
FS frequency	:	4 GHz
FS P-P antenna	:	Recommendation ITU-R F.1245 *G* = 41.56 dB
Monte-Carlo Snapshots	:	15 000

– **FS Antenna at 45 m**

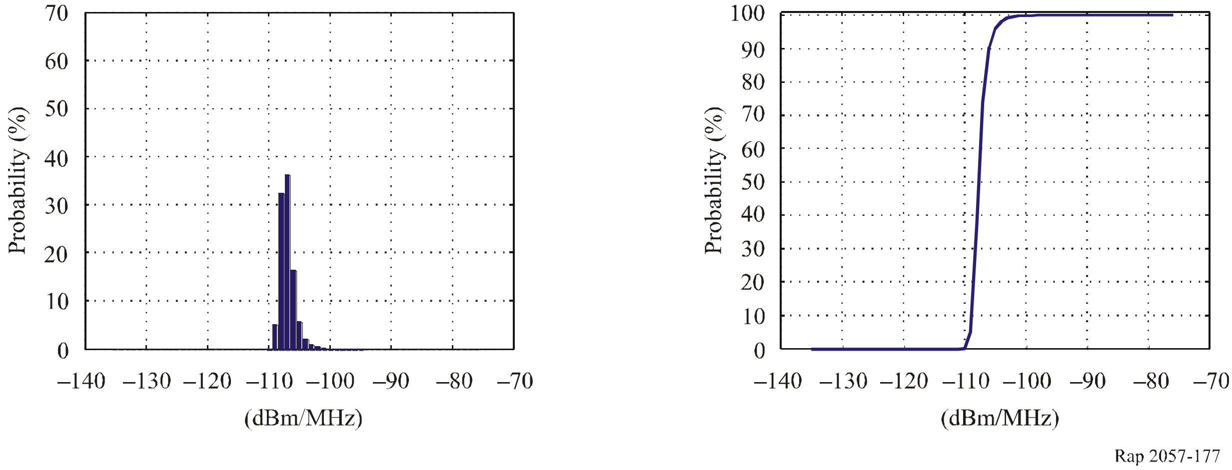
The mean value of the probability density distribution of the aggregated power densities in the various sectors changing the UWB density are:

Mean value Sector 1:	–109.19 dB
Mean value Sector 2:	–109.40 dB
Mean value Sector 3:	–140.85 dB
Mean value Sector 4:	–130.54 dB
Mean value over whole 10 km area:	–106.26 dB

The probability density distribution and cumulative probability function of the overall aggregation are shown in Fig. 177.

FIGURE 177

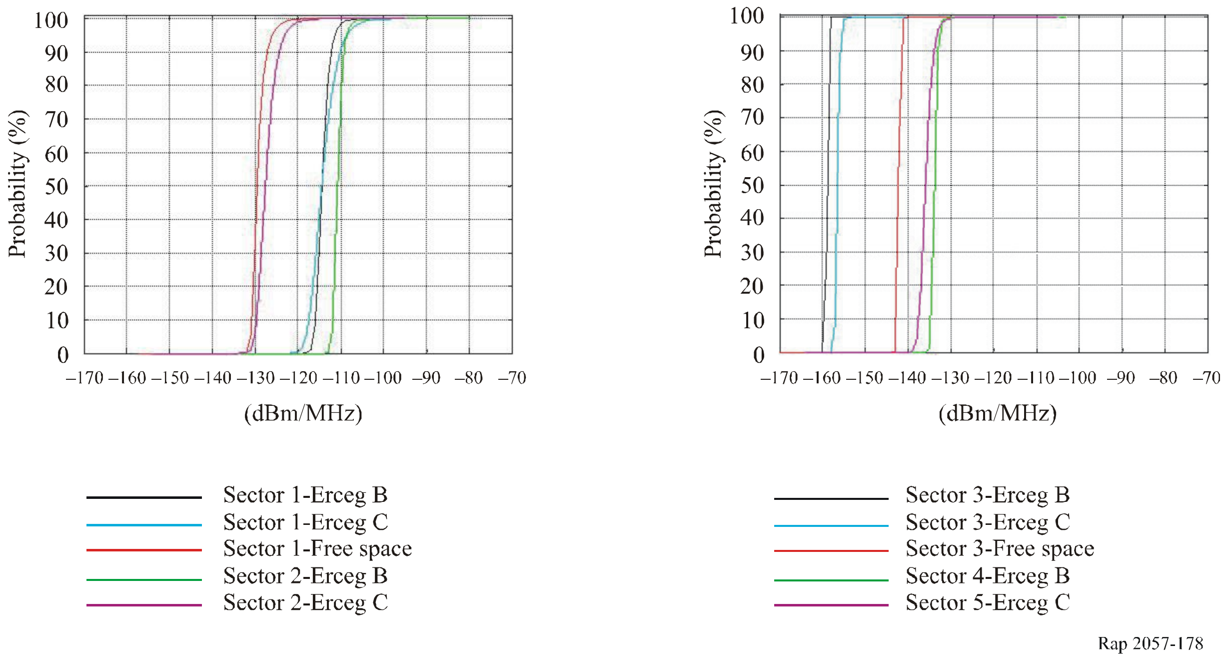
Probability density and cumulative probability of the overall aggregation (Scenario A – urban; FS antenna height 45 m)



It might be interesting to look at separate contributions by each sector and by each set of UWB assigned to various propagation models. Figure 178 shows the separate cumulative probabilities. It should be noted that being sectors 2 and 4 (main beam) limited in UWB height below the threshold triggering free space propagation, there are no contributions under this category.

FIGURE 178

Cumulative probability due the various sectors and set of devices with different propagation models (Scenario A – urban; FS antenna height 45 m)



– **FS antenna at 60 m**

The mean value of the probability density distribution of the aggregated power densities in the various sectors changing the UWB density are:

Mean value Sector 1: –110.29 dB

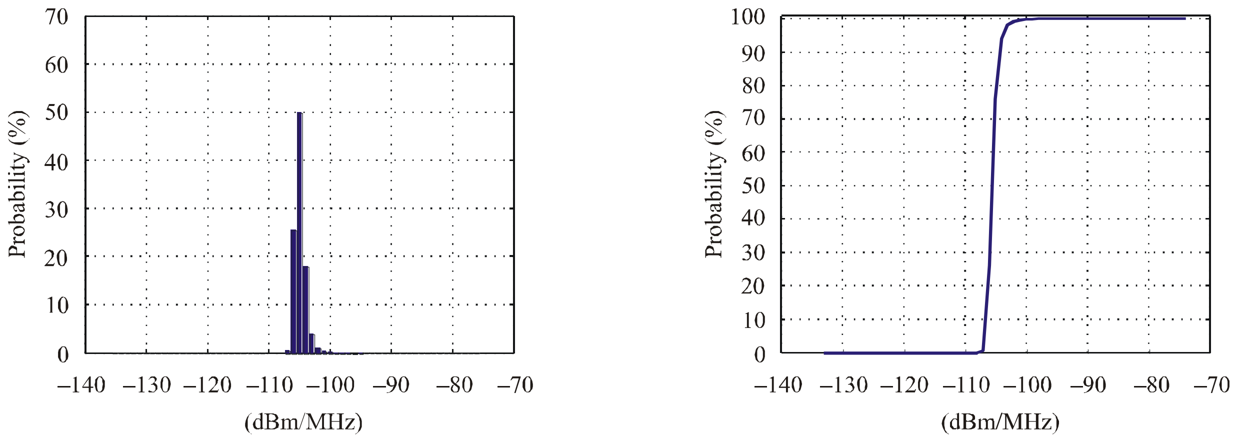
Mean value Sector 2: –105.97 dB

Mean value Sector 3:	–140.47 dB
Mean value Sector 4:	–116.21 dB
Mean value over whole 10 km area:	–104.31 dB

The probability density distribution and cumulative probability function of the overall aggregation are shown in Fig. 179.

FIGURE 179

Probability density and cumulative probability of the overall aggregation
(Scenario A – urban; FS antenna height 60 m)

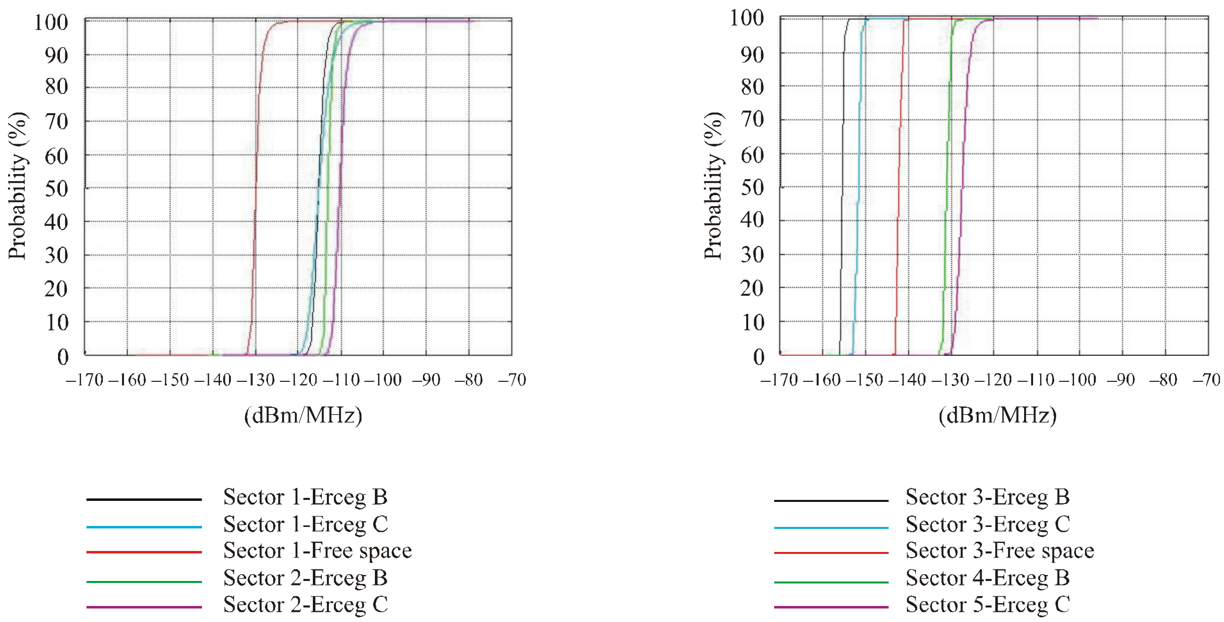


Rap 2057-179

It might be interesting to look at separate contributions by each sector and by each set of UWB assigned to various propagation models. Figure 180 shows the separate cumulative probabilities. In this case, having sectors 2 and 4 (main beam) a higher possible UWB height, the free space threshold propagation is eventually triggered, and contributions under this category appear.

FIGURE 180

Cumulative probability due the various sectors and set of devices with different propagation models
(Scenario A – urban; FS antenna height 60 m)



Rap 2057-180

– **Handheld outdoor UWB impact**

For having information on the impact of a possible additional population of 2 000/km^2 handheld UWB devices, a separate evaluation is reported here.

Device density is kept constant over the whole 10 km radius (no sectors differentiation) and all placed at constant 2 m height.

Two models, Erceg B and Erceg C are used for comparison.

The mean value of the probability density distribution of the aggregated power densities in the various sectors changing the UWB density are:

	Erceg B propagation (dBm/MHz)	Erceg C propagation (dBm/MHz)
Mean value Sector 1:	–111.30 dB	–110.71 dB
Mean value Sector 2:	–110.09 dB	–107.69 dB
Mean value Sector 3:	–148.41 dB	–143.40 dB
Mean value Sector 4:	–123.81 dB	–118.79 dB
Mean value over whole 10 km area:	–107.53 dB	–105.71 dB

Figure 181 shows the cumulative probability of aggregation.

1.3.3.3.3.4.2 Scenario B – Grazing suburban FS station

– **FS antenna at 45 m**

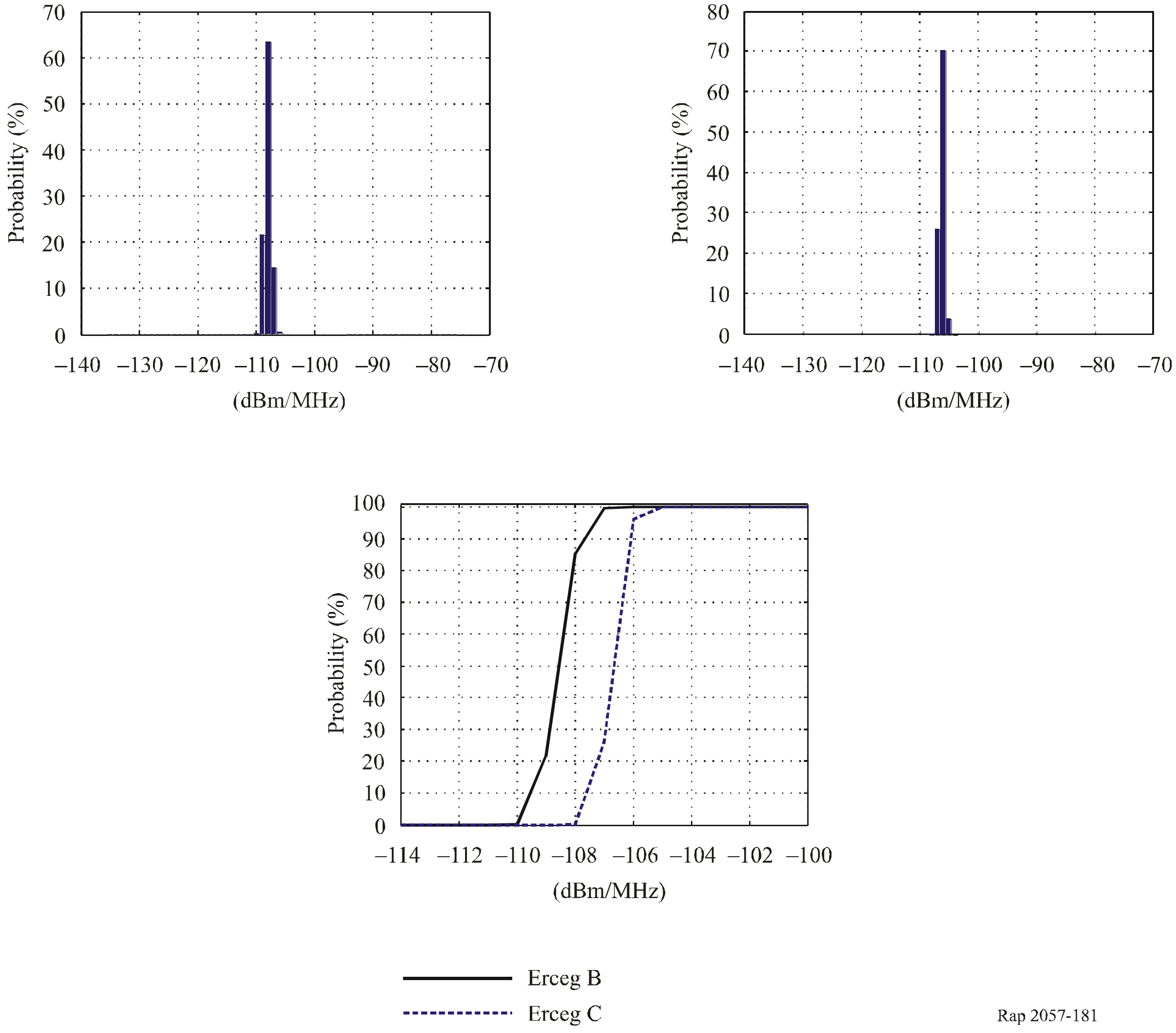
The mean value of the probability density distribution of the aggregated power densities in the various sectors changing the UWB density are:

Mean value Sector 1:	–112.26 dB
Mean value Sector 2:	–115.27 dB
Mean value Sector 3:	–118.67 dB
Mean value over whole 10 km area:	–109.88 dB

The probability density distribution and cumulative probability function of the overall aggregation are shown in Fig. 182.

FIGURE 181

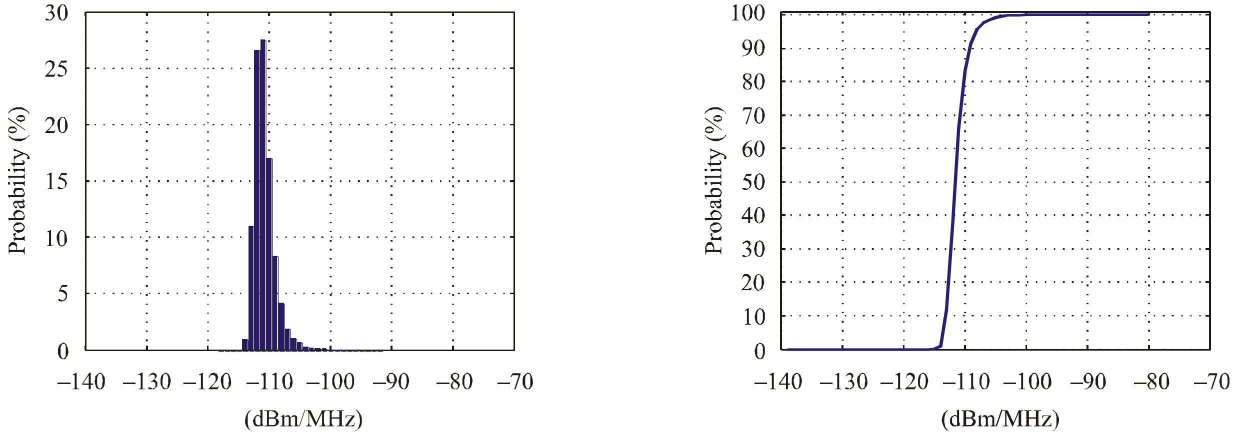
Cumulative probability of aggregate interference caused by outdoor handheld device 2 000/km² density at ground floor (Scenario A – Urban; FS antenna height 45 m)



Rap 2057-181

FIGURE 182

Probability density and cumulative probability of the overall aggregation (Scenario B – Grazing suburban; FS antenna height 45 m)



Rap 2057-182

– **FS antenna at 60 m**

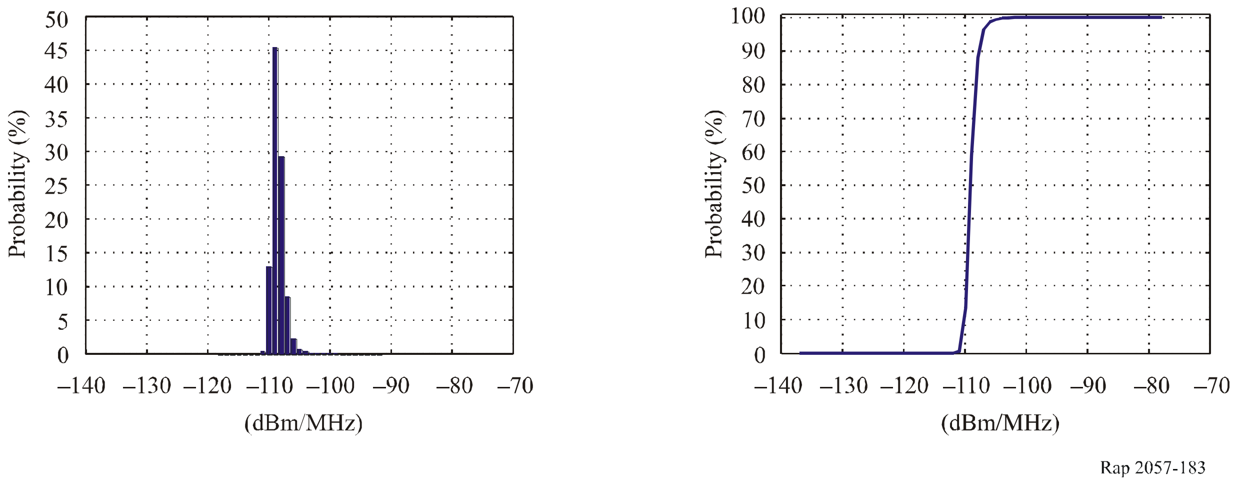
The mean value of the probability density distribution of the aggregated power densities in the various sectors changing the UWB density are:

Mean value Sector 1:	–113.33 dB
Mean value Sector 2:	–109.79 dB
Mean value Sector 3:	–119.72 dB
Mean value over whole 10 km area:	–107.91 dB

The probability density distribution and cumulative probability function of the overall aggregation are shown in Fig. 183.

FIGURE 183

Probability density and cumulative probability of the overall aggregation (Scenario B – Grazing suburban; FS antenna height 60 m)



1.3.3.3.3.5 Results – FWA CS

The same model and scenario applied to the P-P case, has been used with the following specific variations:

– Unlike the P-P case, no building height limitation along the antenna boresight.

– Alternatively, for simulating a “respect area”, likely to happen around an CS-FWA, which location is generally selected over a higher building, a semicircular area (two cases 10 m or 100 m radius) has been created as being free of any UWB devices.

– The different ITU-R F.1336 azimuth and elevation patterns of a sectorial antenna have been combined according to Fig. 184:

FIGURE 184

Azimuth and elevation RPE Combining

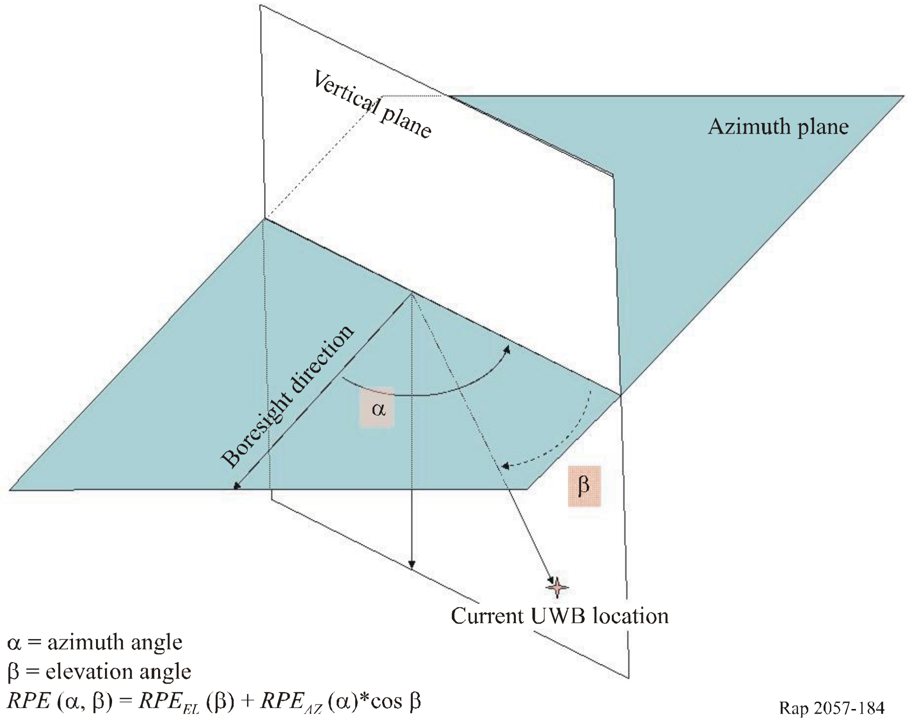


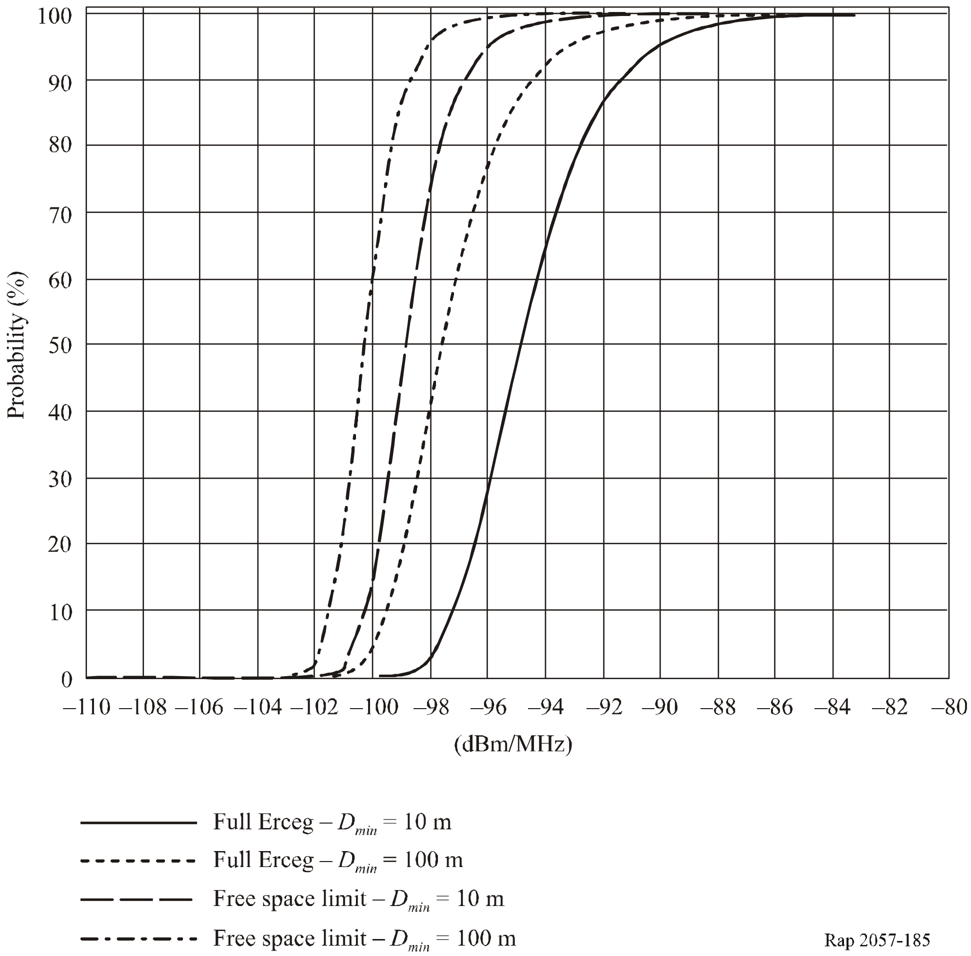
Figure 185 shows the cumulative probability of the aggregate power density evaluated over the 5 000 snap-shots for each aggregation.

In addition, a comparison of results obtained with the free variation of IEEE 802.16 model (as modified for maintaining TS height within the validity range; see previous contribution 1 description) with the same model with an added lower attenuation bound equal to free-space (as in Method A) has been made.

The aggregate power density presented does not include any further mitigation such as average activity factor or polarisation decoupling or average ATPC mitigation, which will be added separately in the conclusions.

FIGURE 185

Cumulative distribution



1.3.3.3.3.6 Comments to results

From the data shown in previous sections we could derive some general considerations on the aggregations:

– In the urban three-dimensional distribution scenario A, the major contributions still come from the devices falling within the footprint of the main lobe of the FS antenna. However, with lower antenna, some contribution comes also from nearby devices.

– Free space cases become relatively significant only in the suburban sectors with higher FS antennas. However, their impact is not determinant over the whole aggregation.

– The above trend, even if less marked, is true also for the grazing suburban scenario B, where only one side of the beam direction is hit by the higher UWB density over a higher rise building probability distribution.

– Higher antennas tend to be slightly more affected; this is possibly due to the higher number of UWB devices permitted by higher buildings within main beam footprint and also by the less attenuation given by Erceg model if the FS antenna is higher.

– The UWB density used for the suburban sectors (here assumed conservatively at 3 000/km^2) is not anyway particularly impacting the overall aggregation still dominated by the urban sectors.

– The variation of probability distribution of the aggregate power with the UWB density, besides obviously increasing approximately linearly, tend to have less variance and steeper cumulative distribution when the UWB density increases. Also, same effect is experienced with FS antenna location increase (but average values decrease).

– The spread of aggregated values within significant probability range is contained in 15/20 dB for FS antenna height 45 m and in ~ 10 dB for 60 m.

– Difference between 45 m and 60 m FS antenna height are confined, at the 95% confidence, within ~ 3/4 dB. In addition, the higher is the antenna and the lower is the variance of the results.

– An eventual additional density (2 000/km^2) of outdoor handheld UWB seems highly affecting the results, giving potential increase of the overall aggregation (assuming equal activity factor) of ~ 3 dB (–105 dBm/MHz at 95% expected, to be added to the –105 dBm/MHz). Therefore, we might here confirm that outdoor UWB applications should be very carefully considered only if very low activity factor would be expected.

– The FWA CS evaluation shows that, in a real urban deployment, this case is expected to be more critical than the P-P one of ~ 10 dB. The rationale is related to the wider area covered by the main antenna sector and lesser elevation directivity, not compensated by the reduction of gain with respect to the P-P antenna. In addition, the non negligible possibility of UWB height locations at the same CS antenna height at close distance (up to around 100 m or less) could make the difference. However, the needed implementation of specific mitigation techniques such as DAA would actively reduce the interference also to the FWA CS, operating at the same frequency; therefore, the impact on FWA CS, even if formally slightly worse, will not considered in the final conclusions that will be based on the P-P example only.

1.3.3.3.4 Interference evaluation and confidence level

1.3.3.3.4.1 Conclusions

1.3.3.3.4.2 Summary of method A

I/*N* ratios with 95% confidence levels are summarized in the Table 96.

TABLE 96

***I*/*N* ratios with 95% confidence levels for various activity factors**

Item number	Shadowing (9 dB)	Power control 0..–8 dB	Activity factor (%)	*I*/*N* value (dB) urban/suburban
1	No	No	1	–21/–23
2	No	No	5	–16/–18
3	No	No	17	–12/–14
4	No	No	100	–5/–7.5
5	Yes	No	1	–21/–23
6	Yes	No	5	–15/–18
7	Yes	No	17	–11/–14
8	Yes	No	100	–3.5/–7
9	Yes	Yes	1	–24/not available
10	Yes	Yes	5	–18.5/not available
11	Yes	Yes	17	–14/not available
12	Yes	Yes	100	–7/not available

1.3.3.3.4.3 Summary of method B

From the point of view of FS protection we should look to the aggregated interference not exceeded for a suitably high probability.

The considerations below are valid for a 95% cumulative probability of not exceeding the levels shown.

We should still evaluate the impact of polarization decoupling and activity factor.

We will use 3 dB for polarization decoupling and variable activity factors of 1% (20 dB), 5% (13 dB) and 17% (7.7 dB).

The urban scenario (Figs. 177 and 179) resulted in slightly (looking to the cumulative distributions of the aggregation) worse cases; therefore we would make final considerations only on this one based on interference values not exceeded at 95% confidence.

For the P-P case, Figs. 177 and 179 give the cumulative distribution of the aggregate power density; at 95% the worst value of FS at 60 m height gives –103 dBm/MHz that would become –100 dBm/MHz if also outdoor handheld UWB devices are added.

Suburban scenario gives ~ 4 dB less aggregation levels.

We should also consider that these results are from a real example on a real city scenario; it also has demonstrated the high sensitivity of the results with the propagation assumptions and, in addition, no contribution from specific source of UWB interference (such as “hot-spot” corporate buildings in unfavourable conditions); therefore the 3 dB margin for “multiple scenario aggregation” should be maintained.

For the FWA CS case, provided that the overall aggregation gives ~ 10 dB more interference, the contribution of hand held devices and multiple scenario aggregation, will count less and here assumed 1 dB each.

Adding the further reduction above, considering the FS protection objective of –127 dBm/MHz, we obtain for various assumptions for average activity factor reported in Table 97.

TABLE 97

Evaluation of e.i.r.p. density for protection with 95% confidence level for various activity factors

P-P case[(1)]			
Activity factor	1%	5%	17%
Activity factor reduction (dB)	–20	–13	–7.7
Polarisation reduction (dB)	–3	–3	–3
Total aggregate power density (dBm/MHz) (with no outdoor UWB applications)	–126	–119	–113.3
Margin for multiple scenario aggregation	3	3	3
Missing to the objective –127 dBm/MHz (indoor UWB only)	**4**	**11**	**16.7**
Missing to the objective –127 dBm/MHz (with additional hand held outdoor UWB)	**7**	**14**	**19.7**

TABLE 97 (*end*)

FWA CS case[(1)]			
Activity factor	1%	5%	17%
Activity factor reduction (dB)	–20	–13	–7.7
Polarisation reduction (dB)	–3	–3	–3
Total aggregate power density (dBm/MHz) (with no outdoor UWB applications)	–116	–109	–103.3
Margin for multiple scenario aggregation	1	1	1
Missing to the objective –127 dBm/MHz (indoor UWB only)	**12**	**19**	**24.7**
Missing to the objective –127 dBm/MHz (with additional hand held outdoor UWB)	**13**	**20**	**25.7**

(1) For FWA CS case, it should furthermore be taken into account that the compatibility of single UWB entry on a FS FWA terminal indoor still requires UWB emission lower than –76.5 dBm/MHz unless suitable mitigation techniques are forced by regulation.

For this reason, the needed implementation of specific mitigation techniques such as DAA would actively reduce the interference also to the FWA CS, operating at the same frequency; therefore, the impact on FWA CS, even if formally slightly worse, will not considered in the final conclusions that will be based on the P-P example only.

In any case, even if this Case 2 evaluation is far more favourable than the simplified conservative approach used for "generic" UWB Case1, the degree of risk of interference in permitting UWB emissions at –41.3 dBm/MHz is considered quite high, unless:

– the activity factor could be somehow regulated for being in average quite less than 0.1%;

– all outdoor fixed UWB application would be forbidden;

– handheld UWB devices either forbidden or regulated for an activity factor less than ~ 0.1% (for not impacting the overall aggregation given by indoor UWB devices).

1.3.4 "Hot-spot" UWB emission r.m.s. aggregate interference (scenario 3a)

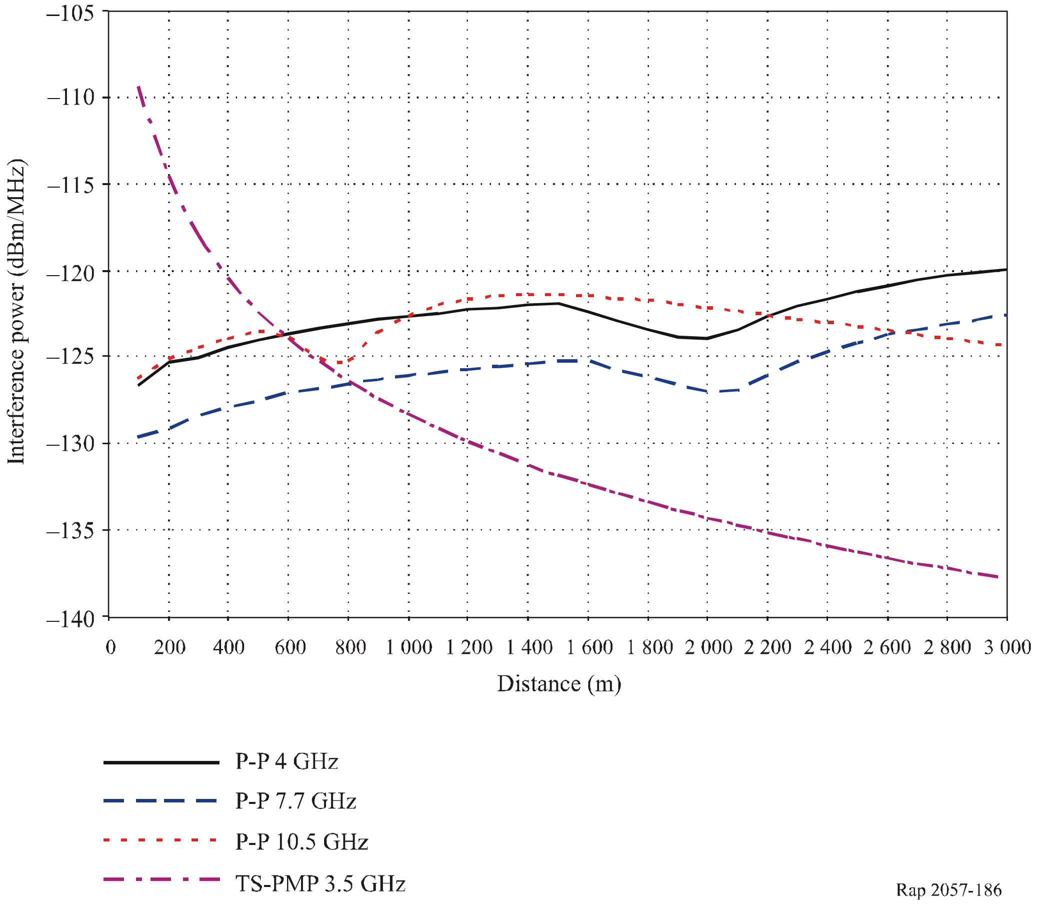
1.3.4.1 Case 1 – Generic UWB applications – Numerical evaluations

In the scenario described in the examples in § 1.2.2, the results in Figs. 186, 187 and 188 are obtained.

Figure 186 shows the worst "single" UWB device interference in the building as function of its distance from the FS receiver. The interference levels that do not take into consideration indoor to outdoor attenuation, are slightly lower than those presented for single outdoor entry in § 1.3.2; however, even if still above the aggregation objectives, the additional indoor and building attenuation would certainly make it less important than that of outdoor UWB evaluated in § 1.3.2.

FIGURE 186

Single UWB device interference (worst device in the building) vs. FS receiver distance (without indoor and indoor/outdoor attenuation)



Figures 187 and 188 provide the aggregate interference level, as function of the FS receiver distance *D* from the UWB hot-spot defined in Figs. 153, 154 and 155.

The data are presented, as in previous section for the uniform UWB, without considering the indoor/outdoor attenuation that will be evaluated separately; in this case the aggregate interference is exceeding the objectives by more than 30 dB, and then mitigation factors would play a fundamental role.

FIGURE 187

Upper bound of aggregate UWB interference density versus FS receiver distance (without indoor and building attenuation, 100% activity)

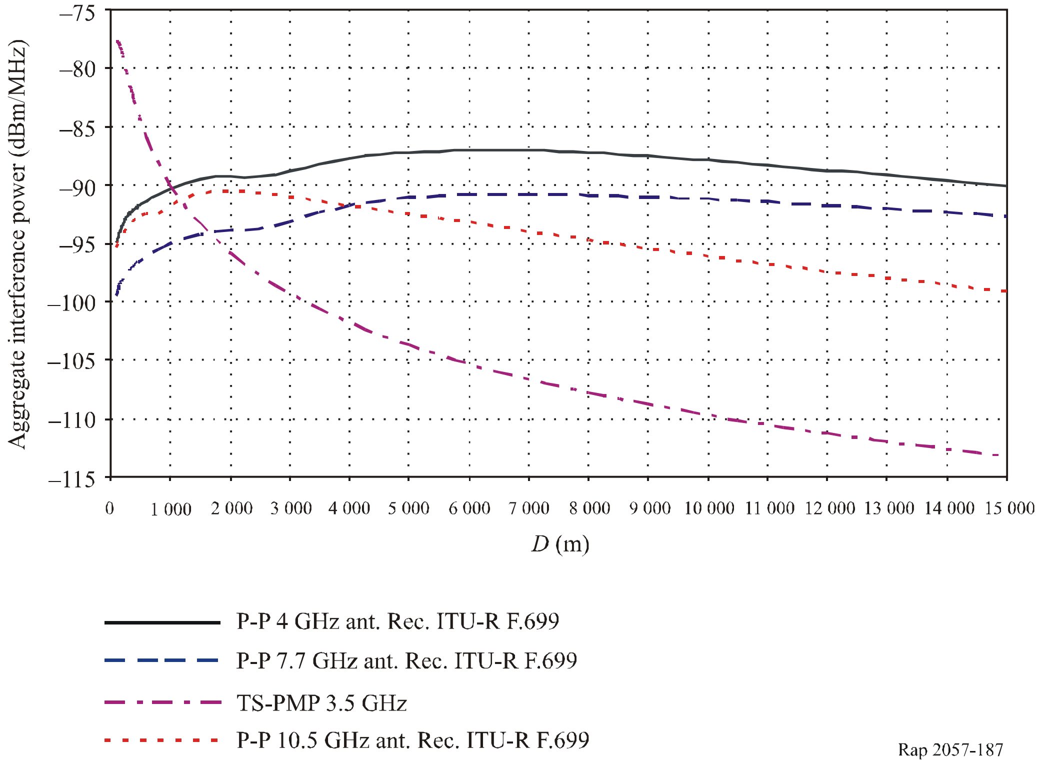
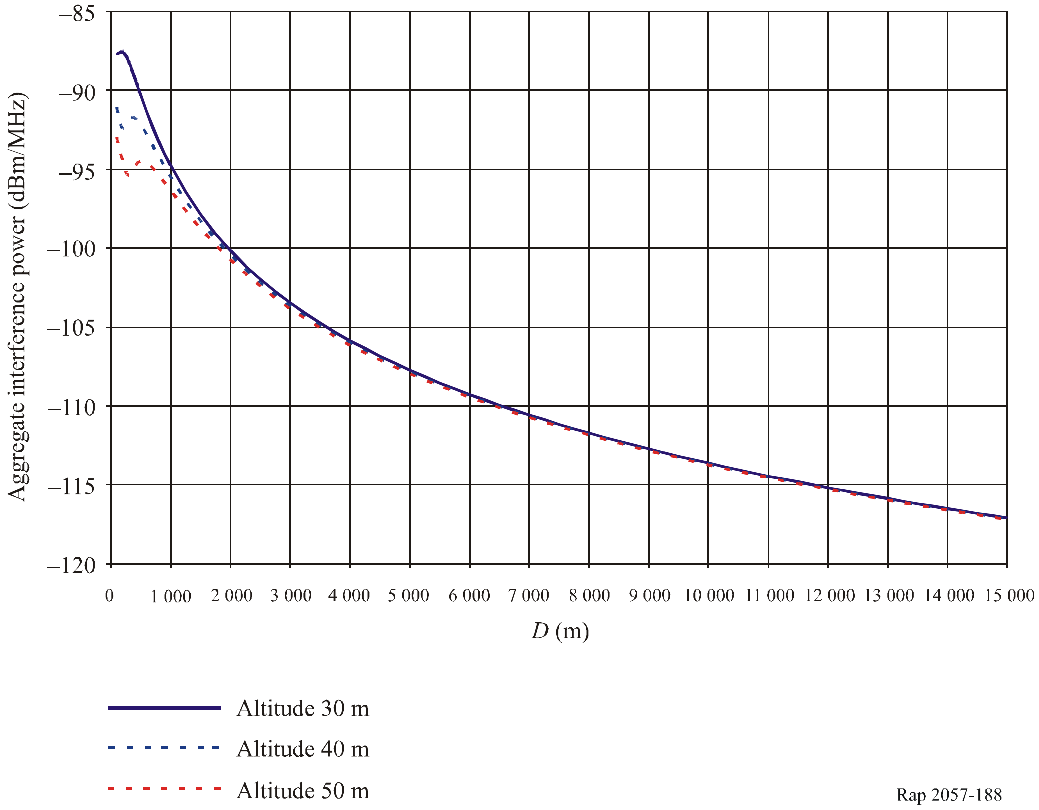


FIGURE 188

Upper bound of aggregate UWB interference density into FWA CS with sectorial antenna versus receiver distance (without indoor and building attenuation, 100% activity)



1.3.4.1.1 Case 1 – Parametric relationship with UWB e.i.r.p. density

From Figs. 187 and 188 we can elaborate different considerations on the impact to FS receivers, according the propagation behaviour and the typical deployment of FS systems.

1.3.4.1.1.1 FWA-TS case

The interference is strongly dependent on the distance from the "hot-spot" location. However, in this case, the objectives are also different according the TS distance from the CS (see Tables 88 and 89).

For cell border TSs, minimum FWA cell size might differ in function of system modulation formats and transmit power. Typical applications for the 3.5 GHz have been taken as cells size up to ~ 9 km (in visibility situation) and fade margin (FM) down to ~12 dB. The absolute upper-bound (without any indoor/outdoor additional attenuation), for the r.m.s. interference level given in Fig. 187, is ~ −109 dBm/MHz.

The interference level, in function of the actual e.i.r.p. of the UWB devices, would hence be given by the following parametric formula for FWA-TS near to cell border:

$$\textit{Aggregate interf(r.m.s.)}(\text{dBm/MHz}) \approx -109 + \{\textit{e.i.r.p.}(\text{dBm/MHz}) + 41\} \quad (79)$$

For TSs near CS (e.g. at 100 m from CS), according the relevant discussion in the FS section of Recommendation ITU-R SM.1757 the upper-bound (without any indoor/outdoor additional attenuation), for the r.m.s. aggregate interference level given in Fig. 176, is ~ −77 dBm/MHz.

The interference level, in function of the actual e.i.r.p. of the UWB devices, would hence be given by the following parametric formula for the upper-bound interference on FWA-TS near to the central station:

$$\textit{Aggregate interf(r.m.s.)}(\text{dBm/MHz}) \approx -77 + \{\textit{e.i.r.p.}(\text{dBm/MHz}) + 41\} \quad (80)$$

In addition, assuming as peak e.i.r.p. density reference value the present regulation set by one administration that allows a 0 dBm/50 MHz (i.e. ~ 41 dB above the r.m.s./MHz) we can derive the following parametric formula the upper-bound interference on 50 MHz receivers:

$$\textit{Aggregate interf.(peak power)}(\text{dBm/50 MHz}) \approx -77 + 41 + \{\textit{e.i.r.p.}_{peak}(\text{dBm/50 MHz})\} \quad (81)$$

1.3.4.1.1.2 FWA-CS case

The aggregate interference in Fig. 183 shows that the maximum interference, obviously decreasing when the CS antenna height increases, is −87 dBm/MHz (assuming that the CS is unlikely closer than 100 m from the "UWB building" that otherwise would block the visibility). The average interference level in function of the actual e.i.r.p. of the UWB devices can hence be derived as:

$$\textit{Aggregate interf(r.m.s. power)}(\text{dBm/MHz}) \approx -87 + \{\textit{e.i.r.p.}(\text{dBm/MHz}) + 41\} \quad (82)$$

1.3.4.1.1.3 Point-to-point case

The aggregate interference in Fig. 187 shows an asymptotic absolute worst-case (without any indoor/outdoor additional attenuation) value of ~ –87 dBm/MHz for the 4 GHz frequency band and hence, the expected interference is expressed, in function of the actual e.i.r.p. of the UWB devices, as:

$$\textit{Aggregate interf(r.m.s. power)}(\text{dBm/MHz}) \approx -87 + \{\textit{e.i.r.p.}(\text{dBm/MHz}) + 41\} \quad (83)$$

1.3.4.2 Case 2 – WPAN UWB applications – Numerical evaluations

In the hot-spot scenario, communication UWB devices are operating in the same area and may interfere with each other. Since communication UWB devices are intended to provide WPAN functionality according typical characteristics foreseen for IEEE 802.15.3a forthcoming standard, several UWB devices are communicating inside a group (or "piconet") and correspond to peripheral devices of one user. A generic piconet structure of a UWB WPAN network is presented in Fig. 189. Operations of devices inside a piconet are scheduled to prevent simultaneous usage of the available time/frequency resources. Resource usage of two devices in neighbouring piconets is uncoordinated, which does result in devices interfering with each other. Thus, some shielding protection is required to ensure operability of neighbouring piconets.

FIGURE 189

Deployment of UWB devices: piconet structure

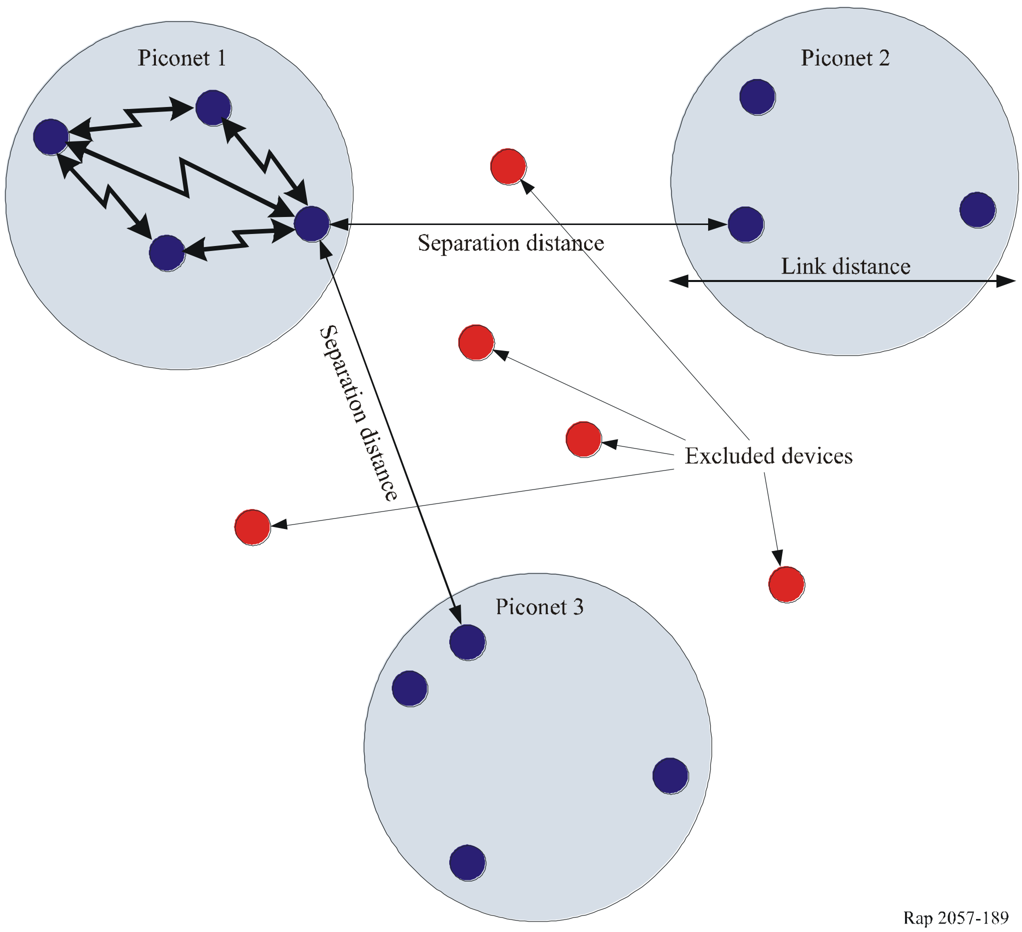


Figure 189 shows a revised hot-spot scenario ("hot-spot with resource-sharing"), in which devices in piconets (blue points) are protected from uncoordinated emission by removing potentially detrimental devices (red points).

Modelling of "hot spot with resource-sharing" is more complicated than the original hot-spot scenario. The model is determined by two parameters: link distance (maximum distance between devices in a piconet) and separation distance (minimum distance between devices from different piconets). Hot-spot with resource sharing is obtained from the original hot-spot scenario by collecting close devices in piconets in a random manner, satisfying conditions of link and separation distances, as shown in Fig. 189. Devises that cannot be connected to either of the available piconets with satisfaction of above-described conditions, are removed. Device removal leads to appearance of empty spaces that model walk passages or other separators of personal working areas.

Since all devices in the same piconet share time/frequency resources (usually TDMA is used), at the given point of time, only one device from a piconet occupies a given frequency sub-range (if FDMA is also used). This requirement should be satisfied when taking into account activity factors. The activity factor in this case is applied by random assignment of operating devices by the following rules:

– Probability that a piconet is active is equal to the activity factor times the number of devices in the piconet. Active piconets are determined by random choice with corresponding probabilities.

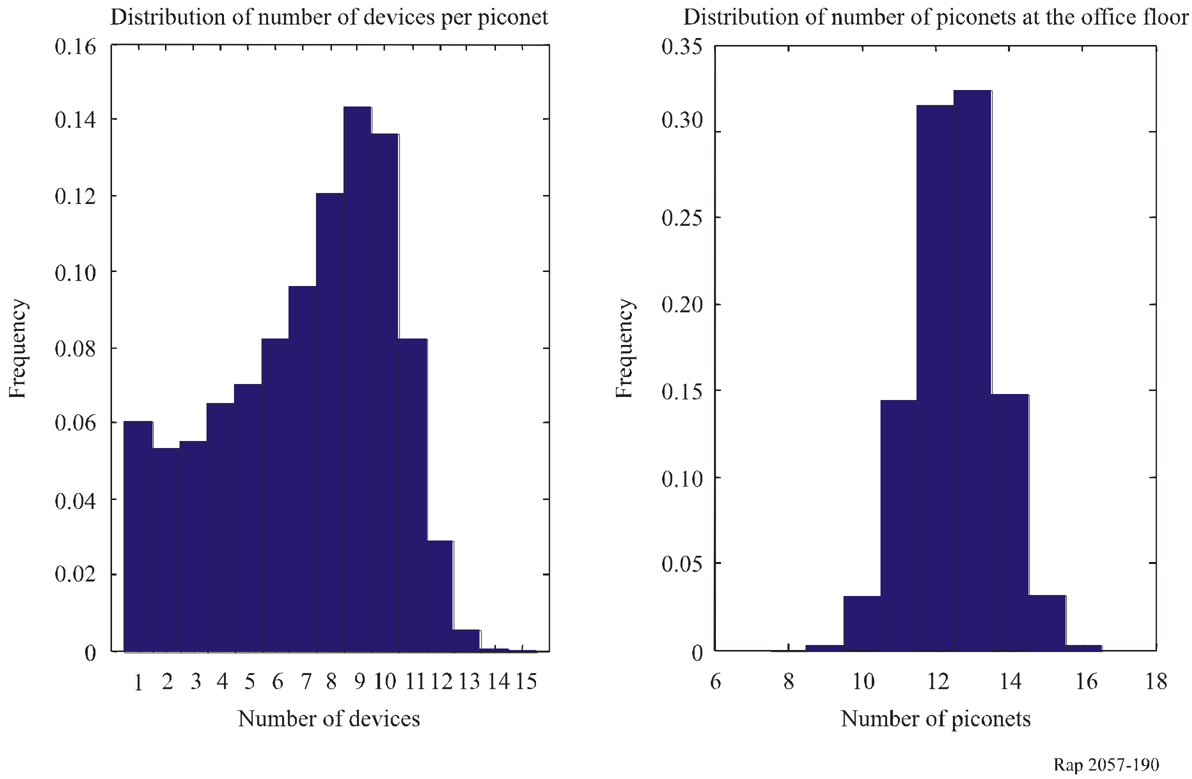
– Active device in the active piconet is determined by random choice (activity of all devices is equiprobable).

Interference power obtained using hot-spot with resource-sharing scenario is dependant on operation distance of devices (i.e. on the sort of devices), but it is possible to introduce a common rule that separation distance should be at least twice link distance.

Figures 190 and 191 show the statistical properties of hot-spot with resource-sharing for two examples. Example 1 is presented in Fig. 186 and corresponds to 10 m link distance and 20 m separation, as proposed by one manufacturer[46]. In this case, average number of independent piconets on the floor is 12.5 with 6.5 devices (in average) in each.

FIGURE 190

Piconet structure statistics in example 1 (proposal from one manufacturer): link distance 10 m and minimum separation 20 m

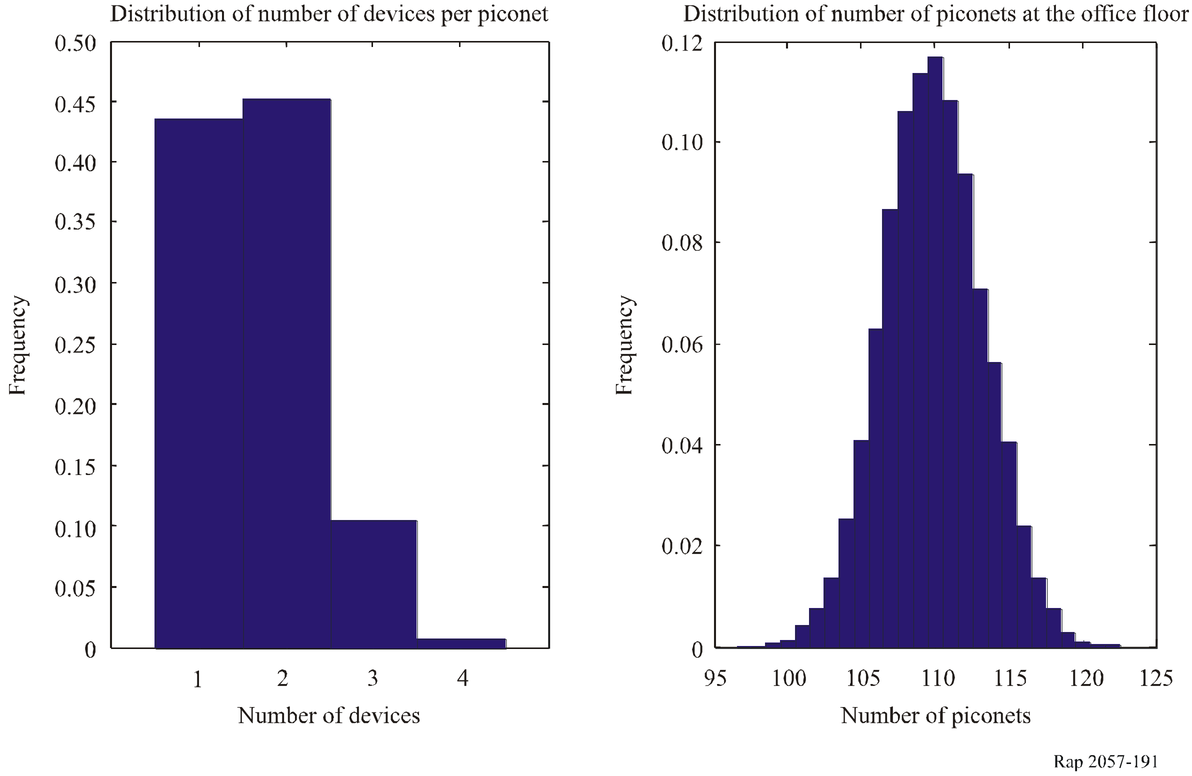


[46] Technical Response by one manufacturer to the Alion Study in Document 1-8/109.

Example 2 corresponds to 3 m link distance and 6 m separation. Its statistical properties are illustrated in Fig. 191. Average number of piconets per floor in this case is ~112, average number of devices in piconet is ~1.5. In the both examples, statistics are obtained for 5 000 random trials.

FIGURE 191

Piconet structure statistics in example 2 (alternative proposal): link distance 3 m and minimum separation 6 m



Results of interference evaluation are presented in Figs. 192 and 193 for examples 1 and 2 described previously. Plotted is root-mean-square interference power, obtained from 5 000 random trials. Figure 194 compares the results for different activity factors with and without using a generic resource sharing model.

Free-space propagation is assumed for all devices, and all devices are assumed to transmit at the current United States FCC limits of –41 dBm/MHz power spectral density. The following additional mitigation factors are also taken into account:

– K_B = 10 dB – propagation through building walls.

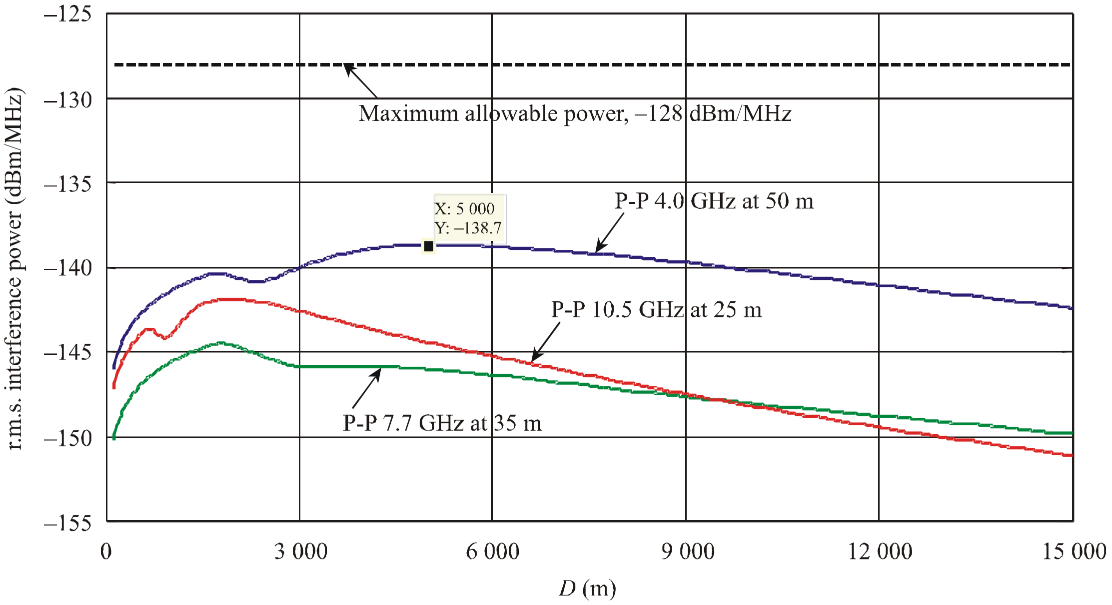
– K_{LOS} = 5 dB – under assumption that only 1/3 of all devices is LoS with the exiting wall. NLoS devices give negligibly small contribution.

– K_{pol} = 3 dB – effective influence of random polarization of UWB emission.

– $K_{\%}$ factor – activity factor was determined through thorough analysis of WPAN activity and is assumed to be 0.3%. Results are also shown for a much more conservative activity factor of 1% as an additional comparison point.

FIGURE 192

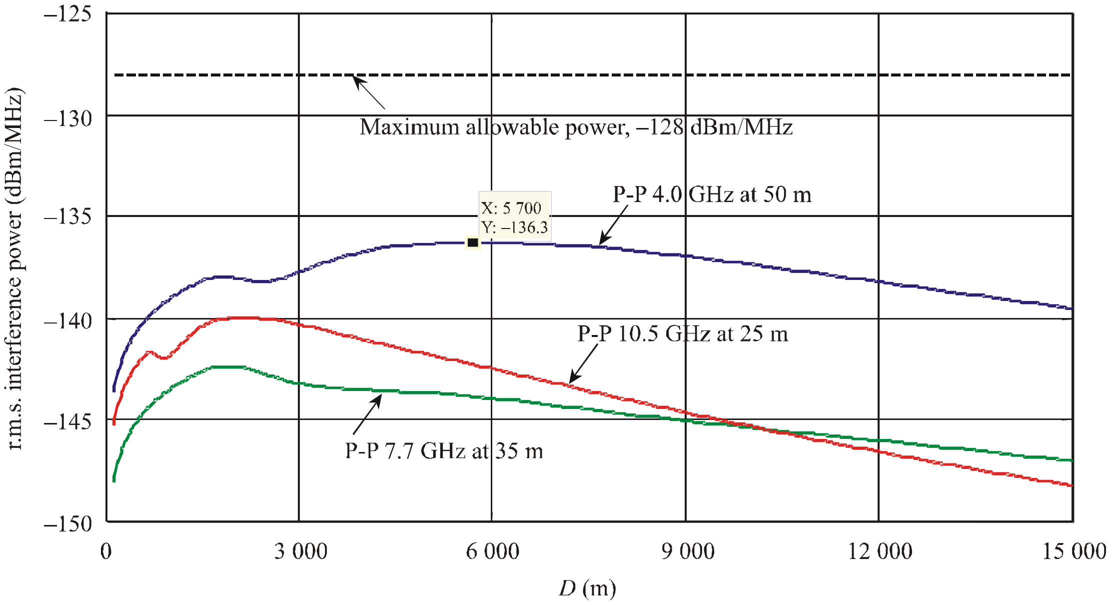
Interference to PP antennas in example 1



Rap 2057-192

FIGURE 193

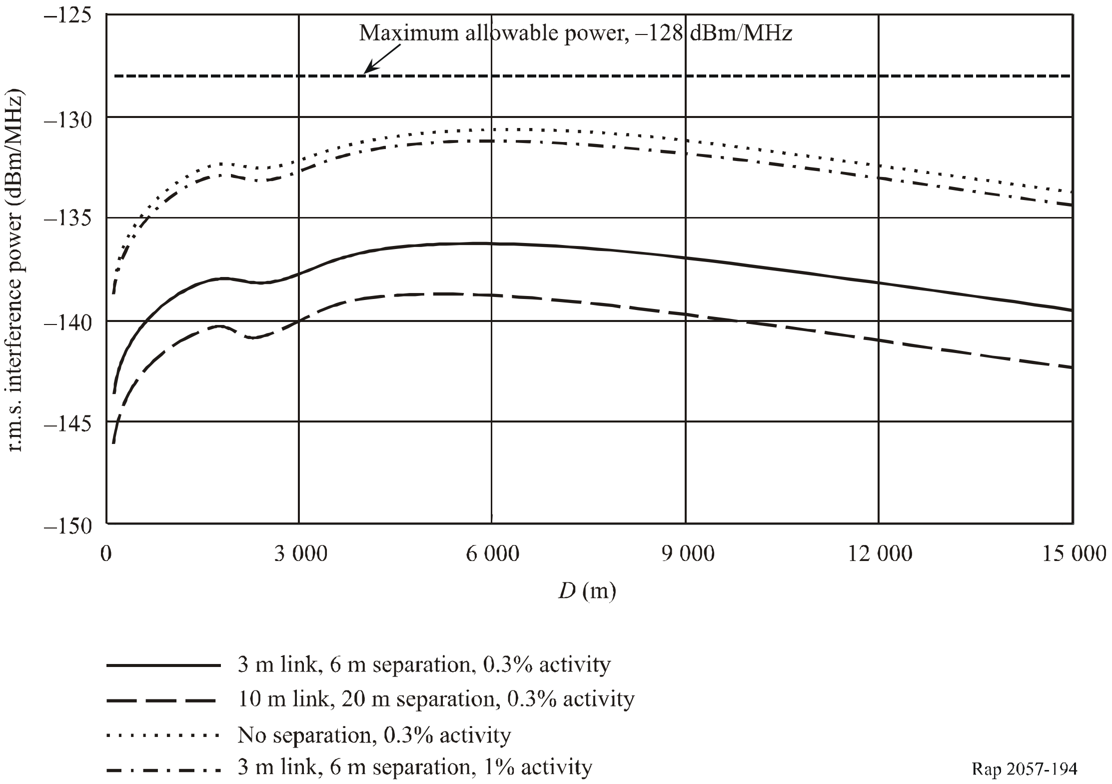
Interference to PP antennas in example 2



Rap 2057-193

FIGURE 194

Comparison of interference power to 4 GHz P-P in various approaches



Note that the difference between a 1% activity factor and a 0.3% activity factor is about 5 dB, as would be expected by using the equation 10 $\log_{10}(1/0.3)$ to estimate the difference. As a result, the e.i.r.p. limit can then be derived from the above results as follows, based upon an interference criterion of –129 dBm/MHz[47]:

$$e.i.r.p._A(\text{dBm/MHz}) \approx -129 - (\text{Maximum interference power in dBm/MHz}) - 41$$

Anyhow from Fig. 194 it might be seen that, also taking into account the additional worst-case allowance (3 dB) for “multiple scenario aggregation and propagation variance”, the evaluated interference is meeting (or is very close to) the objectives in all analysed conditions. Therefore it might be concluded that the WPAN applications characteristics could coexist with FS for what the “hot-spot” scenario is concerned.

Note that these results still assume free-space propagation based upon the shortest geometric distance between the indoor UWB device and the outdoor FS antenna. Although a building attenuation factor and an NLoS factor is included in the analysis, there are still a number of factors which effect propagation and are not accounted for here. For example, the following effects are only budgetary taken into account in K_{LoS} for in this analysis: propagation through office partition modules inside the building; propagation through walls surrounding elevators, restrooms, and conference rooms; propagation through people inside the building; and diffraction effects due to propagation around corners when the UWB device is not in direct LoS to the FS antenna. Including these effects in typical WPAN environments might also significantly reduce the potential for interference.

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47 Note that Fig. 194 show a maximum allowed interference power of –128 dBm/MHz, which is the lowest criterion for 4, 7, and 10 GHz P-P systems described in Table 92. However, in order to generalize an e.i.r.p. limit for the most sensitive system, a criterion of –129 dBm/MHz can be adopted.

1.3.5 Minimum UWB distance from indoor TS applications

1.3.5.1 Numerical evaluation

With the characteristics, protection criteria and scenario assumed in § 1.2.4 the graphs of Figs. 195 and 196 are obtained.

NOTE 1 – No other mitigation factor (e.g. activity factor are taken into account in these figures). They will be dealt with, as appropriate in the specific section for mitigation factors.

FIGURE 195

Minimum distance UWB → FWA indoor terminal versus UWB e.i.r.p.

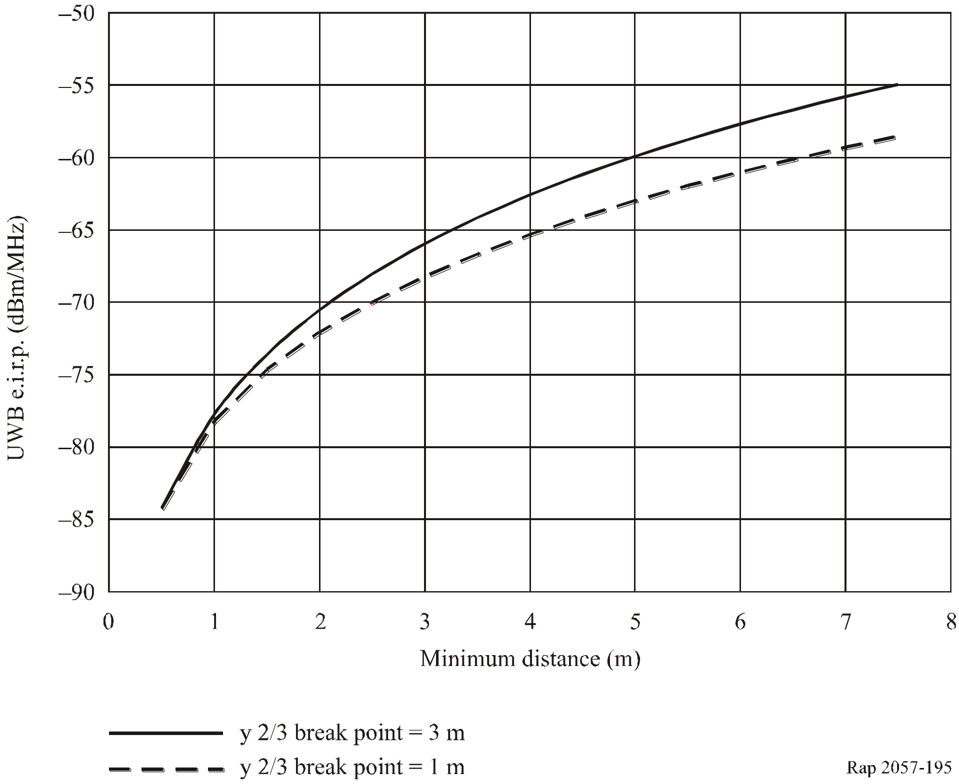
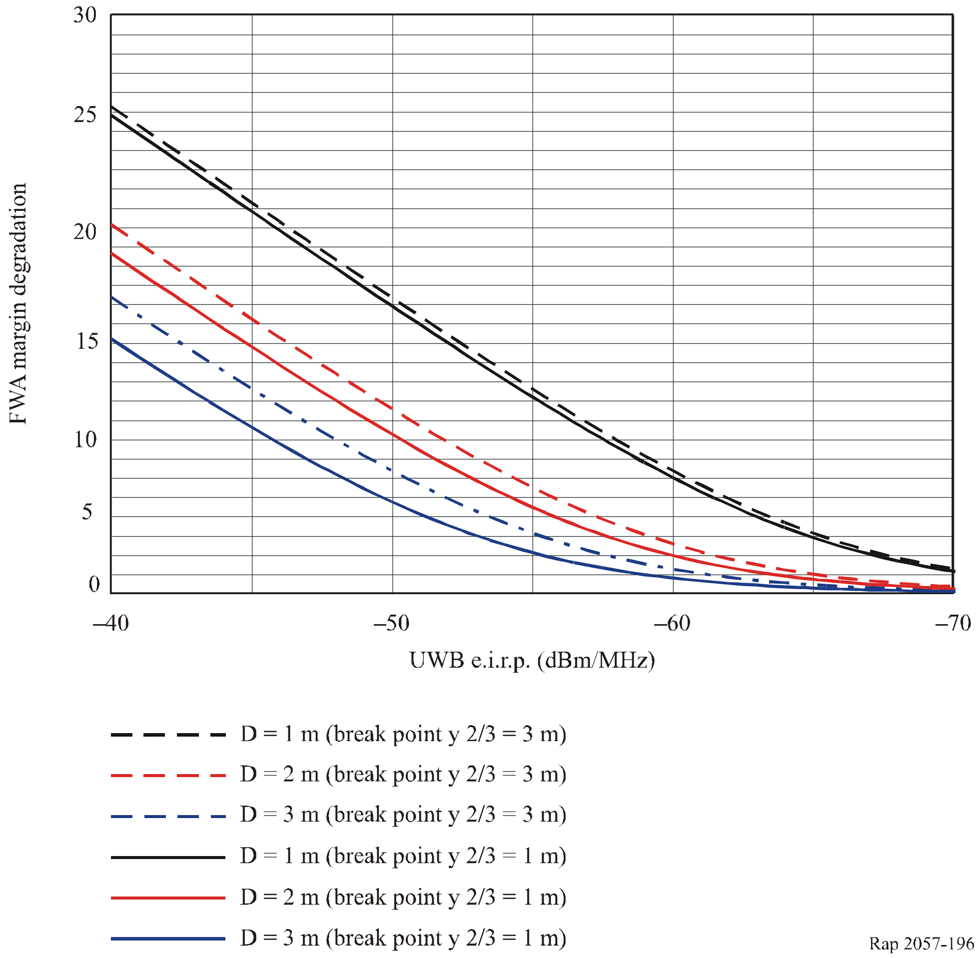


FIGURE 196

FWA indoor terminal link budget degradation versus UWB e.i.r.p.



1.3.5.2 General comments to the results

Based on the preliminary assumptions in § 1.1.1.3 and Table 94 the worst-case data presented in Fig. 195, it can be derived that the –41.3 dBm/MHz e.i.r.p. density, currently proposed for UWB communication devices, results in interference objectives being exceeded when UWB and FWA TS indoor terminals are in the same room. The minimum distance exceeds a normal room size. In addition, Fig. 196 shows that even at larger distance (e.g. 3 m), the expected margin degradation of more than 10 dB would cause blocking in the FWA connection any time the UWB device is activated (a typical FWA margin could be also in the order of 10 dB or even less).

An UWB functionality of detecting narrow-band interference and consequent channel reselection (as often presented as a possibility by UWB proponents) seems highly attractive as interference protection of these FWA applications from UWB.

1.3.6 Peak power limits requirement

Following the technical discussions for:

– peak impact on the ITU-R objectives (relevant FS section of Recommendation ITU-R SM.1757) that led to the objectives in Tables 88 and 89;

– practical relationship between PRF and peak value within 50 MHz victim receiver bandwidth for dithered and non dithered pulsed UWB applications.

The 50 MHz peak objectives should be derived from the r.m.s. e.i.r.p. density objective as:

$$50\ \text{MHz}\ \textit{peak e.i.r.p. limit}\ (\text{dBm/50 MHz}) = \textit{r.m.s. e.i.r.p. limit}\ (\text{dBm/MHz}) + 42 \tag{84}$$

1.3.7 Summary of parametric formulas from aggregate interference study in bands from 3 to 11 GHz

Based on the worst cases of the above § 1.3.4 and 1.3.5, the following equations will be used to determine, after applying the suitable mitigation factors, the adequate limits for FS protection to be applied to UWB devices:

– for the "uniform deployment" scenario 1, P-P 4 GHz worst case:

$$\textit{Aggregate interf.}(\textit{r.m.s.power})(\text{dBm/MHz}) \approx -85 + 10\log\frac{UWB/km^2}{1\,000} + \{\textit{e.i.r.p.}(\text{dBm/MHz}) + 41\} \tag{85}$$

for "hot-spot" scenario 3a, P-P 4 GHz worst case:

$$\textit{Aggregate interf.}(\textit{r.m.s.power})(\text{dBm/MHz}) \approx -87 + \{\textit{e.i.r.p.}(\text{dBm/MHz}) + 41\} \tag{86}$$

– for wide-band peak PSD relative to r.m.s. (see § 1.1.1.5):

$$50\ \text{MHz}\ \textit{peak e.i.r.p. limit}\ (\text{dBm/50 MHz}) = \textit{r.m.s. e.i.r.p. limit}\ (\text{dBm/MHz}) + 42 \tag{87}$$

1.4 Determination of UWB e.i.r.p. levels for FS protection considering mitigation parameters and multiple scenarios aggregation in bands below 10.6 GHz

1.4.1 Bands from ~ 3 GHz to 10. 6 GHz

In the relevant FS section of Recommendation ITU-R SM.1757 the ITU-R objectives for interference from the aggregation of UWB devices have been discussed. Comparing those values with the single entries and parametric equations given in § 1.3.7, we can derive UWB e.i.r.p. density limit for FS protection by parametric relationships.

In this section we will derive the maximum acceptable e.i.r.p. density (both r.m.s. and 50 MHz peak) of pulsed UWB emissions for the protection of FS systems in bands from 3 to 10.6 GHz taking into the parametric formulas in § 1.3.7 associated with expected UWB deployment density and indoor/outdoor mix defined for the reference scenarios, mitigation factors for environment and emission characteristics, which depends on propagation characteristics and UWB implementation-specific characteristics. The mitigation for activity factor is also defined within the reference scenarios.

However, it should also be considered that some of the mitigation factors introduced below, might be applied as far as the aggregate interference would not drop below the "single entry" interference that, in most cases, might represent the upper bound of acceptable interference.

1.4.1.1 Mitigation factors for the aggregate interference evaluation

For the aggregation evaluation, the following mitigation factors have been provisionally considered:

Propagation related factors

– $\boldsymbol{K_B}$ factor: possible building attenuation experienced by any indoor UWB application. For the purpose of comparing various indoor and through windows propagation models, this factor could be functionally subdivided into two contributions:
  – $\boldsymbol{K_{Bindoor}}$ as the pure indoor-indoor path attenuation additional to the free-space;
  – $\boldsymbol{K_{Bwindow}}$ as the attenuation given in the passage from indoor to the outdoor path.

– $\boldsymbol{K_{LoS}}$ factor: due to the percentage (K_{LoS} = 10 log(P_{LoS}%/100)) of UWB “non LoS” with regard to the FS receiver. For the purpose of comparing various indoor and through windows propagation models, this factor could be functionally subdivided into two contributions:
  – $\boldsymbol{K_{LoSh}}$ as “horizontal” contribution of floor services (e.g. elevators, meeting rooms...) in indoor propagation;
  – $\boldsymbol{K_{LoSv}}$ as “vertical” contribution due to path trespassing of a floor or a roof for indoor propagation attenuation.

  NOTE 1 – K_{LoS} factor only account for the ratio of UWB devices that are non-LoS with regard to the FS receiver. It does not take into account any attenuation due to building infrastructure that are taken into account in K_B factor.

– $\boldsymbol{K_{outdoor}}$ factor, which may be considered for non LoS UWB devices (e.g. scattering,...) in the outdoor portion of the interfering path. For the present study, that only account for LoS devices, this factor is not considered relevant.

– $\boldsymbol{K_{pol}}$ factor, in aggregation of large number of UWB device, employing very simple antenna (nearly omnidirectional), the mixture of starting polarization direction plus the different paths including, for indoor applications, at least one wall trespassing will likely generate random arrival polarisation on the FS antenna. Using FS mostly either vertical or horizontal polarisation, this will result in a 3 dB mitigation.

UWB implementation related factors

– $\boldsymbol{K_{\%}}$ factor: depends on the actual utilization rate over a fixed period of time ($K_{\%}$ = 10 log(P_U%/100) of the devices (idle gating periods); this factor might range from 100% (industrial applications) to few % for some communication devices.
– $\boldsymbol{K_{power}}$ factor: depending on any automatic power reduction control implemented by UWB devices for keeping minimal emission when full-power is not required.

1.4.1.2 Evaluation of the e.i.r.p. density limits for bands between 3 and 11 GHz

1.4.1.2.1 Case 1 – Numerical values of mitigation factors

The definition of UWB e.i.r.p. density limits for protection of the considered FS applications have been made considering the following numerical values for the mitigation factors:

– $\boldsymbol{K_B = K_{Bindoor} + K_{Bwindows}}$**: = 10 dB** (for single entry and “hot-spot” situation);

– $\boldsymbol{K_B = K_{Bindoor} + K_{Bwindows}}$**: = 13 dB** (for aggregation over aggregation of large number of buildings of different nature).

The 10 dB value (i.e. difference between indoor and outdoor limits for GPS and other sensitive Services protection) has been taken from the regulation of one administration as well as from SEAMCAT handbook that also suggest the same 10 dB default value for indoor/outdoor attenuation. The slightly higher value for wide areas aggregation is justified by the evaluations made in Appendix 1 to this Annex.

$\boldsymbol{K_{LoS}}$

From the probabilistic considerations reported in Appendix 1 to this Annex it is conservatively assumed that:

– $\boldsymbol{K_{LoS}}$ = K_{LoSh} + K_{LoSv} = 14 dB for “uniform deployement” urban and suburban scenarios.

– $\boldsymbol{K_{LoS}}$ = K_{LoSh} + K_{LoSv} = 5 dB for “hot-spots” scenarios, assuming conservatively that 2/3 of the devices are in NLoS conditions to the external wall.

For the latter, it should be noted that relatively smaller NLoS condition is related only to internal building services and furniture (relatively smaller in “open-space” corporate buildings); it can be also noted that, in this case, similar figures for $\boldsymbol{K_B}$ and $\boldsymbol{K_{LoS}}$ for indoor applications have also been derived using empirical indoor propagation model Recommendation ITU-R P.1238 for the indoor to outdoor portion of the interference.

$\boldsymbol{K_{\%}}$

$K_{\%}$ = 0 dB (100% utilization) will be used for single-entry UWB interference evaluation.

$K_{\%}$ = 10 log (100/activity %) dB; the activity factor has been defined for the reference aggregation scenarios presented in the main body of this ECC Report as:

- 5% (13 dB) average in peak utilization hours for scenarios 1 (generic distribution of UWB on the territory with mixture of industrial, business and home applications);
- 20% (7 dB) average in peak utilization hours for scenario 3a (corporate building with UWB high-speed communication systems).

$\boldsymbol{K_{pol}}$

K_{pol} = 3 dB for all aggregated interference evaluation.

K_{pol} = 0 dB for single entry interference.

For the evaluation of UWB level for 1 m minimum distance from an indoor FWA TS the above mitigations are not applicable in general but defined on a case by case, based on actual UWB characteristics (particularly the activity factor and its distribution over the time, power control ....) of the UWB device .

1.4.1.2.2 Definition of UWB e.i.r.p. density in the reference scenarios

The e.i.r.p. density limits for protection of FS will be separately defined for the different reference scenarios relevant to FS applications:

– Single entry outdoor UWB to an outdoor FS station.
– Aggregate scenario 1c (generic UWB distribution).
– Aggregate scenario 3a (hot-spot from a large business building).
– Single UWB minimum distance from an indoor FWA TS.

Each one will have its own set of applicable mitigation factors.

In the following sections the expected interference levels, with UWB reference e.i.r.p. density of –41 dBm/MHz, are used as reference.

1.4.1.2.2.1 Single entry outdoor UWB

For this single entry scenario no mitigation factor is applicable.

Comparing the expected worst interference from the graphs in Figs. 160 and 161 (evaluated with UWB e.i.r.p. density reference value of –41 dBm/MHz) with the interfering objectives in, 16 dB are missing (i.e. –111 + 127 = 16).

Therefore the e.i.r.p. density limit for protection of FS in this case would be:

UWB e.i.r.p. density limit (*r.m.s.*) = –41 – 16 = –57 dBm/MHz

1.4.1.2.2.2 Aggregate scenario 1c (modified as required)

1.4.1.2.2.2.1 Case 1 – Generic UWB applications

The UWB distribution on the territory is 10 000 UWB/km^2 compose by 2 000 UWB/km^2 deployed outdoor and 8 000 UWB/km^2 deployed indoor; average activity factor 5%.

For deriving the expected aggregate interference, we should add in power the separate contributions of indoor and outdoor UWB density, each with its own mitigation factor.

Using the parametric equation (85) and the mitigation factors we obtain for the worst 4 GHz band:

indoor UWB portion aggregate interference (dBm/MHz) =

$= -85 - K_B + 10 \log (8\,000/1\,000) - K_{LoS} - K_{pol} - K_{\%}$

$= -85 - 13 + 9 - 14 - 3 - 13 = -119$ dBm/MHz

outdoor UWB portion aggregate interference (dBm/MHz) =

$= -85 + 10 \log (2\,000/1\,000) - K_{LoS} - K_{pol} - \mathrm{K}_{\%}$

$= -85 + 3 - 14 - 3 - 13 = -112$ dBm/MHz

The total power aggregation, with UWB e.i.r.p. density reference value of –41 dBm/MHz, is then:

$$\text{Total power aggregation} = 10 \log (10^{-11.9} + 10^{-11.2}) = 111.3 \text{ dBm/MHz}$$

Comparing this expected interference with the interfering objectives in, 15.8 dB are missing (i.e. –111.3 + 127 = 15.7).

Therefore the e.i.r.p. density limit for protection of FS in this case would be:

$$\textit{UWB e.i.r.p. density limit (r.m.s.)} = -41 - 15.7 = -56.7 \text{ dBm/MHz}$$

This value is assumed to be valid up to ~ 7.125 GHz where all FS bands are used for very high capacity trunk applications with large antennas.

In higher bands, as shown in Fig. 163, there might be a relaxation of 2.5 dB up to 8.5 GHz and of further 2.5 dB for the 10.5 GHz Band.

1.4.1.2.2.2.2 Case 2 – WPAN UWB applications-based

Provided that Case 2 considers 100% of indoor devices, the results given in § 1.3.3.3.3 do not need further elaboration.

1.4.1.2.2.3 Aggregate scenario 3a (modified as required)

1.4.1.2.2.3.1 Case 1 – Generic UWB applications

The UWB distribution in the building is 1 UWB/10 m^2; average activity factor 5%.

For deriving the expected aggregate interference, we will use the parametric equation (86) and adding the mitigation factors we obtain:

aggregate interference (dBm/MHz) =

$= -87 - K_B - K_{LoS} - K_{pol} - K_{\%}$

$= -87 - 10 - 5 - 3 - 7 = -112$ dBm/MHz

For comparing this expected interference with the interfering objectives in, we remind that both FWA-CS and 4 GHz P-P lead to the same aggregate interference; however, having 2 dB different objectives, we will use the mean value of –128 dBm/MHz.

16 dB are missing (i.e. –112 + 128 = 16).

Therefore the e.i.r.p. density limit for protection of FS in this case would be:

UWB e.i.r.p. density limit (*r.m.s.*) = –41 – 16 = – 57 dBm/MHz[48]

Also in this case, according the result in Fig. 187, there might be a relaxation of ~ 4 dB for bands above 7.125 GHz.

1.4.1.2.2.3.2 Case 2 – WPAN UWB applications-based

Provided that in Case 2 all mitigations are included in the single-shot results in § 1.3.4.2, those results do not need further elaboration.

1.4.1.2.2.4 Minimum distance from FWA TS

For this single entry scenario no mitigation factor is applicable.

Comparing the expected worst interference, from the graphs in Fig. 195, the e.i.r.p. density limit for protection of an indoor FWA TS at 1 m distance would be:

UWB e.i.r.p. density limit (*r.m.s.*) = –76.5 dBm/MHz

1.4.1.3 UWB e.i.r.p. requirements for bands between 3 and 11 GHz

1.4.1.3.1 Correction for multiple scenario aggregation and propagation variables

1.4.1.3.1.1 Case 1 – Generic UWB applications

As all engineering problems, the UWB e.i.r.p. levels summarized in the previous section need validation that cannot be made in practice. A number of assumptions are just guessing of future deployment and scenarios that, in practice might be far different when UWB technology will become popular on the market.

In this study so far each UWB deployment scenario (uniform deployment (1c) and hot spot (3a)) has been considered on an individual basis with respect to its potential interference to a FS station. In the actual deployment of UWB "hot-spot" (scenario 3a) interference would be "additive" and not "alternative" to the uniform UWB distribution of scenario 1c. It should also be considered that more than one hot-spot source might interfere with the same FS station.

In addition, being the UWB deployment assumed on a "no interference" bases, the degree of risk that, once deployed in full, interference will happen and at that stage, in practice, it might not be possible to stop the market of consumer devices, the interfered bands would be jeopardized from the primary allocated service.

On the other hand, the peculiar interfering scenarios between UWB applications, likely used at height levels lower that potential FS victim receivers, which on the contrary are generally quite higher than the average height of surrounding buildings and other natural obstacles, present a challenging situations from the point of view of the propagation assumption for the interfering sources aggregation that are in a mixed LoS and NLoS situation; the percentage split between LoS and NLoS has been insofar conservatively taken into account as 66% of NLoS for single building "hot-spot" and as conservative statistical average value over a significant example of western Europe big city,

48 A similar scenario has also been evaluated using different density parameters resulting from application of UWB devices of a unique typology, derived from standardisation on going in IEEE 802.15.3a. The results are more favourable; however, they are not here considered because not representative of more impacting potential UWB applications that have been considered for defining the reference scenario 3a; in addition, scenario 1c would in any case remain worse.

corresponding to a mitigation factor K_{LoS} = 5 dB and K_{LoS} = 14 dB, respectively; however, real data on this factor are also depending on future unpredictable deployment situation of UWB devices.

With the above consideration, an additional reduction factor of the e.i.r.p. density of 3 dB is considered appropriate.

1.4.1.3.2 Case 2 – WPAN based UWB applications

Method A

Since several levels of conservatism are already built into the assumptions used in the analysis, this factor is not included in this Case 2 analysis.

Method B

We should also consider that these results are from a real example on a real city scenario; it also has demonstrated the high sensitivity of the results with the propagation assumptions and, in addition, no contribution from specific source of UWB interference (such as "hot-spot" corporate buildings in unfavourable conditions); therefore the 3 dB margin for "multiple scenario aggregation" should be maintained.

1.4.1.3.2.1 Summary of estimated e.i.r.p. density requirements

1.4.1.3.2.2 Case 1 – Generic UWB applications

The studies and considerations above lead to proposed UWB e.i.r.p. limits reported in Table 98.

TABLE 98

e.i.r.p. density limits for protection of FS from UWB applications

Scenario	**r.m.s. interference (with UWB e.i.r.p. density = –41 dBm/MHz) (dBm/MHz)**	**Additional correction for multiple aggregation and propagation variance (dB)**	**Interference objective (dBm/MHz)**	**UWB e.i.r.p. density (r.m.s.) for FS protection (dBm/MHz)**	**UWB e.i.r.p. density (peak) for FS protection (dBm/50 MHz)**
Single entry outdoor	–111	–	–127	–57	–15
1a (rural distribution)	–131.3	3	–127	–57 (or – 39.7)(1)	–15 (or +2.3) (1)
1b (suburban distribution)	–121.3	3	–127	–57 (or – 49.7)(1)	–15 (or –7.7)(1)
1c (urban distribution)	–111.3	3	–127	–59.7	–17.7

TABLE 98 (*end*)

Scenario	r.m.s. interference (with UWB e.i.r.p. density = –41 dBm/MHz) (dBm/MHz)	Additional correction for multiple aggregation and propagation variance (dB)	Interference objective (dBm/MHz)	UWB e.i.r.p. density (r.m.s.) for FS protection (dBm/MHz)	UWB e.i.r.p. density (peak) for FS protection (dBm/50 MHz)
3a (hot spot)	–112	3	–128	–60	–18
Minimum distance (1 m) from indoor FWA TS	–86	–	–121.5	–76.5	–34.5
Final UWB e.i.r.p. density limit (worst case of the above)				**–76.5 (or –60)**(2)	**–34.5 (or –18)**(2)

(1) The limits for outdoor FS protection have upper-bounds derived from the "single entry" interference, unless regulatory provision for avoiding UWB applications at fixed outdoor locations.

(2) Unless specific mitigation techniques (e.g. DAA) are implemented as prerequisite for introducing UWB devices on the market, this value is driven by the single UWB entry for indoor FWA TS applications that would be likely limited to bands below 4.2 GHz. Then, above 4.2 GHz, the limit would be driven by the value for aggregate scenario (1c) to bands up to 7.125 GHz; according to the study, there might be a relaxation of 2.5 dB up to 8.5 GHz and of further 2.5 dB for the 10.5 GHz band.

1.4.1.3.2.1 Case 2 – WPAN based UWB applications

The studies and considerations above lead to proposed UWB e.i.r.p. limits reported in Table 99 and Table 100 for the two methodology A and B used for case 2 study.

TABLE 99

e.i.r.p. density limits for protection of FS from UWB applications (Method A)

Scenario	r.m.s. interference (with UWB e.i.r.p. density= –41 dBm/MHz) (dBm/MHz)	Additional correction for multiple aggregation and propagation variance (dB)	Interference objective (dBm/MHz)	UWB e.i.r.p. density (r.m.s.) for FS protection (dBm/MHz)	UWB e.i.r.p. density (peak) for FS protection (dBm/50 MHz)
1b (suburban distribution)	–130	0	–127	≤ –38	≤ 4
1c (urban distribution)	–127	0	–127	≤ –40	≤ 2
3a (hot spot)	–131	0	–128	≤ –38	≤ 4
Final UWB e.i.r.p. density limit (worst case of the above)				**–40**	**2**

NOTE 1 – No contribution from additional population of hand-held outdoor UWB devices has been considered.

NOTE 2 – It should be reminded that case 2 studies consider that:

– No UWB devices in fixed outdoor location are present.

– Specific mitigation techniques are implemented on UWB devices for protection of indoor FWA TS.

TABLE 100

e.i.r.p. density limits for protection of FS from UWB applications (Method B)

Scenario	r.m.s. interference (with UWB e.i.r.p. density= –41 dBm/MHz) (dBm/MHz)	Additional correction for multiple aggregation and propagation variance (dB)	Interference objective (dBm/MHz)	UWB e.i.r.p. density (r.m.s.) for FS protection (dBm/MHz)	UWB e.i.r.p. density (peak) for FS protection (dBm/50 MHz)
1b (suburban distribution)	–127	3	–127	≤ –44	≤ –2
1c (urban distribution)	–123	3	–127	≤ –48	≤ –6
3a (hot spot)	–131	3	–128	≤ –41	≤ 1
Final UWB e.i.r.p. density limit (worst case of the above)				**–48**	**–6**

NOTE 1 – 3 dB contribution from additional population of hand-held outdoor UWB devices.

NOTE 2 – It should be reminded that case 2 studies consider that:

– No UWB devices in fixed outdoor location are present.

– Specific mitigation techniques are implemented on UWB devices for protection of indoor FWA TS.

1.4.2 Bands below 3 GHz – Qualitative considerations

Some bands below 3 GHz are allocated on primary bases to FS and are extensively used for particular applications in many countries.

Major applications are:

High capacity links for trunk networks: bands from 1.7 GHz to 2.3 GHz (now reduced in size for recent redistribution of band to IMT-2000), have been widely used in the past for this purpose. Legacy systems are then expected, as well as new systems, even if limited to the bands still available and in limited cases where no other bands (e.g. 4, 5 or 6 GHz) are practical.

P-P, low, medium capacity and P-MP systems for rural and remote areas: the same 2 GHz bands and other primary FS bands around 1.5 GHz and 2.6 GHz, as well as, on national basis, some bands even below 1 GHz offer suitable propagation characteristics for very long links and large cell coverage.

In addition, new applications are envisaged as follows:

Urban NLoS P-MP applications: similar systems are already on the market for “unlicensed” bands (e.g. in 2.4 GHz); recent standardization activities (ETSI BRAN and IEEE 802.16) are defining interoperable RF interfaces for this use. Licensed bands are not specifically defined in those standards because depending on their availability in various countries; however, any FS band suitable for such application (e.g. those below ~4.2 GHz) is potentially practical. Therefore, all the above mentioned might be candidate for it.

In term of system characteristics performance objectives and scenarios, that might be relevant to the protection of FS systems from UWB devices, there are no significant differences with the corresponding applications in 3.5 and 4 GHz; only antennas might have slight different characteristics, but the expected reduced directivity and gain would somehow compensate each other. Only the bandwidth used would be less due to the limited spectrum availability; then only the peak e.i.r.p. density might have some relaxed objective.

In conclusion, the r.m.s. e.i.r.p. density objectives for UWB should be considered very similar to those evaluated for the higher bands in § 1.4.1.3.2.1 (Table 98) or 1.4.1.3.2.2 (Tables 99 and 100); then they would be retained valid unless a more detailed study would be required.

1.5 Studies on impact of short range radars for automotive applications on FS in bands around 24 GHz

1.5.1 Introduction

This section explores the possible impact of automotive SRR operating in the 24 GHz band on FS in the 23 GHz and 26 GHz bands. Interference objectives, FS characteristics and interference scenarios are proposed for FS P-P systems as well as P-MP systems for FWA.

Initial analysis had shown that aggregation of SRR interference into P-P receivers could be more critical. Therefore, more focus is given on the impact on P-P FS systems; however studies are also presented for FWA P-MP. Also some practical measurements were carried out to investigate the influence of automotive SRR on FS receivers and to validate the objectives with actual SRR emissions.

The scenarios are obviously based on FS stations placed along major roads, where SRR emission aggregation is expected.

According the expected deployment of SRR over the FS primary allocated band on “no harmful interference” basis, the studies in this report are made using the “worst-case” methodology, as confirmed by Radiocommunication WP 9D.

However, the potential interference scenarios simulated in this study depend on many different parameters, which highly affect the aggregated interference power. The choice of the appropriate set of parameters for building up a reasonable “worst case” could vary from administration to administration. This is due to a number of reasons such as:

– The different historical evolution of FS applications in various countries. FS applications for telecommunications infrastructures are in use since more than 50 years. Different geographic, demographic and regulatory aspects influenced the deployment of FS links in the 23 and 26 GHz bands. The introduction of FS links in telecommunications infrastructures in these bands followed different evolution in various countries; for example, in CEPT countries many hundreds of thousands of FS links in the 23 and 26 GHz band are used for mobile networks links between GSM or 3G base-stations. A large number of existing and planned links are located along major roads and highways.

– In other countries this application may be far less in use, due to extensive use of wired connections, or is made in different bands.

– The search for the reasonable parameters for building up a “worst-case” scenario also depend on a number of mitigation factors that, being mostly of unpredictable and uncertain nature, can not be definite with a unique value or their presence can not be guaranteed in all cases; also for them the “subjective” perception of administration may vary for local, historical, national policy, geographical or other reasons.

– Finally, in selecting this reasonable set of parameters for “worst case” evaluation, also the “degree of risk” that administrations wish to take for balancing the protection of the FS primary service and the attractive use of SRR emerging technology, depends on the above mentioned factors. It is recognized that where a mutual density of FS stations and roads is low and their closeness normally avoided, the occurrence of a worse cases situation might be very low. On the other hand, because the potential interference generated by a single car in LoS to the FS receiver is already very close to the interference objectives, the possibility of situations with multiple SRR aggregation exceeding those objectives should be carefully taken into account.

Therefore, while maintaining the same general interference scenarios, the study will derive two different numerical conclusions based on two different FS deployment cases:

FS Deployment Case 1: for cases where high density of FS links in bands around 24 GHz and vehicles are expected and their closeness is likely to happen. Also any additional mitigation factors which are of unpredictable and uncertain nature will not be taken into account so that the risk of potential interference from SRR to the FS is maintained low in any circumstances.

FS deployment Case 2: where the above mutual dense deployment and closeness are not expected to be probable. This interference scenario analysis uses a different parameters set that takes into account other specific factors (e.g. geographical, meteorological, ergonomic, historical, national policy, etc.) and average mitigation factors which normally might assure SRR operation free from causing harmful interference to FS links, but may exceed the FS protection objectives by some dB in extreme situations.

1.5.2 Frequency bands

The SRR operational frequency range being targeted is from ~22 GHz to ~29 GHz. The fixed service is allocated in the 21.2-23.6 GHz, 24.25-26.5 GHz and 27.5-29.5 GHz bands.

For example, within CEPT countries, the 23, 26 and 28 GHz bands are extensively used for FS links. In some other countries wireless FS links play less of a role in these bands because many base stations of the mobile networks are linked by cable.

1.5.2.1 23 GHz band (22-23.6 GHz)

The 23 GHz band is used throughout Europe for digital FS systems with low/medium and high capacity P-P links. In many cases this is used for the provision of regional telecommunication infrastructure (e.g. for public mobile telephony networks), but also for multi-purpose RRL, such as private FS networks. For example, the number of links has doubled in the period 1997-2001 and is now 37 000 links for mobile telephony networks infrastructure within CEPT countries.

In most countries the channel arrangement follows Recommendation ITU-R F.637, with channel widths of 3.5/7/14/28 MHz. In some countries 50 MHz or 56 MHz channels are also in use. The average recorded hop length in this frequency band is around 7 km.

1.5.2.2 26 GHz band (24.5-26.5 GHz)

With a fast growing tendency (P-P links grow from 500 in 1997 to about 13 000 in 2001), the 26 GHz band is used throughout CEPT countries for FS in accordance with the channel arrangements in Annex 1 of Recommendation ITU-R F.748. This encompasses the FS applications for the provision of regional telecommunication infrastructure (e.g. for public mobile telephony networks) using digital P-P, but also P-MP fixed links (generally licensed on block assignment regime) should be taken into account[49]. The capacity of the links ranges between low, medium and high.

This band is also one of the preferred bands for FWA introduction in Europe, in accordance with its identification in ERC/REC 13-04. Assignment of channels for FWA also follows arrangements given in T/R 13-02. Together with the band 3 400-3 600 MHz this band (or parts of it) constitutes the band

[49] As in other FWA bands, the actual extent of FWA deployment is difficult to estimate because of lack of data on user terminals. Only a number of licensed networks or a number of central stations is reported in most cases.

for the provision of FWA within CEPT. The average length of reported (P-P) links in this band is 6 km.

1.5.2.3 28 GHz band (27.5-29.5 GHz)

In Europe, the band was not widely used for a number of years, the adoption of ERC Decision ERC/DEC(00)09 has taken away the uncertainty regarding shared use of this band by FS and transmitting earth stations in the FSS.

The FS usage plans in this band foresee provision of spectrum either for infrastructure support links (within the public mobile telephony networks) or FWA, or both, depending on the individual requirements in a particular country. It is expected that the 28 GHz band will soon be exploited at the same extent as the 26 GHz band, with particular regard to the 3 G mobile networks infrastructures.

1.5.3 Fixed service protection objectives

See § 1.1.1

1.5.3.1 Long-term criteria

See § 1.1.1.1 where the long-term criteria is expressed as $I/N = –20$ dB for short range radars around 24 GHz with an apportionment of 0.5% of the total degradation of a FS link budget.

1.5.3.2 Short-term criteria

See § 1.1.1.2.

For this study, being generic and not focused to a specific SRR emission, these criteria have not been considered at this stage and would need a case by case consideration with the definition of a representative aggregate APD statistics.

1.5.3.3 Consideration of peak interference objectives

See § 1.1.1.5 where the rationale for the aggregate peak power objective $I_{P50}/N_{A50} \leq +5$ dB is assumed to be sufficient to protect the fixed service.

This is equivalent to:

$$I_{P50} \text{ (dBm/50 MHz)} \leq I_A \text{ (dBm/MHz)} + 42 \text{ dB}$$

1.5.4 FS characteristics in bands around 24 GHz

Recommendation ITU-R F.758 provides guidance on technical characteristics and sensitive parameters of FS systems.

Assessment of the effects of interference into the FS from other services requires knowledge of the performance characteristics of the radio receiver. The following receiver parameters are important for frequency sharing studies:

– noise figure and noise floor;
– equivalent noise bandwidth;
– fade margin (typically used only for “short-term” objectives assessment, not addressed for this study);
– antenna gain and radiation pattern;
– feeder loss;
– antenna height and its positioning in respect to roads in vicinity (e.g. horizontal offset).

1.5.4.1 Noise figure, noise floor and equivalent noise bandwidth

Recommendation ITU-R F.758-3 specifies for the noise figures a range of 5 to 12 dB. However the industry and market evolution offer the better data (e.g. the system used for the test campaign exhibits an overall measured noise figure of 4.5 dB) combined with fully outdoor application (without feeders) as unique request by the market.

Therefore, a 6 dB noise figure has been taken into account that leads to a noise floor of –168 dBm/Hz.

In general the interference into a FS receiver depends not only on the interference power at the receiver input but also on the modulation type of the receiver. By referencing interference to the receiver thermal noise level the problem is greatly simplified, since the permitted interference PSD so derived will be dependent solely on receiver noise figure and independent of the modulation scheme. The receiver thermal noise level is defined as:

$$N = 10 \log(k_B * 290K * BW) + NF = -114 \text{ dBm} + 10 \log(BW/1 \text{ MHz}) + NF$$

where:

k_B: Boltzmann constant

BW: equivalent noise bandwidth, assumed to be the 3 dB receiver bandwidth of the victim system

NF: noise figure.

Recommendation ITU-R F.758 provides the relevant data for several different kinds of FS P-P systems in the 23 GHz band and the 26 GHz band to be used when developing criteria for sharing with other services.

TABLE 101

Characteristic parameters of FS P-P systems in the 23 GHz band and the 26 GHz band

Parameter	Assumed values
Equivalent noise bandwidth	Typically < 50 MHz but 50/56 MHz systems are on the market
Noise figure	6 dB
Minimum feeder/multiplexer loss	0 dB(1)
Maximum antenna gain	See § 6.4.2

(1) In the 24 and 26 GHz bands it is nowadays common practice to have integral antenna on outdoor mounting transceivers. However, also older equipment and 1-1 protected links are still in use in many countries.

1.5.4.2 Antenna gain and radiation pattern

There are a number of Recommendations and standards dealing with FS P-P antennas. However, for international sharing studies Recommendation ITU-R F.699-5 should be used. This Recommendation provides information on the whole range of angles (0-180°) and for frequencies from 1 to 70 GHz.

For FS P-P links radiation patterns are assumed to be rotational symmetric.

Considering the aggregated interference power from several sources of interference, there will be interference entries at both the peaks and troughs of the actual receiver antenna. While Recommendation ITU-R F.699-5 gives only a peak envelope of the side-lobes, Recommendation ITU-R F.1245 provides an antenna envelope based on averaging the peaks and troughs of the actual radiation pattern. The latter should be used for calculating the aggregated interference from several sources of interference.

Figures 197 and 198 depict the relative antenna radiation pattern of a 41 dBi antenna according to Recommendations ITU-R F.699 and ITU-R F.1245, respectively (corresponding to a 0.6 m dish size).

FIGURE 197

Relative antenna radiation pattern according to Recommendations ITU-R F.699 and ITU-R 1245 for maximum gain = 41 dBi

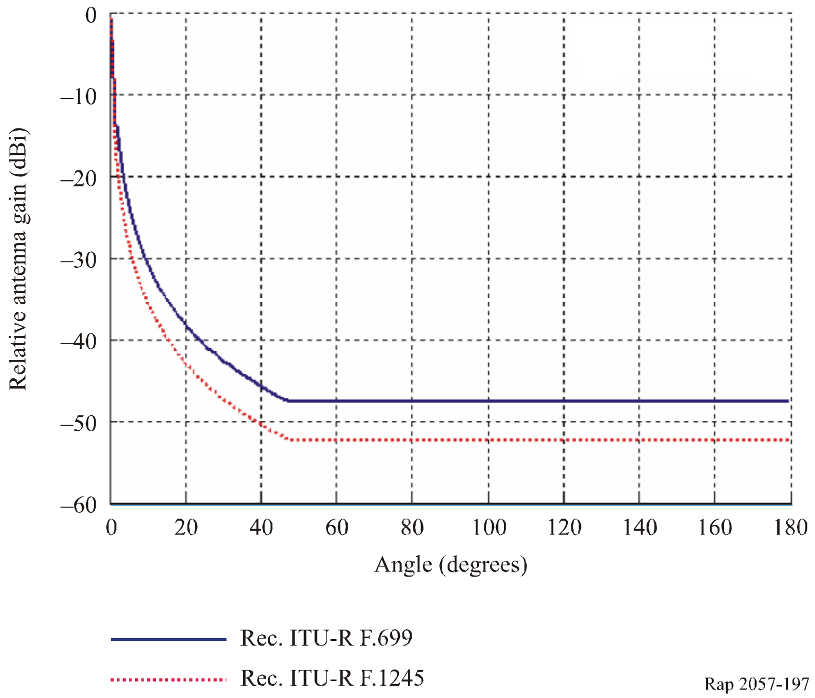
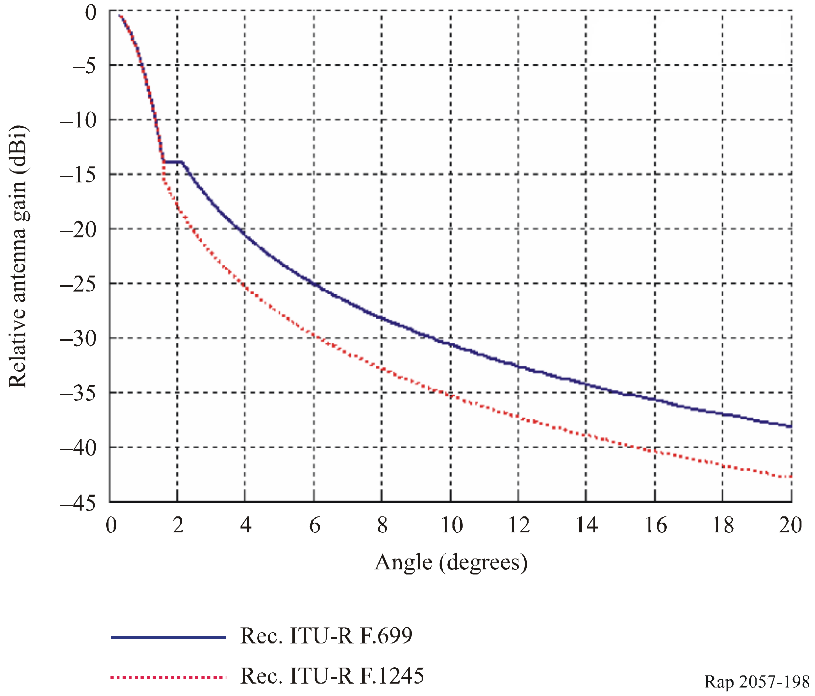


FIGURE 198

Zoom into high gain region of Fig. 197

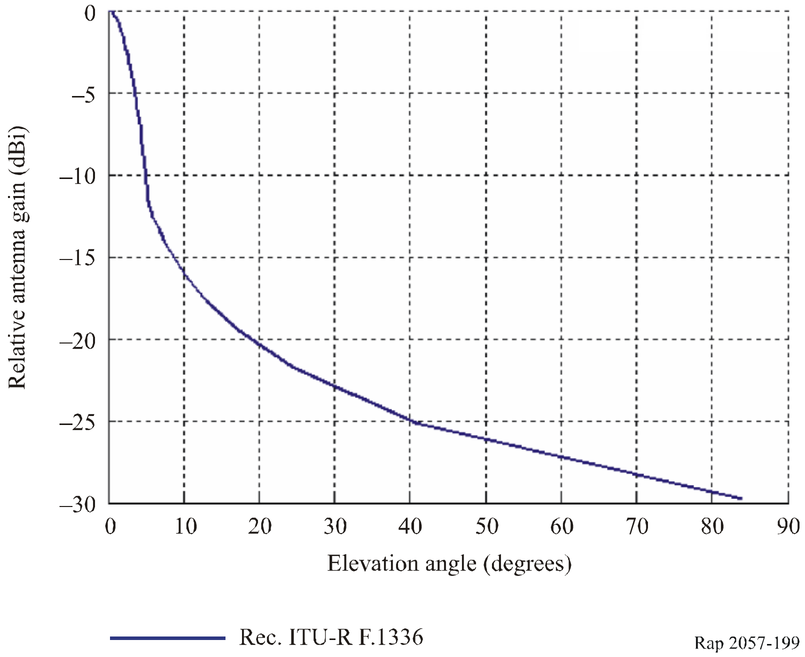


For FWA central stations, a 90° sector antenna of 18 dBi maximum gain has been considered as typical. Recommendation ITU-R F.1336 provides reference antenna patterns of omnidirectional and sectorial antennas in P-MP systems in the frequency range 1-70 GHz for the use in sharing studies. Figure 199 depicts the relative antenna pattern as function of the elevation angle of a 90° sectorial antenna with 18 dBi maximum gain.

In order to ensure an adequate coverage of the FWA cells, CS stations are down tilted. A 2° down tilt has been considered in the present study. However, since the interference into a FWA central station turned out to be less critical, only P-P FS links will be discussed in the following.

FIGURE 199

FWA antenna elevation pattern according Rec. ITU-R F.1336 for a 90° sectorial antenna with 18 dBi maximum gain



In the interference study the following antenna parameters have been used:

– According to Recommendation ITU-R F.699 for single entry evaluation with P-P (see Fig. 197).

– According to Recommendation ITU-R F.1245 for aggregate scenarios with P-P (see Fig. 197).

– According to Recommendation ITU-R F.1336 for scenarios with FWA (see Fig. 199).

– P-P Antenna gain = 41 dBi.

1.5.4.3 Feeder losses

For the typical systems in the 23 and 26 GHz bands as described above, the radio receivers are generally implemented close to the antenna which implies that the feeder losses are negligible. In some cases, for so-called protected systems using 1 + 1 protection, a combiner are necessary associated with additional losses ranging from ~ 1 to 4 dB; however this could not be taken as a rule due to the majority of systems deployed in stand-alone configuration, for which this attenuation do not apply.

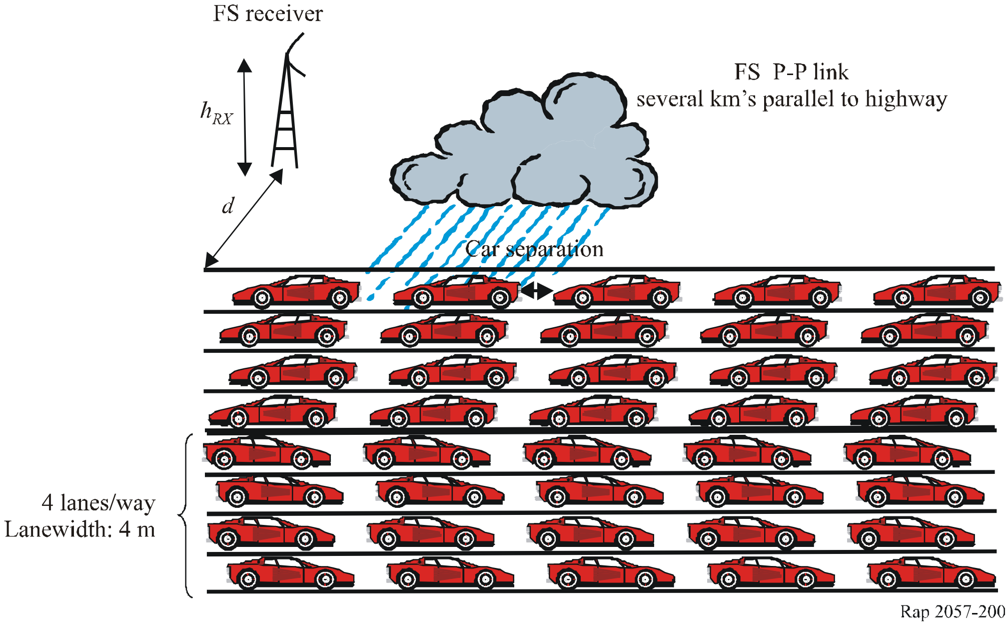
Hence for general case considerations a 0 dB feeder loss is used in the calculations keeping in mind that in some cases the interference power is overestimated by some dBs.

1.5.4.4 FS antenna height and horizontal offset

The vertical and horizontal location of the antennas and their decoupling with regard to the road play a fundamental role, as shown in Fig. 200.

FIGURE 200

Vertical/horizontal planes scenario



For FWA CS higher locations are sought for enhancing cell coverage.

For defining the range of data to be used it should be taken into account that the history of FS deployment in bands around 24 GHz has continued for more than 15 years; in that time the purpose, deployment practice and constraints have changed in many aspects and may change again in the future. In addition, FS links are not only used as infrastructures for mobile networks, but in a number of public and private applications where the antenna masts arrangements follow different considerations. It is also recognized that the deployment practice and constraints can change from country to country; then experience in the deployment of FS systems may differ for geographical and historical reasons. Therefore the FS parameters (e.g. the antenna mast height) used for as representative of the "worst case" may vary in the perception of various administrations.

The antenna height plays significant role; worst case is expected with the lower FS antenna location. For FWA CS higher locations are sought for enhancing cell coverage.

For this parameter, even if the average value could be sensibly higher, evidence of pole mounting heights of 10 m and even below were reported. Therefore, while recognizing that height of ~20 m or above are more typically found, a 10 m antenna height will be used as the lower-bound for this study.

Also the horizontal offset from the road border will significantly affect the results. The greater the offset the lower is the aggregated interference power. Similarly to the antenna height, the real deployment constraints might result in very low values. However, among various lower-bound figures range from 10 m (possibly more appropriate for normal roads, e.g. with 1 lane only) up to 30 m (possible when wide highways are concerned).

It should be noted, that in some countries regulations for construction may exist, limiting, as far as possible, for new deployments, the minimum allowed distance between highway or major roads and buildings like FS poles (e.g. the German "Bundesfernstraßengesetz" rules out FS poles within 40 m along both sides of a highway and within 20 m along major roads).

The calculations in this report are then carried out with a mixture of FS receiver heights and offsets.

– For the FS Deployment Case 1, antenna height of 10 m, 18 m and 25 m, mixed with offsets of 10 m and 30 m, are used.

– For the FS Deployment Case 2, antenna heights of 18 m, 25 m, 30 m, mixed with offsets of 20 m, 40 m and 60 m, are used.

1.5.5 SRR parameters

The relevant parameters of the SRR devices, necessary for the long-term FS objective assessment are assumed to be:

e.i.r.p. density (r.m.s.): –41.3 dBm/MHz

e.i.r.p. wide-band peak: 0 dBm/50 MHz

SRR antenna elevation pattern: two different antenna patterns for SRR sensors, one that is more stringent in elevation have been proposed as shown in Table 102.

The e.i.r.p. density is intended to include the effect of gating time necessary to elaborate the received signals in radars applications.

TABLE 102

SRR limitation in antenna elevation pattern

Less stringent elevation option		More stringent elevation option	
Vertical antenna angle θ (degrees)	**Spatial antenna gain**	**Vertical antenna angle θ (degrees)**	**Spatial antenna gain**
θ □< –70°	G_{max} (dBi) – 26.66 dB	θ□ < –70°	G_{max} (dBi) – 26.66 dB
–70° < θ □< –30°	G_{max} (dBi) + 2/3 × (θ + 30°) (dB/°)	–70° < θ □< –30°	G_{max} (dBi) + 2/3 × (θ □+ 30°) (dB/°)
–30° < θ □< 0°	G_{max} (dBi)	–30° < θ □< 0°	G_{max} (dBi)
0° < θ□ < 40°	G_{max} (dBi) – 2/3 × θ□ (dB/°)	0° < θ□ < 30°	G_{max} (dBi) – 7/6 × θ□ (dB/°)
□θ□ > 40°	G_{max} (dBi) – 26.66 dB	θ□ > 30°	G_{max} (dBi) – 35 dB

However, the second, more stringent option is only intended for satellite systems protection and only applicable in the 23.6 to 24.0 GHz range in the assumed scenarios for FS interference study it has been shown that the difference is absolutely negligible and furthermore not applicable as no FS systems are emitting intentionally in the restricted band from 23.6 to 24.0 GHz.

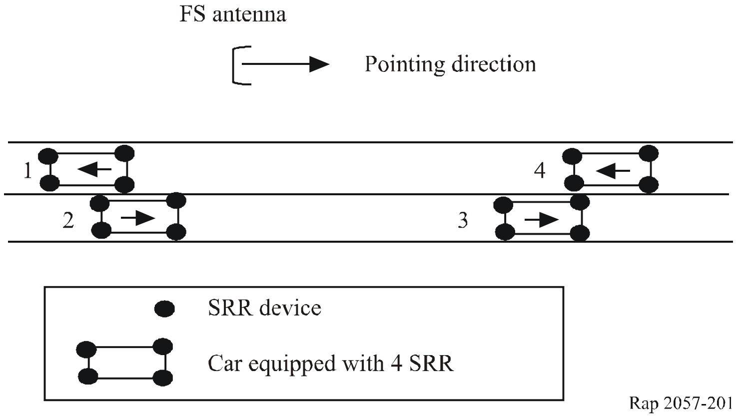
1.5.6 Additional parameters for interference calculations

1.5.6.1 Number of active SRR device per car

On the basis of this Report it is assumed that a maximum of four active sensors per car are representative for an average long-term situation, two pointing frontward and two backward. Fig. 201 summarizes all possible situations of cars relative to an FS station.

FIGURE 201

Description of all different possible SRR locations considered in the study



For car situations No. 1 and 2, the radars will interfere in the back lobe of the FS antenna and have not been taken into account because the contribution of the SRR devices in the back lobe of the FS antenna has been shown to be negligible.

Similarly, the contribution of car situation No. 3 (farthest lanes from the FS location) was expected to be negligible and has also not been taken into account.

It should be noted, for car situation No. 4, that the position of the sensors right in the corner of the car (as depicted in Fig. 201) could results in the same interference potential for forward and backward pointing sensors as for side sensors, because the antenna pattern of SRR is currently not restricted within the horizontal plane.

It has been noted that, for applications like pre-crash sensing utilizing forward (or backward) pointing SRR devices, a sensor set-up as depicted in Fig. 201 would be unrealistic, because the area right in front of the car is not within the SRR field of view. A distance between the two devices of 40 to 70 cm would be more realistic. It is likely that for high traffic densities, a modified SRR sensor set-up with the two forward pointing devices positioned 20 cm inside from the profile border might result in a mitigation of the interference power into a FS receiver.

On the other hand, it can be noted that, explicitly, no radars pointing to the side were considered in the studies, although it was assumed that they could increase the interference potential to FS station in the vicinity of the road.

Finally, only the two frontward radars from car situation No. 4 were considered in the studies, while their positioning will be:

– For the FS Deployment Case 1, the four devices are placed at the car profile corners.

– For the FS Deployment Case 2, the two front devices are placed 20 cm inside from the car profile.

1.5.6.2 Bumper loss

Since SRR sensors would be commonly mounted behind bumpers, their attenuation has to be taken into account because regulatory levels would be set for SRR "bare" sensors only.

A typical bumper has a thickness of about 4 mm to meet the mechanical requirements and consists of the recyclable plastic material Poly Buthylen Terephtalat (PBT). The commonly used plastic has a transmission loss of about 3 dB which further slightly increases if humidity is absorbed by the plastic. The painting of the bumpers causes further losses that depend on the paint which is used. The highest noted losses are caused by metallic paints.

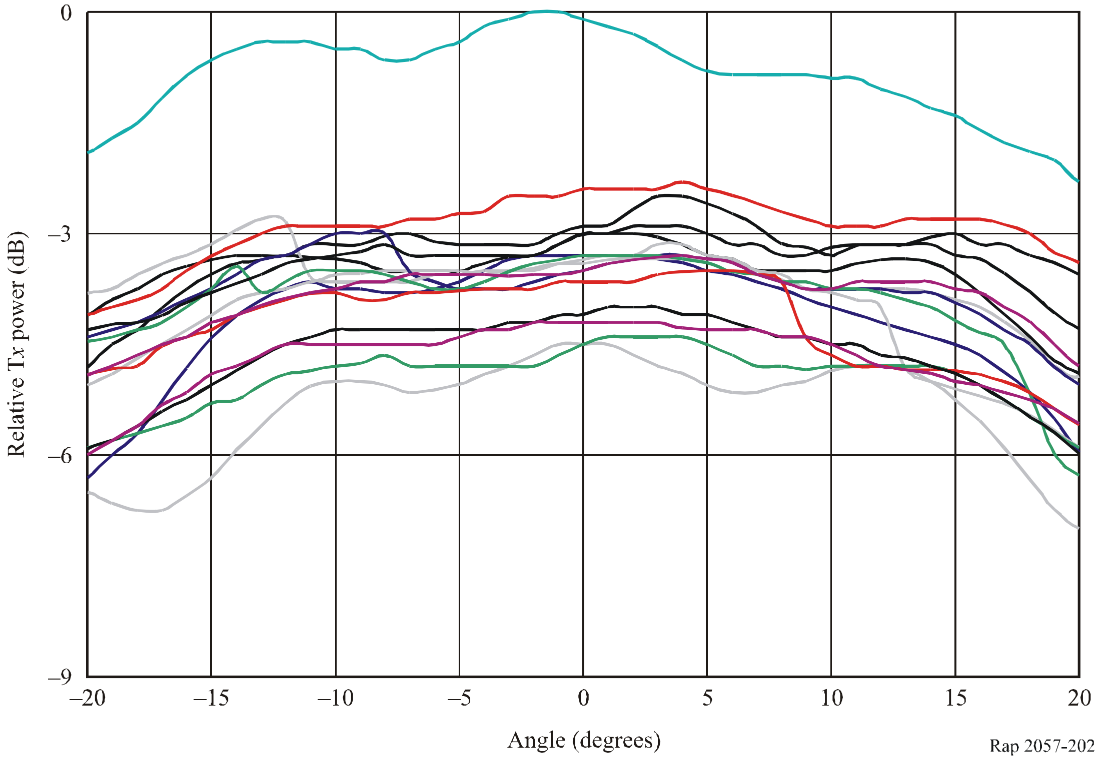
Tests have been conducted with results given in Fig. 202 that are showing that the typical or average loss of the bumper is higher than the assumed 3 dB.

To reproduce the real case, the bumper damping was measured with a SRR using UWB technology placed behind a piece of bumper in an anechoic environment. The transmitted mean power was measured by using a power meter connected to a pick up horn at bore sight of the Tx antenna.

It can be noted that the uppermost light blue curve relates to a SRR device without bumper and that the relative SRR Tx PSD is measured versus azimuth angle.

FIGURE 202

Losses caused by the bumper measured with different bumper colours



On the other hand, it is also considered that as far as the SRR penetration on the market will increase, also the technology of bumper paints, taking into account a possible new requirement, might improve in this respect.

– On this basis, 3 dB additional losses have been used in both study cases.

However, considering that it is not possible to foresee technology and "styling" evolution in the automotive market, in case of a "bare" mounting of the sensor, the adopted SRR e.i.r.p. level should be reduced accordingly.

1.5.6.3 SRR sensor height

As the height of the SRR sensors mounting increases, the expected interference is assumed to increase, due in particular to the loss of shielding given by preceding vehicles.

For trucks a maximum height of 1.5 m is realistic. The higher height is compensated by a higher shielding effect. For cars, representing the majority of all vehicles, an average height of 0.5 m is more appropriate.

For both studies an average SRR mounting height of 0.5 m is assumed for passenger cars.

1.5.6.4 Rain correlation and road water spray attenuation

1.5.6.4.1 Rain correlation

Since long-term criterion as defined in § 1.6.4.1 is justified by a margin degradation in rainy conditions (that controls the FS availability), it was determined that attenuation due to rain on the FS link path would also result in an attenuation due to rain on the interfering path between the radar and the FS receiver. This rain attenuation correlation is another factor that might affect sensibly the results.

Based on Recommendations ITU-R P.452[50] and ITU-R P.530 which give statistics on rain distributions and rain cell sizes, and comparing the typical hop length of the FS link ~ 5 to 7 km to the cell rain size for various rain zones. It was determined that, for the studied case of 23 GHz (Vpol), a specific attenuation ranging from 0.6 dB/km to 3 dB/km (for the 26/28 GHz bands values ~ 1.5 dB higher are expected) on the interfering path might be considered in the simulations.

On the other hand the rain cells, in particular in high intensity rain zones, might dynamically move quite fast, therefore the probability of a stable situation with constant attenuation would not be high.

The studies will therefore use:

– For the FS Deployment Case 1, taking into account also low rain rate zones, rain correlated attenuation of 0.6 dB/km will be used; a value of 3 dB/km would also be used for comparison.

– For the FS Deployment Case 2 an average of 2 dB/km will be used, still evaluating the variation with the maximum of 3 dB/km.

1.5.6.4.2 Road water spray

In addition, a possible additional attenuation due to water spray caused by preceding vehicles has also been evaluated. It was reported that during rain period, the attenuation of SRR radiation due to spray from preceding cars might be much stronger than the attenuation due to the rain itself. On the other hand, it was also noted that new anti-spray pavement is becoming more and more popular on roads with high traffic density. However, for the rain rates relevant for interference scenarios of SRR into FS (28 mm/h or even higher) the efficiency of such anti-spray pavement might be sensibly reduced. On the other hand, assuming the rain cell size to be lower than the link length, the rain rate in vicinity of the FS station might be far lower.

Due to the lack of technical evidence on numerical value of such impact the rain spray mitigation factor is:

– Not taken into account for the FS Deployment Case 1 case.

– For FS Deployment Case 2 a spray attenuation of 3 dB is considered as a conservative assumption.

In any case, when the cars separation distance increases up to 50 m or more, this effect will be reduced.

1.5.6.5 Car shielding

When vehicles, queuing on roads, come closer, the preceding vehicle acts as shielding towards the FS victim antenna. As shown by measurements the effect of shielding SRR radiation by preceding cars is on the order of several 10 dBs. The results of these measurements are shown in Fig. 203.

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[50] The qualitative rain-cell model of Recommendation ITU-R P.452 is here used to calculate the influence of hydrometeor scatter and is not for link planning as Recommendation ITU-R F.530.

In Fig. 202, the relative shielding loss L_S is shown as a function of the difference between the elevation angle α of top of shielding vehicle and the LoS angle α_R. (The configuration of the measurements is shown in Fig. 203.) The shielding loss is normalized to power that would be received in the absence of any shielding object. The red curve (straight line projections) gives a simplified shielding model to be used in the calculations:

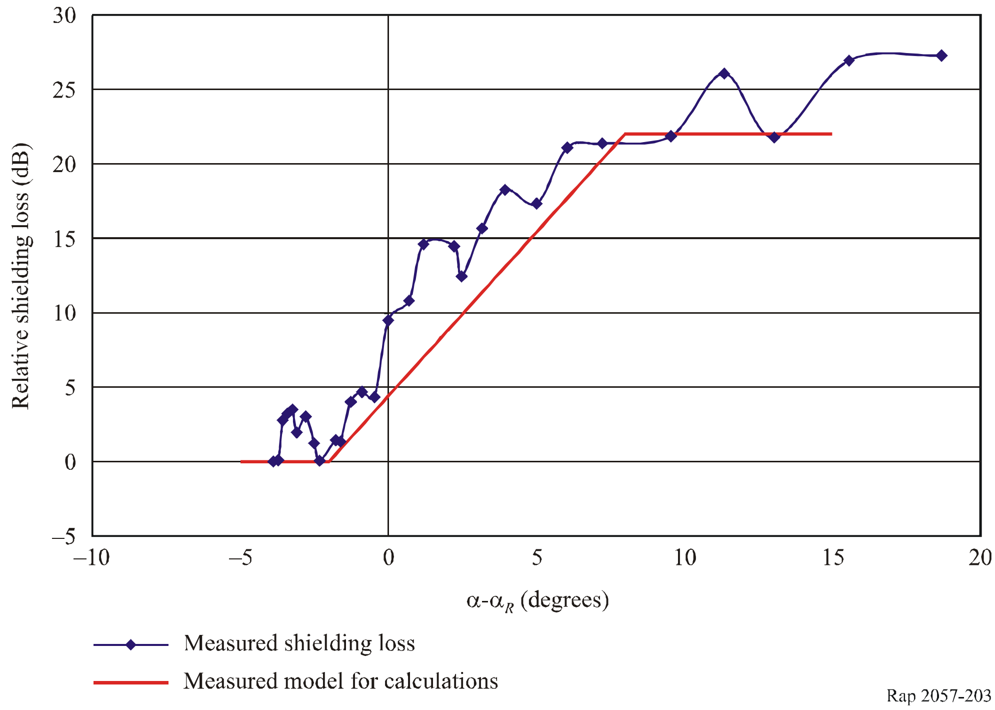
$L_S = 0$ for $\alpha - \alpha_R < -2$

$L_S = 2.2*(\alpha - \alpha_R) + 4.4$ for $-2 < (\alpha\text{-}\alpha_R) < 8$

$L_S = 22$ for $(\alpha - \alpha_R) > 8$

FIGURE 203

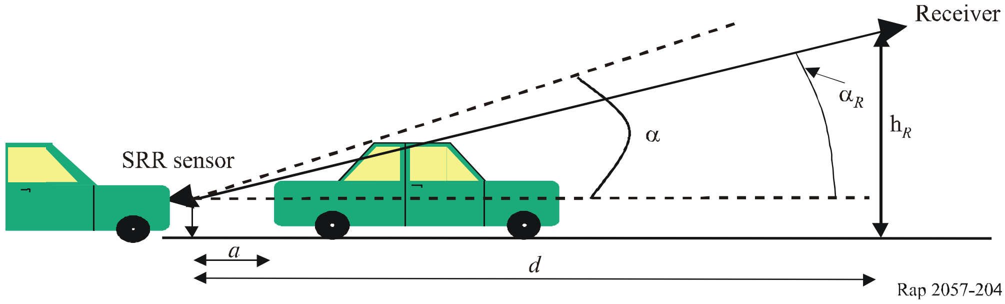
Results of shielding measurement



It is important to notice that the measurements in Fig. 203 show that there is already shielding loss of ~ 4.5 dB for a 0° grazing LoS angle. Full SRR interference into the FS receiver is only applicable as long as the LoS angle stays ~ 2° above the obstructing object.

FIGURE 204

Sketch of a NLoS-connection between SRR and receiver



Note that the angle α depends on both the separation of cars and the height of the preceding car. For the latter a value of 1.5 m is assumed, which is valid only for normal cars but not for trucks, buses and vans. In order to account for other vehicles than cars, a stochastic approach is unavoidable, which will lead to an additional attenuation. On the other hand, it was also acknowledged that the radars are likely to be mounted higher on trucks and vans and hence would experience less shielding.

Because of the horizontal offset between FS link and road border the shielding due to preceding cars will be reduced with respect to the model derived above from the measurements for the pure elevation angle dependence of shielding. However, in addition to shielding due to preceding cars, the shielding by vehicles on adjacent lanes must then be considered. This becomes very important especially when the lane next to the P-P link is congested with large trucks, which presumably would be a common effect on major highways, and results in an attenuation of the interference of the same order as the above discussed shielding by preceding cars.

However, the car variance is difficult to assess and varies from day to day (working days, weekend (no trucks), etc.), it would have posed very difficult burden to the mathematical model.

SRR devices mounted on vehicles driving on the outermost lane contribute the major portion to the aggregated interference power into the FS link while the impact of the other lanes is negligible due to the shielding of cars running on the outermost lane.

In the calculations the above described shielding effect may apply only with regards to the elevation plane, as the test were actually done, along the uppermost profile of a car, stopping the shielding effect in the azimuth plane, with on/off LoS function, exactly when the lateral car profile ends. However, the same shielding model might be also considered for the azimuth plane, along the lateral borders of the car profile. As no actual measurements were available for the azimuth case, it has been noted that the same model would not be perfectly fit for the lateral profiles of cars, where the different shapes and relative deepness of car portions (cockpit and rear luggage volumes) would not result in a straight profile as it is the case for the tested uppermost profile.

However, some example calculations performed with the two models have shown that when applying the vertical shielding model also for the horizontal shielding the aggregated interference power decreases by ~5 dB, when the distance between cars is 20 m and to ~ 3 dB, when the distance between cars is 30 m, which could hence allow assuming that it is likely to vanish for higher distances between cars.

The studies here reported use:

– For the FS Deployment Case 1, the shielding model for the elevation plane and LoS on-off function for the azimuth plane.

– For the FS Deployment Case 2, the shielding model of the elevation plane is also used for the azimuth plane.

In both cases, for further simplification the study does not account explicitly for the dependence of the shielding on the azimuth angle for all but the outermost lane (closest to FS receiver), assuming that all emissions from these lanes are shielded. This compromise also balances the assumption of an average vehicles height that is based on cars only.

1.5.6.6 Clutter loss

Besides shielding due to other vehicles, clutter loss due to shielding by objects such as traffic signs, bridges, trees, guardrails, buildings etc. may be taken into account in the interference calculations where the clutter scenario is known. Where there are doubts as to the certainty of the clutter environment this additional loss should not be included. This is also stated in Recommendation ITU-R P.452:

"... Considerable benefit, in terms of protection from interference, can be derived from the additional diffraction losses available to antennas which are imbedded in local ground clutter (buildings, vegetation etc.). This procedure allows for the addition of such clutter losses at either or both ends of the path in situations where the clutter scenario is known. Where there are doubts as to the certainty of the clutter environment this additional loss should not be included. ... ..."

Even if a potential attenuation in the range from 5 dB to 15 dB is possible applying Recommendation ITU-R P.452, it is difficult to quantify these effects without evidence, recognizing that it can sensibly vary depending on the considered location.

The assumptions for the two study cases will be:

– For the FS Deployment Case 1 no clutter losses are considered.

– For the FS Deployment Case 2 an average clutter loss of 7 dB has been assumed in line with the example reported in Appendix 4.

1.5.6.7 Reflection/diffraction from surrounding vehicles

The reflection/diffraction caused by surrounding vehicles has the potential to increase the interference from SRR to the FS stations.

As an example, the backward SRR devices emissions may reflect on the front of the following vehicle and be redirected towards the victim antenna and hence add to the aggregate interference caused by direct LoS path emissions.

However, this effect is also difficult to assess and possibly not particularly relevant unless in heavy traffic conditions and might somehow balance the simplified (no azimuth) shielding model; therefore it has not been taken into account in both studies.

For example, one test made on a passenger car, reported in Appendix 5, shows that, in that case the reflections gave negligible contributions; however further tests (on different car types etc.) might be required to fully assess this factor.

1.5.6.8 Polarization decoupling

For SRR, rain attenuation is of minor importance; so H or V or even slant polarization (in next generations of SRR) are possible. It was proposed that ~50% (i.e. 3 dB) of devices would transmit on different polarization than that used by the FS victim station; e.g. during the measurement campaign between FS and SRR some manufacturer offering SRR devices for the test use horizontal polarization while others rely on vertical polarization. In addition, also for devices using the same polarization as the FS receiver, the imprecision of mounting and the road plane differences would also rotate the co-polar emission of some random angle giving a further decoupling.

On the other hand, it was also considered that the propagation characteristics at 24 GHz are more effective using vertical polarization, which is the preferred one for FS links due to the lower rain attenuation for V-polarization.

Finally, it was also noted that Recommendation ITU-R F.1245 only considers a potential polarisation gain for "circular-polarized" interferer in main beam to main beam scenario.

Nevertheless, a mitigation of the interference power up to 3 dB due to the polarization decoupling could be considered when balancing the safe guard margins.

Therefore the two study cases will adopt:

– no polarization decoupling for the FS Deployment Case 1;

– 3 dB mitigation for the FS Deployment Case 2.

1.5.6.9 Gating and activity factors

Gating

In practice all SRR sensors are idle for a given time period that is necessary for the receiver to elaborate the received signals. It is assumed that the maximum e.i.r.p. mean power density limit for the SRR assessment already considers this gating effect.

With the above assumption, no additional mitigation due to gating is considered in the calculations below.

Activity factor

In addition, a number of other factors might reduce the aggregated interference potential through a reduced average number of devices active in the same time or frequency domain (e.g. penetration of the SRR technology over the whole car population or the possible shift to narrower band operation in some traffic circumstances). This results in an activity factor for the 24 GHz SRR devices with a possible reduction factor to the aggregated interference power that may vary from 0 dB to 7 dB. However, even if possibly occurring, it is of unpredictable impact.

Therefore this study will use:

– no additional reduction by the 24 GHz SRR activity factor (worst case) for the FS Deployment Case 1;

– 7 dB additional activity factor mitigation for the FS Deployment Case 2.

1.5.7 Methodology and scenarios

Besides the "single vehicle" potential interference (presented in § 1.6.8.1), for this study, the following aggregate interference scenarios have been assumed as reference for representative worst case situations.

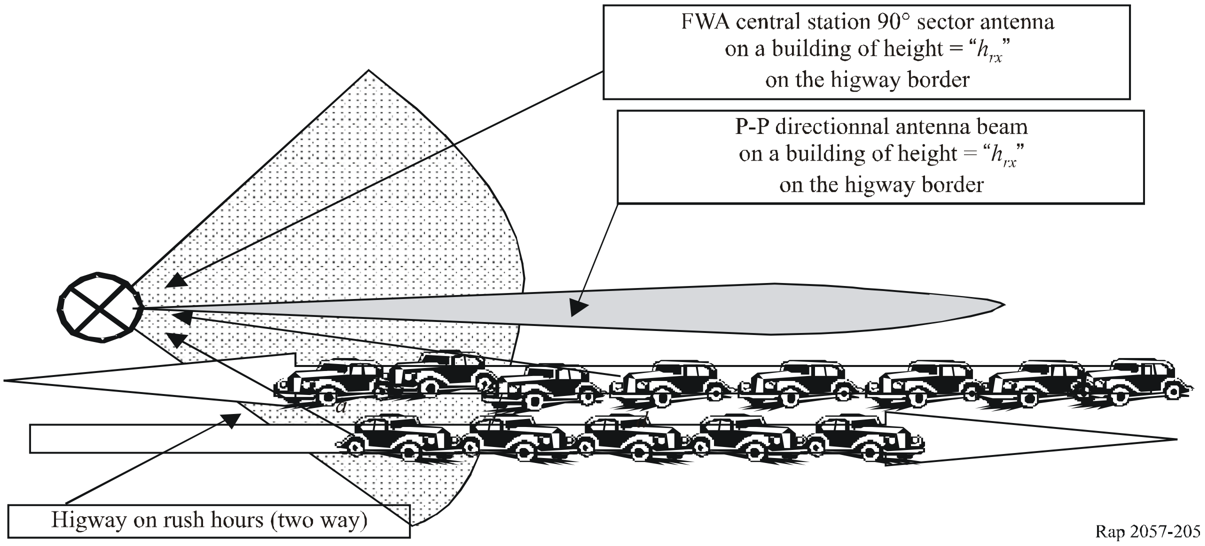
1.5.7.1 SRR aggregate interference due to vehicles driving (or queuing, in rush hours), on road or highway within FWA CS sector coverage or parallel to a P-P link (P-P case)

Parameters like the receiver height and receiver offset, which are sensible to the result of interference calculation for this scenario, are discussed in § 1.6.4. It was shown that the parallel alignment (or close to parallel alignment) between P-P FS link and highway is the worst case. For P-P links outside a ± 5° range around the parallel alignment the interference power due to SRR devices is lower by ~ 10 dB.

The integration length might be longer for the highway scenario (e.g. a few km). For calculations a maximum integration length of 3 km is assumed.

FIGURE 205

The road or highway scenario (plan projection)



In the interference analysis, taking into account the relative positions of the FS link plane and the interference path plane, the off-axis angle at the FS receiver and at the SRR transmitter is calculated. This angle is then used to determine the receiver and transmitter antenna off-axis gain which are considered in calculating the interference level together with the radar e.i.r.p. and the interference path loss (comprising free space propagation and atmospheric attenuation)..

The I/N produced by one single radar is calculated as follows:

$$\frac{I}{N} = (P_{rad} - A_{bump} + Discri_{rad} - FSL - A_{rain} + Gain_{FS} - k\ T\ B\ F) - M$$

with:

P_{rad}:	power of the radar (dBm/Hz)
A_{bump}:	attenuation due to bumpers (dB)
$Discri_{rad}$:	discrimination of the radar in the direction of the FS receiver (dB)
FSL:	free space losses (dB), function of the distance
A_{rain}:	attenuation due to rain (dB), function of the distance
$Gain_{FS}$:	gain of the FS in the direction of the radar (dBi) (c.f. Fig. 197, Rec. ITU-R F.699)
$k\ T\ B\ F$:	noise floor of the FS (dBm/Hz)
M:	additional possible safeguard mitigation/enhancement like clutter loss, polarization loss, diffraction etc. (see NOTE 1).

NOTE 1 – Provided that these safeguard are not easily quantified, the following aggregate evaluations do no take them into account; they will be separately considered in final conclusions.

For the P-P scenario, two different study cases have been considered for a separation distance between cars of 20, 50, 100 and 150 m:

– P-P scenario 1: Aggregation of multiple cars on one lane (road). With two relevant radars per car.

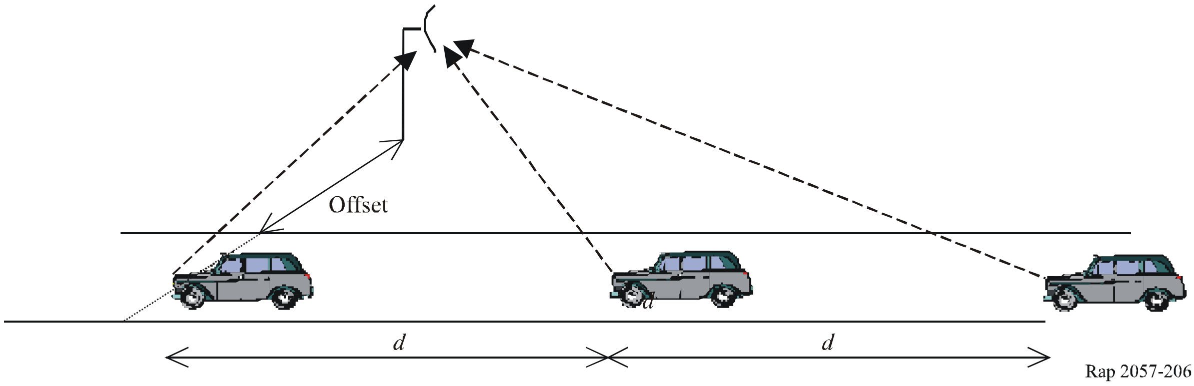
– P-P scenario 2: Aggregation of multiple cars on four lanes (highway). Two relevant radars per car.

1.5.7.1.1 P-P scenario 1 – Aggregation of multiple cars on 1 lane (road)

This scenario proposes to calculate the aggregate interference from multiple cars with two frontward radars per car. The distance between cars is *d* (see Fig. 197).

FIGURE 206

Sketch of scenario 1 (1 lane scenario)



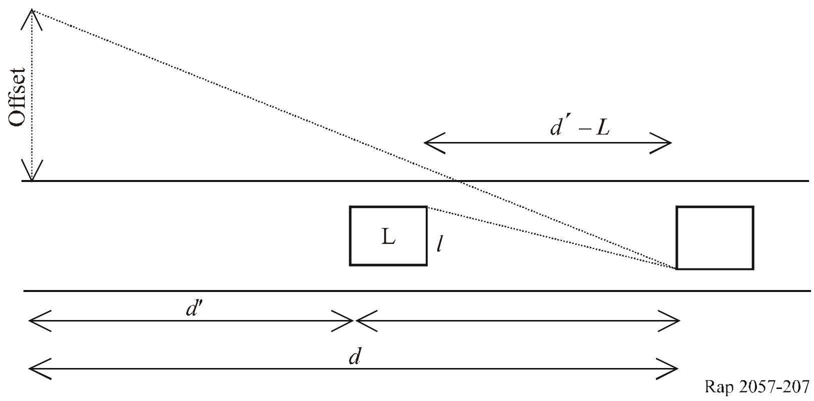
The two radars are implemented frontward, one on the right, and the second on the left of the car.

Due to the fact that the FS station is offset from the road, no shielding due to preceding car is taken into account for the right hand radar. For the left-hand radar, the shielding due to the preceding vehicle is considered according:

– to the simplified, elevation only, model described in Fig. 204 (deployment case 1). For the left-hand radar, the shielding due to preceding car as described in Fig. 203 is taken into account if, approximately, $\frac{(Offset + l)}{d} < \frac{l}{d' - L}$ (see Fig. 207);

– to the combined elevation and azimuth models (deployment case 2).

FIGURE 207



where:

d′: distance between cars

d: distance of the considered car from the FS receiver

l: width of the car

L: length of the car

Offset: offset of the FS receiver from the road.

The lane-width is assumed to be 4 m.

1.5.7.1.2 P-P scenario 2 – Aggregation of multiple cars on 4 lanes (highway)

This scenario proposes to calculate the aggregate interference from multiple cars on a four lane highway with two frontward radars per car. The distance between cars is *d*.

For the right lane, the scenario is similar to scenario 1 above.

For the three other lanes, even though in many cases the interference from radars will not be attenuated, it has been considered that the shielding due to preceding cars applies to all radars. This simplification would also trade-off for no explicit consideration of vehicle-heights and width (the assumed values of 1.5 m for both quantities hold only for normal cars but not for trucks, busses, vans etc., which would have resulted in a mitigation of the interference also from SRR devices on the closest lanes).

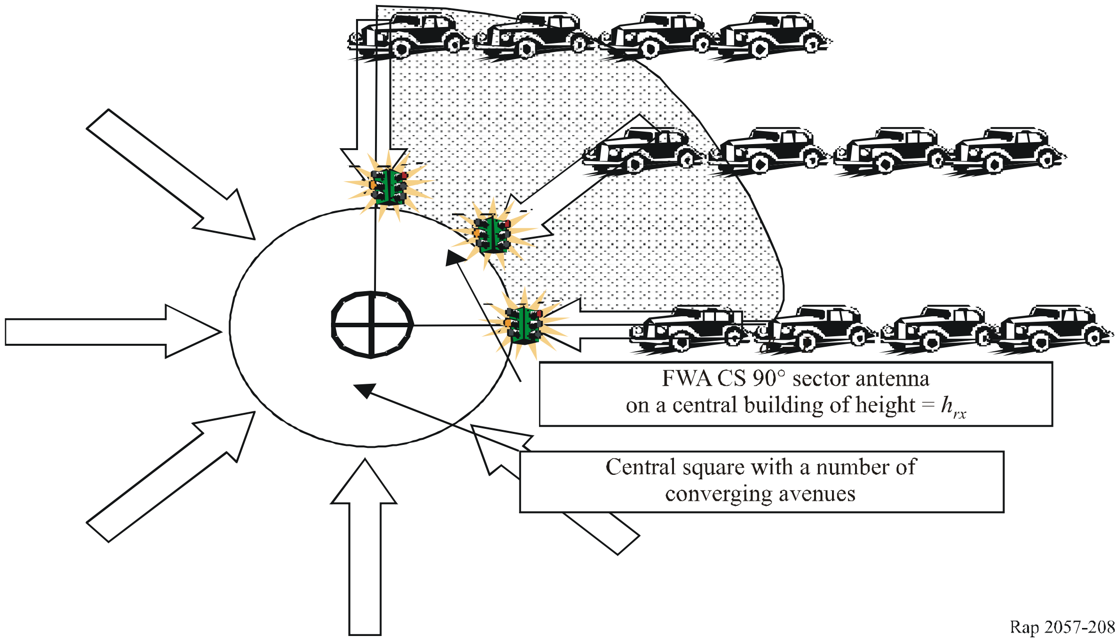
1.5.7.2 SRR aggregate interference to an FWA base station due to vehicles, queuing in front of traffic lights or traffic jamming on avenues converging to a city central square (FWA case)

The fixed wireless CS is placed on a medium-high location (e.g. 30 m height might be commonly assumed) on a building where some large streets converge. It is assumed that three of that street, with three lanes per street, will generate interference. The CS will have a typical sector antenna with 90º horizontal (equal gain) beam width, and a slight tilt down (e.g. 2°) as common engineering rule for enhanced coverage, placed on a high building overlooking the square. The length of the queuing is assumed to be ~100 m (~15-20 vehicles lines).

A second possibility, for a similar scenario in suburban area, is in proximity of a large roundabout for the city entrance. In this case the building might be lower (e.g. a six floor would lead ~ 20 m); the number of converging roads and lanes is assumed to be the same, but the potential length of visible road higher due to the less dense urban environment.

FIGURE 208

FWA central square scenario (plane projection)



1.5.8 Calculation results

1.5.8.1 Single car interference

For final evaluation of the aggregate interference, it might be helpful having interference level data also from a "single car" placed along side the main beam (e.g. for P-P in a ~1° beam area of ~ 0.2 km^2 when considering that the interference level is contained within ~ 5 dB for SRR distances up to 3 km or more from the FS antenna).

In this case the interference source is not bounded to any road nearby; interference might came from any car on any road within that beam area that appear to be in LoS with the FS antenna.

Each car, independently from the actual orientation of the road in respect to the FS link, will show at least two sensors to the victim, the 3 dB bumper loss will balance the two sensors aggregation.

The interference from single car may represent a "lower bound" for the "P-P along highway worst-case"; any mitigation parameters on that scenario if resulting in aggregate interference lower than the above-mentioned additional scenario, would not be relevant to the interference study.

The interfering power density from a single car (two visible sensors and bumper loss included), at a distance *D* from the victim receiver, is given in Figs. 209 and 210 for the FWA CS and P-P cases, respectively.

FIGURE 209

Single vehicle interference mean power (FWA CS)

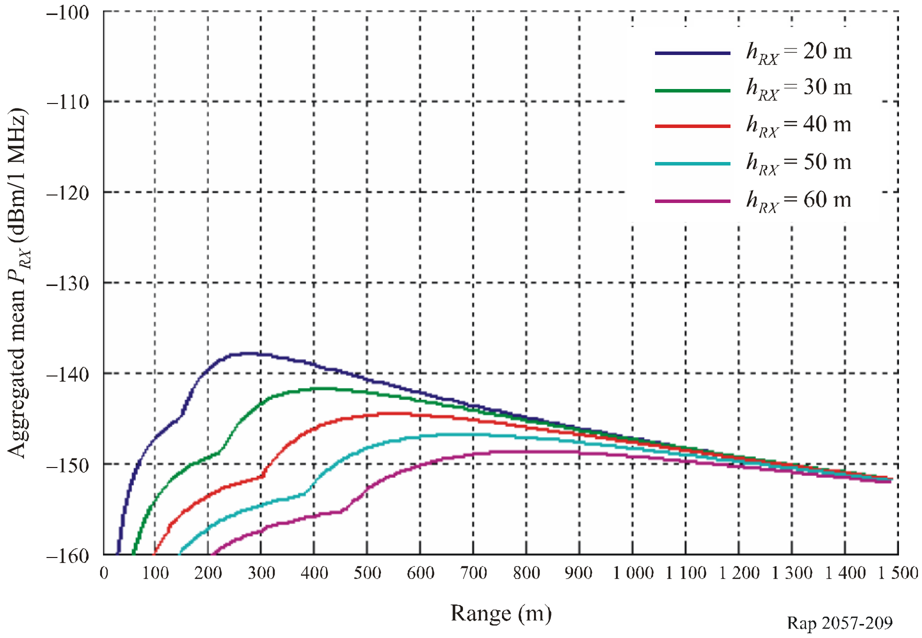


FIGURE 210

Single vehicle interference mean power (P-P)

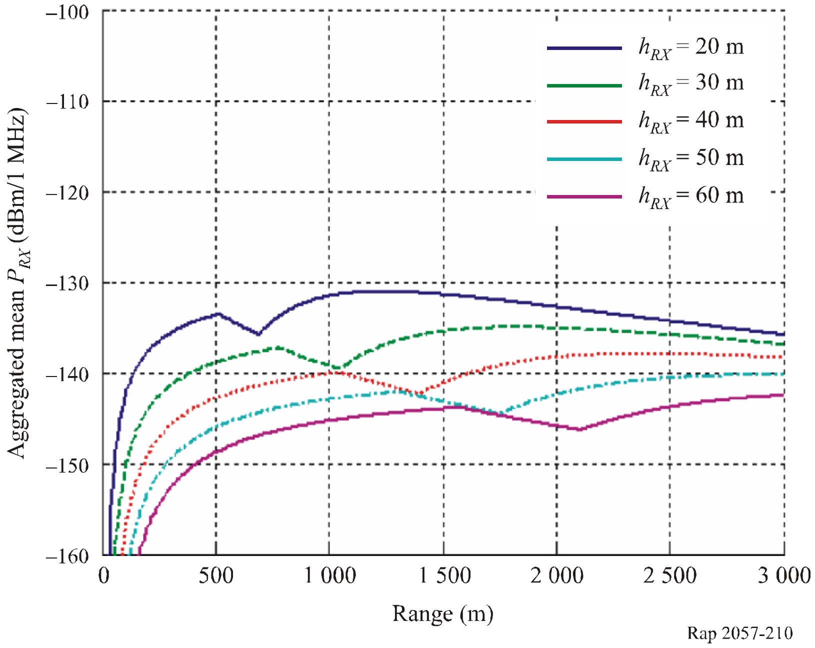


Figure 210 shows that, in case the 24 GHz SRR will use a long-term e.i.r.p. density of −41.3 dBm/MHz, the following conclusions may be derived:

– one single car (even with 20 m height P-P antenna), may already give interference power that almost reaches the overall limit, so giving no allowance for any aggregation effect;

– evaluation with P-P FS antenna height = 10 m give ~10 dB worse result, but the probability of LoS situation might not be relevant.

1.5.8.2 P-P highway scenario – aggregated interference

Based on the above, for the two study cases, calculations have been performed for a number of combinations of the following parameters:

– rain attenuation: 0.6 dB/km, 2 dB/km and 3 dB/km

– FS antenna height: 10 m, 18 m, 25 m and 30 m

– FS antenna offset: 10m, 20 m, 30 m, 40 m and 60 m

– distance between cars: 20 m, 50 m and 100 m and 150.

In all figures of this section, the input parameters used for each simulation are summarized on a simple basis as in the following example:

2.0p 25h 20 off 020

which means that the rain attenuation is 2.0 dB/km, the FS antenna height is 25 m, the offset is 20 m and the distance between cars is 20 m.

Table 103 reports the two specific sets of parameters that are used for the two study cases.

TABLE 103

Parameters directly considered in all the graphs for calculating the aggregated interference

Parameter	**Range of values**	**Value assumed for FS Deployment Case 1 analysis**	**Value assumed for FS Deployment Case 2 analysis**	**Remarks**
FS receiver parameters (informative values only, not relevant for the graphs generation)				
Equivalent noise bandwidth (used only for peak PSD emission evaluation only)	< 2-70 MHz	50 MHz	50 MHz	Typical value is 28 MHz but 56 MHz also are on the market. 50 MHz has been adopted as average worst case and for commonality of some existing national regulations
Frequency	22-29 GHz	23 GHz	23 GHz	23 GHz band has the higher utilisation. Results are applicable to other bands if appropriately corrected by the frequency dependent rain-rate and free space loss terms (the latter balanced by antenna gain)
23 GHz/28 GHz bands: Propagation attenuation and 0.6 m antenna gain difference	20 log(28/23)	1.7 dB	1.7 dB	The two terms compensate each other

TABLE 103 (*cont.*)

Parameter	**Range of values**	**Value assumed for FS Deployment Case 1 analysis**	**Value assumed for FS Deployment Case 2 analysis**	**Remarks**
***FS receiver parameters (informative values only, not relevant for the graphs generation)* (*cont.*)**				
23 GHz/28 GHz rain attenuation (Rec. ITU-R P.838 28 mm/h rain-rate)	23 GHz: Vpol 23 GHz: Hpol 28 GHz: Vpol 28 GHz: Hpol	3.09 dB/km 3.76 dB/km 4.22 dB/km 5.1 dB/km	3.09 dB/km 3.76 dB/km 4.22 dB/km 5.1 dB/km	Due to more favourable attenuation V polarization is most commonly used for FS links, unless for coordination with other links. Studies will be carried at 23 GHz Vpol
Scenario parameters not linearly scalable				
FS antenna pattern		Rec. ITU-R F.1245	Rec. ITU-R F.1245	cf. Figs. 197 and 198
FS maximum antenna gain	35-50 dBi	41 dBi	41 dBi	For typical 0.6 m antenna
SRR antenna elevation pattern	Table 13			Due to the low elevation of interfering path, SRR antenna pattern has no influence on the FS interference study results
FS receiver height h_{RX}	10 m->30 m	10 m 18 m, 25 m	18 m, 25 m, 30 m	18 m was suggested as typical for the FS Deployment Case 1, while 10 m was recognized as particular but not infrequent case for the study
Horizontal offset between FS receiver and edge of closest lane: (see Fig. 198)	≥ 10 m	10 m, 30 m	20 m, 40 m, 60 m	Majority of cases would be < 20 m; 10 m or even less were recognized as particular but not infrequent case in some populated areas. In some countries higher distance is recommended
Relative angle between bore sight axis of FS antenna and the road	0°-360°	0°	0°	When the typical use of P-P is for mobile infrastructures, the near parallel alignment between FS link and highway is considered the most usual situation
Length of straight road populated by an average car density, parallel to FS-link		3 000 m	3 000 m	

TABLE 103 (*cont.*)

Parameter	Range of values	Value assumed for FS Deployment Case 1 analysis	Value assumed for FS Deployment Case 2 analysis	Remarks
***Scenario parameters not linearly scalable* (*cont.*)**				
Number of road lanes	1 to 4	1 and 4	1 and 4	
Average separation distance of vehicles	<1 m to 150 m	20 m, 50 m, 100 m, 150 m	20 m, 50 m, 100 m	~ 20 m is expected to be worst case(1)
Average vehicle length	4 m to 20 m	5 m	5 m	Only cars are taken into account for the average vehicle profile (see § 1.5.6.5)
Average vehicle height	1.3 m to 4.5 m	1.5 m	1.5 m	Only cars are taken into account for the average vehicle profile (see § 1.5.6.5)
Number of SRR devices/car	0 to 10	4 average (2 pointing forward, 2 backwards)	4 average (2 pointing forward, 2 backwards)	As a long term SRR deployment, 100% of cars are assumed to be equipped with this average number of devices. Forward or backward pointing devices are negligible in PP scenario calculation model (being on more distant lanes of the opposite direction)
SRR sensor position in the vehicle front	Everywhere along the car profile	At the 4 corners of the car profile	In the front and back sides, 20 cm from the vehicle corner	See § 1.5.6.1
Average sensor height	< 1.5 m	0.5 m	0.5 m	Typical height for cars (see § 1.5.6.3)
Shielding effect		Model as described in § 6.5.5	Model as described in § 6.5.5	see § 1.5.5.5
Specific rain attenuation on interference path	0.6 dB/km to >3 dB/km	0.6 dB/km and 3 dB/km	2 dB/km and 3 dB/km	
Scenario parameters linearly scalable				
FS noise figure	4 to 12 dB	6 dB	6 dB	
Minimum feeder/multiplexer loss	0 to 4 dB	0	0	Normal case for actual outdoor applications

TABLE 103 (*end*)

Parameter	Range of values	Value assumed for FS Deployment Case 1 analysis	Value assumed for FS Deployment Case 2 analysis	Remarks
Scenario parameters linearly scalable (end)				
Vehicles equipped with SRR	0 to 100%	100%	100%	Expected long term SRR deployment
SRR e.i.r.p. density (r.m.s.)	–41.3 dBm/ 1 MHz	–41.3 dBm/ 1 MHz	–41.3 dBm/ 1 MHz	
SRR bumper damping	3 dB-6 dB	3 dB	3 dB	See § 1.5.5.2

(1) For higher car densities (less separation) the shielding due to ahead driving vehicles becomes more effective resulting in less interference power.

TABLE 104

Other unpredictable parameters not considered in all the graphs to be linearly subtracted from resulting aggregate

Parameter	Range of values	Value assumed for FS Deployment Case 1 analysis	Value assumed for FS Deployment Case 2 analysis	Comments
Clutter losses	0 dB-15 dB	0 dB	7 dB	The lower the receiver, the higher, are the clutter losses, whenever present; clutter loss adds linearly to calculated result
Spray attenuation	0 dB->5 dB	0 dB	2 dB	Probably most important for small car separation; spray attenuation adds linearly to calculated result
Polarization loss	0-3 dB	0 dB	3 dB	Polarization loss adds linearly to calculated result.
Reflection/diffraction	Up to few dB	0 dB	0 dB	See § 1.5.6.7 and Appendix 2
24 GHz SRR activity factor	0 dB up to 7 dB or more	0 dB	7 dB	See Rec. ITU-R SM.1757
Sum of the above mitigation	–	0 dB	12 dB	To be added linearly to the graphs

Table 103 provides the summary of relevant parameters and values for calculating the aggregated interference into a FS-receiver due to a large number of SRR devices aligned along a single road parallel to the link direction.

Several evaluations with a mixture of the parameters presented in Table 103 have been produced; however, only the most relevant for the two study cases are here reproduced.

Note that all following graphs include 3 dB bumpers loss mitigation.

1.5.8.2.1 FS Deployment Case 1 analysis.

The results of Figs. 211 to 218, summarized in Table 105, show the various cases for the single lane (scenario 1) and 4 lanes (scenario 2) considered in the study. These figures show that using an e.i.r.p. density = –41.3 dBm/MHz, and comparing the aggregate interference with the protection requirement of the interference would exceed the FS protection criteria (I/N = –20 dB), by up to 20 dB depending on the combination of the values for parameters within the scenario.

Being all possible additional mitigation factors, described in Table 104, of unpredictable and uncertain in nature, no further aggregate interference reduction, due to these additional mitigation factors, is felt appropriate so that the risk of potential interference is maintained low in any circumstances.

In addition, Figs. 215 to 218 provide a comparison of the effect of variation of each independent input parameter. With this respect, it is interesting to note on Fig. 218 that the interference for scenario 1 (1 lane) and scenario 2 (4 lanes) are almost similar which means that due to shielding effect, the interference is mainly due to the vehicles on the near-side lane.

TABLE 105

Resulting interference power and objectives comparison for different parameter combinations in the FS Deployment Case 1

No. of lanes	Aggregate interference range (dBm/MHz)	Additional mitigations (dB) (Table 104)	Aggregate interference objective (Table 88) (dBm/MHz)	Difference (dB) (–) objective exceeded (+) margin to the objective	Notes
1	–108.5 to –128	0	–128	–19.5 to 0	(1)
4	–108 to –128	0	–128	–20 to 0	(2)

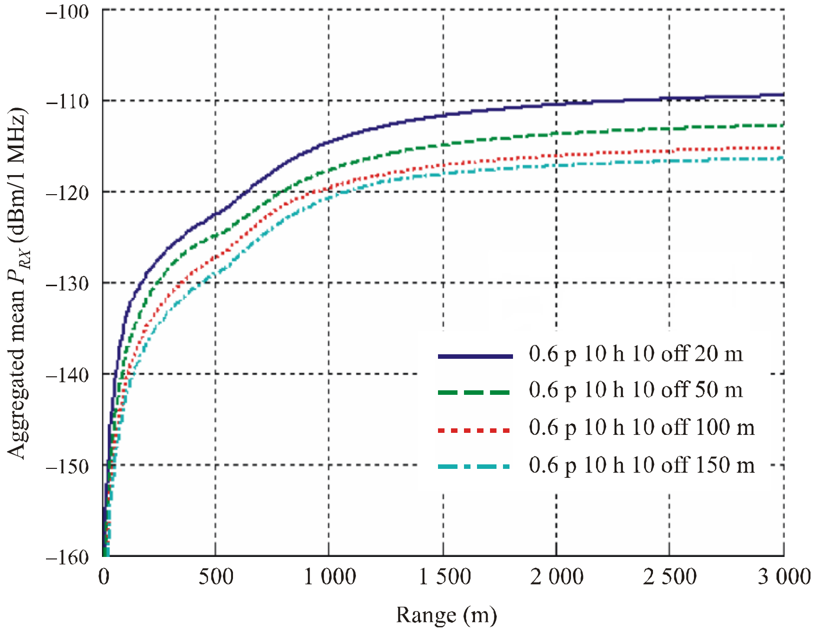
(1) The differences between 1 and 4 lanes is negligible due to the shielding model adopted.

(2) The most adverse situations imply the combination of the most demanding situations e.g.:
- 10 m antenna height
- 10 m antenna offset
- 0.6 dB/km rain on interfering path
- ~ 20 m cars distance.

The most favourable conditions imply a combination of less demanding situation e.g.:
- 25 m antenna height
- 30 m antenna offset
- 3 dB/km rain on interfering path
- 50 m cars distance.

FIGURE 211

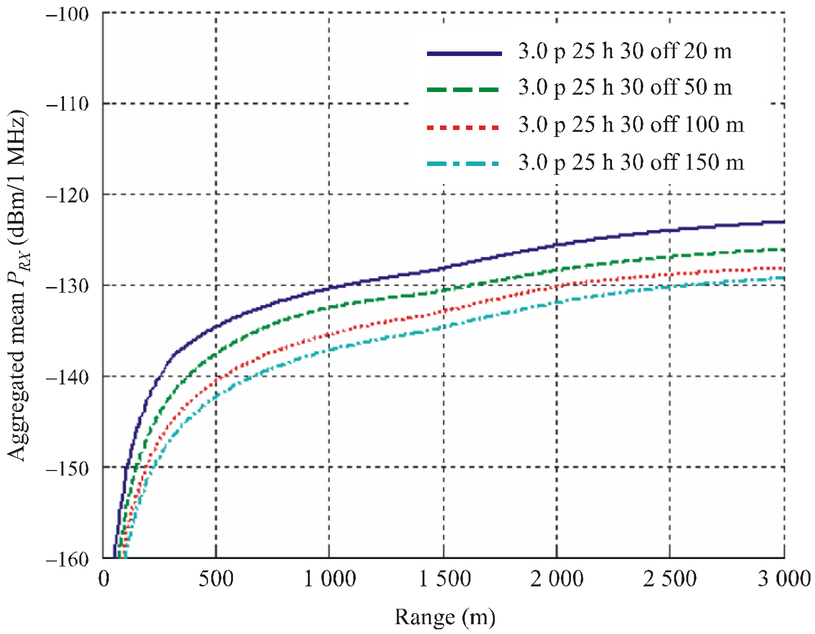
1 lane scenario (0.6 p-10 h-10 off)



Rap 2057-211

FIGURE 212

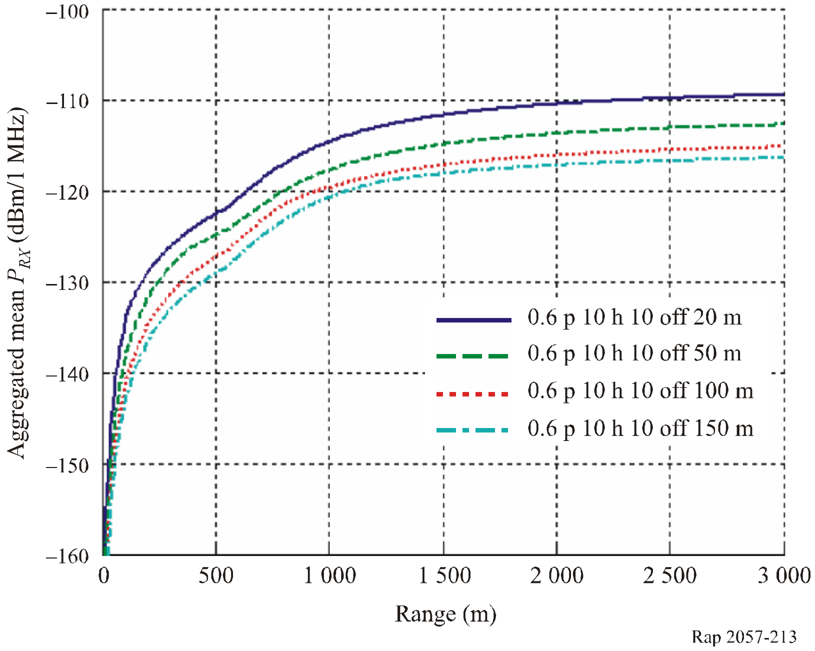
1 lane scenario (3 p-25 h-30 off)



Rap 2057-212

FIGURE 213

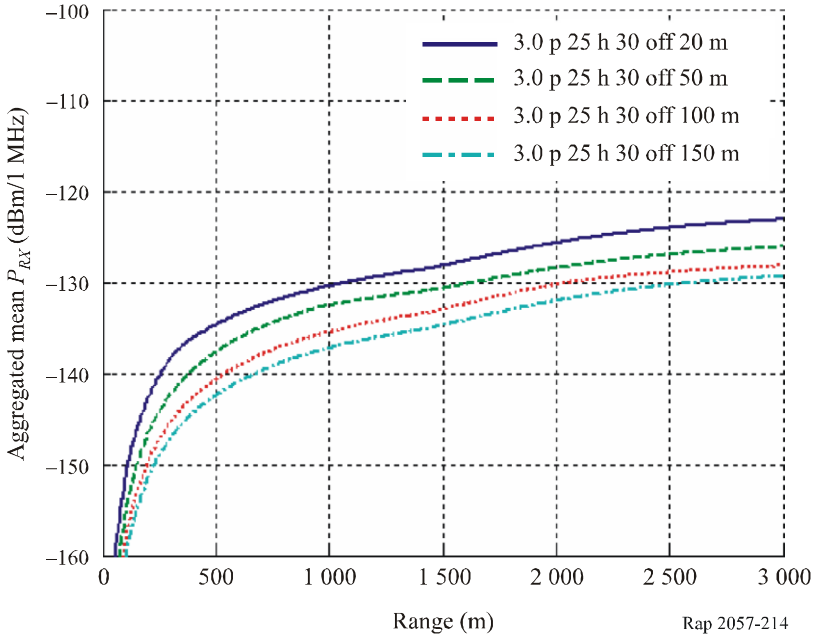
4 lanes scenario (0.6 p-10 h-10 off)



Rap 2057-213

FIGURE 214

4 lanes scenario (3 p-25 h-30 off)



Rap 2057-214

FIGURE 215

1 lane scenario (rain comparison)

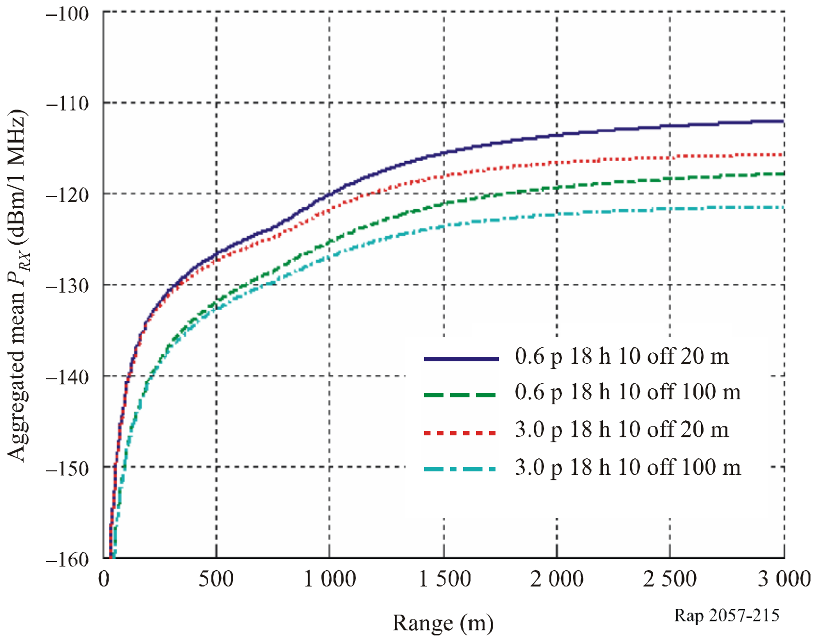


FIGURE 216

4 lanes scenario (offset comparison)

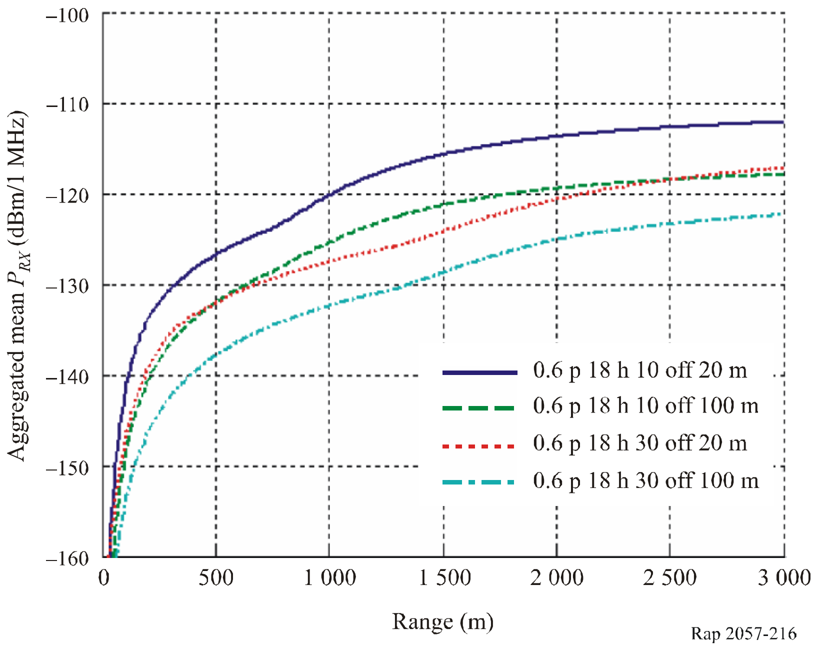


FIGURE 217

1 lane scenario (FS antenna height comparison)

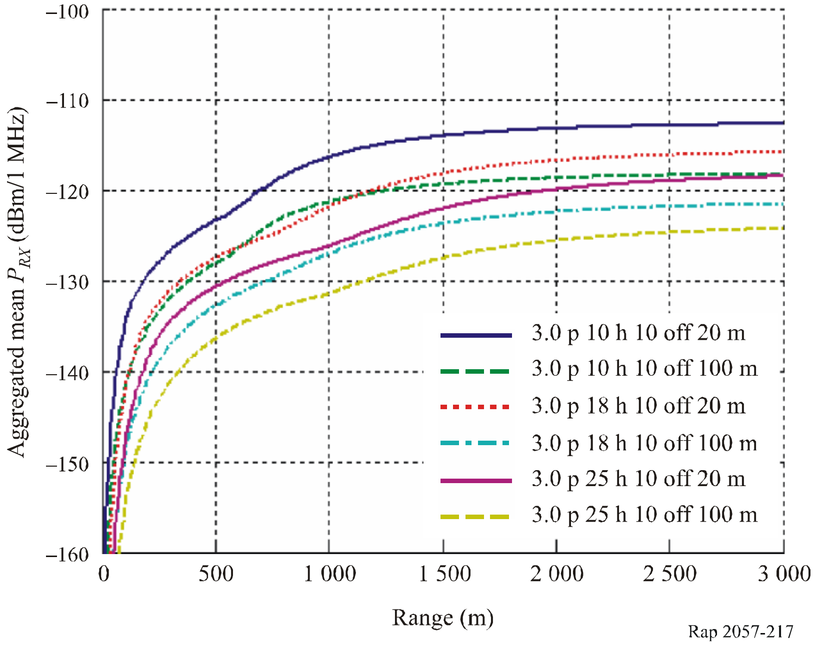
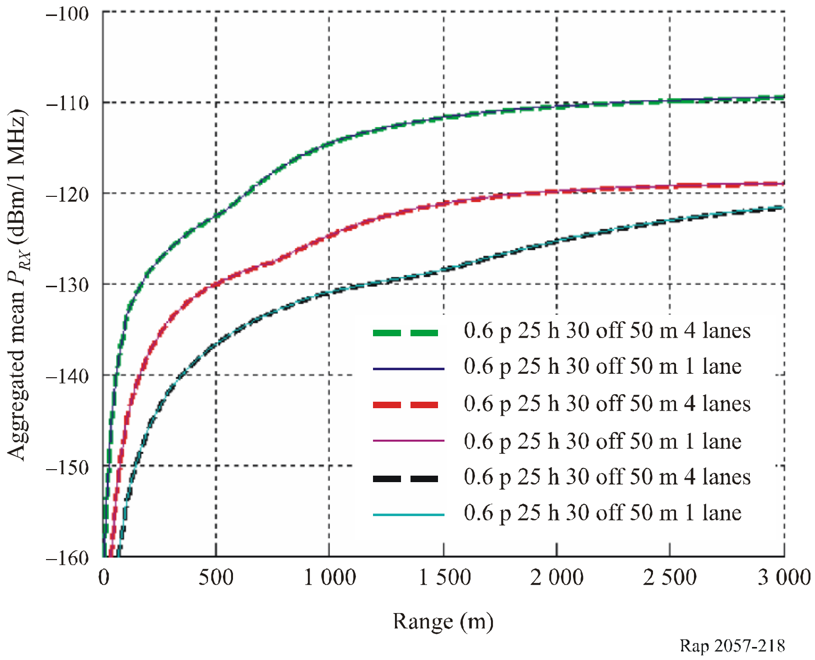


FIGURE 218

1 lane and 4 lanes scenarios comparison



NOTE 1 – In Fig. 218, graphs of 1 lane and 4 lanes overlap.

1.5.8.2.2 FS Deployment Case 2 analyses

The results of Figs. 219 to 225, summarized in Table 106, show the various cases of aggregate interference for the single lane (scenario 1) and 4 lanes (scenario 2) considered in the study. Note that, in some Figures, for better showing the variance of aggregate interference with some parameters, ranges of values wider than that considered appropriate for the study case 2 (see Table 103) have been used.

In addition, Fig. 225 compares the interference power for different alignment of the FS link with respect to the road. A tilt ranging from -10° to +10° towards the road results in a variation of interference power of ~18 dB. When the tilt is in opposite direction (away from the road) further reduction is obviously experienced.

Depending on the combination of the parameters and mitigation factors values within the scenario, these figures show that, using an e.i.r.p. density = –41.3 dBm/MHz, the FS protection criteria (I/N = –20 dB), derived for SRR from Recommendation ITU-R F.1094 with a 50% apportionment of the Z = 1% parameter (see § 1.5.3.1), could either be violated by ~ –6 dB or met with up to ~ 0 dB margin, depending on which set of parameters is selected.

Therefore, when adding the 19 dB, as average of the other unpredictable and uncertain mitigation factors (but anyhow, in most cases, present), as depicted in Table 104, the objective may be met with a positive margin.

In addition, it should be noted that the interference objectives for the 24 GHz short range radar systems is based on the I/N = –20 dB with an apportionment of 0.5%, leaving the remaining 50% of the Z = 1% parameter, as defined in Recommendation ITU-R F.1094, for other secondary services or unwanted emissions; considering the negligible joint probability of links interfered, up to the maximum permissible extent, by both SRR and any other secondary or unwanted emission, additional 3 dB more margin could be taken into account by attributing an apportionment of 1% completely to the 24 GHz short range radar systems[51] before a FS link is unfavourably affected.

[51] The apportionment value is implicitly included in the I/N objective, i.e. the I/N objective for all secondary services and other unwanted emissions with an apportionment of Z = 1% results in I/N = –17 dB. Radiocommunication WP 9A made in its liaison statement to Radiocommunication TG 1/8 a further breakdown of this 1% apportionment and attributed 50% to SRR (i.e. an apportionment of 50% of the 1% apportionment), resulting in an I/N for SRR only that is I/N (for 1%) = –17 dB minus 3 dB (for the additional 50% apportionment) resulting (for the assumed 0.5%) in I/N = –20 dB.

TABLE 106

Resulting interference power and objectives comparison for different parameter combinations in the FS Deployment Case 2

No. of lanes	Aggregate interference range (dBm/MHz)	Additional mitigations (dB) (Table 104)	Aggregate interference objective (Table 88) (dBm/MHz)	Difference (dB) (–) objective exceeded (+) margin to the objective	Notes
1	N.A.	19	–128	Not applicable	(1)
4	–122 to –134	19	–128	+13 to +25	(2) (3)

(1) The differences between 1 and 4 lanes is negligible due to the shielding model adopted.

(2) The situations with less margin imply the combination of the most demanding situations e.g.:
- 18 m antenna height
- 20 m antenna offset
- 2 dB/km rain on interfering path
- ~ 20 m cars distance.

The conditions with more margin imply a combination of less demanding situation e.g.:
- 30 m antenna height
- 60 m antenna offset
- 3 dB/km rain on interfering path
- 50 m cars distance.

(3) Another 3 dB of positive margin may be added if the full 1% allowance given by Recommendation ITU-R F.1094 is given to SRR interference only; this might be justified by the unlikeness of other source of unwanted emissions and radiations interference in these bands.

FIGURE 219

Aggregated interference power as function of range for scenario 2 and different receiver heights

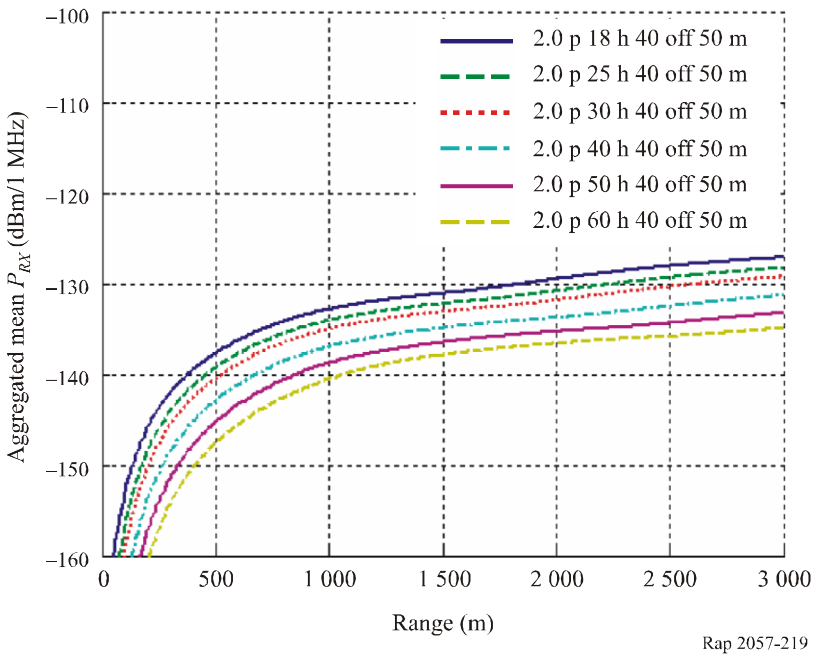


FIGURE 220

Scenario 2: Variation of horizontal offset

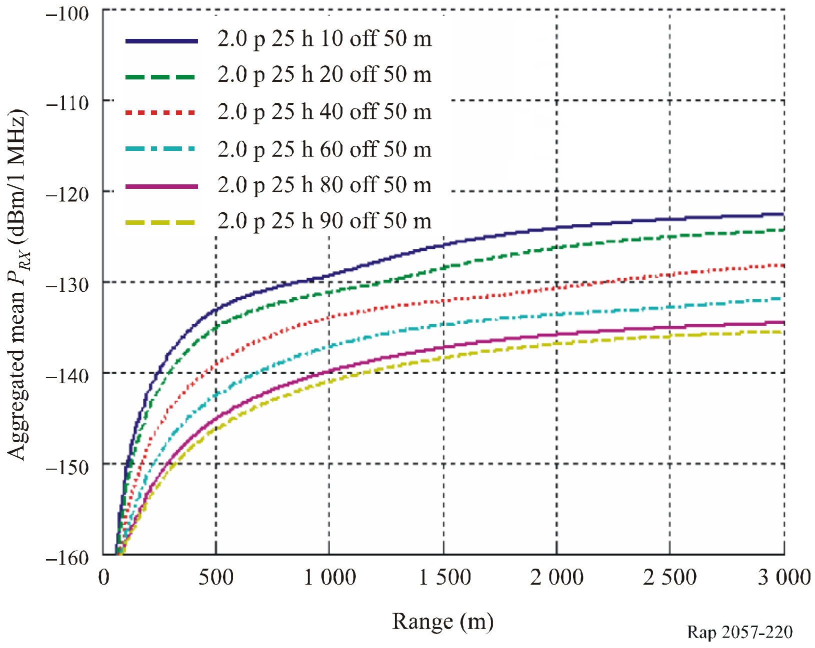


FIGURE 221

Scenario 2: Variation of car separation

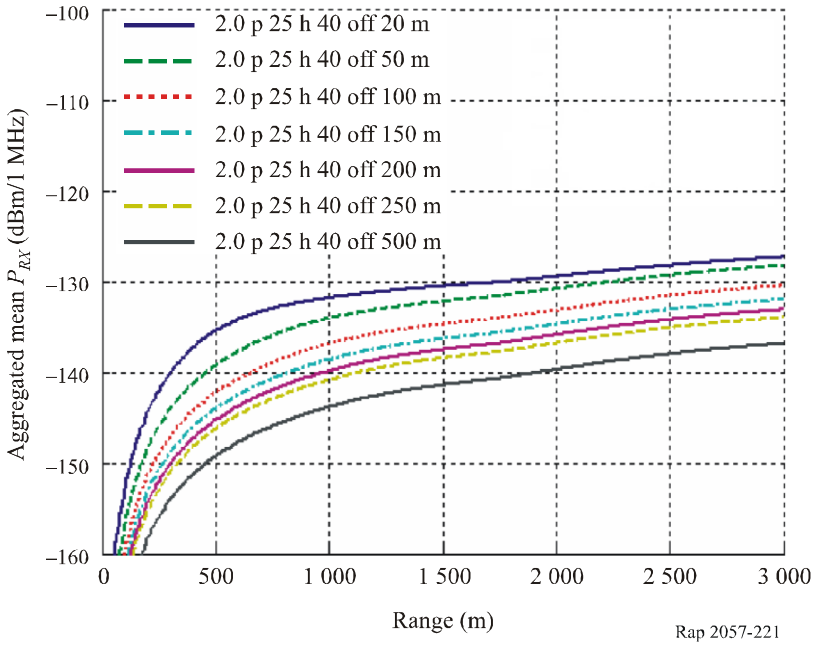


FIGURE 222

Scenario 2: Variation of rain attenuation along interference path

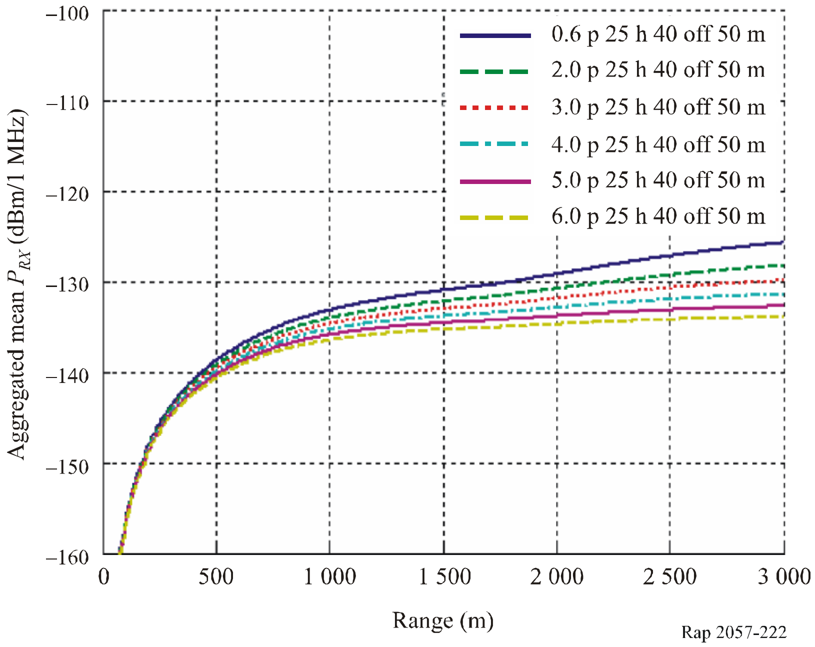
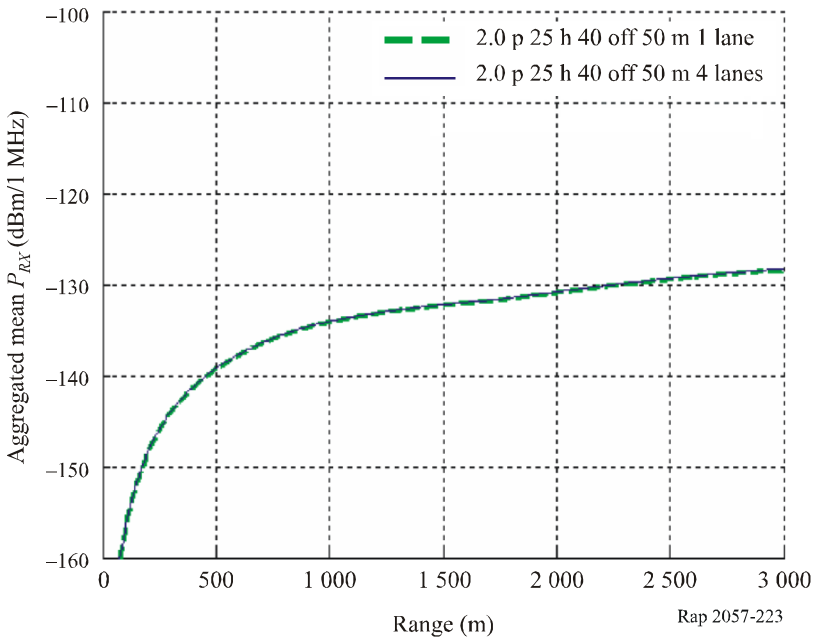


FIGURE 223

Comparison scenario 1 (1 lane) and scenario 2 (4 lanes)



NOTE 1 – In Fig. 223, graphs of 1 lane and 4 lanes overlap.

FIGURE 224

Scenario 2: Comparison of different parameter sets (extreme values only)

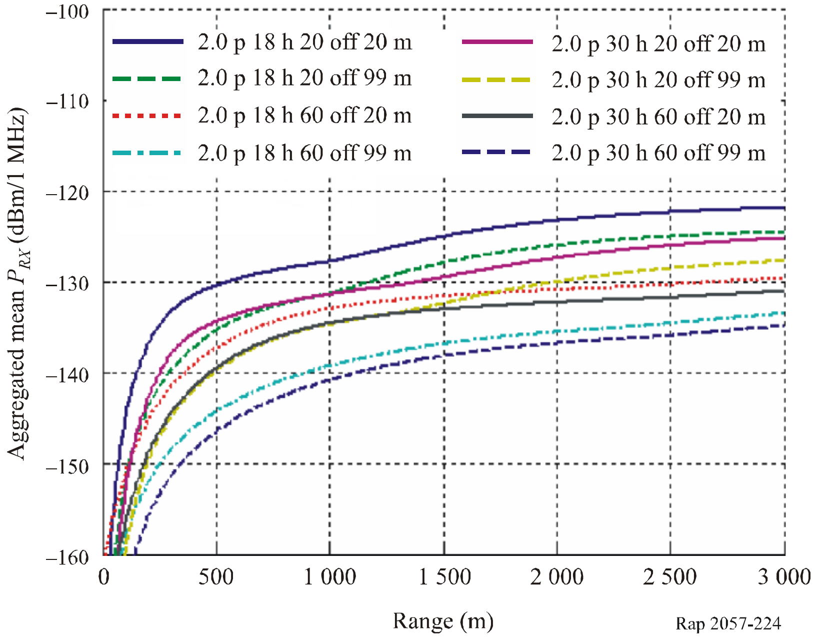
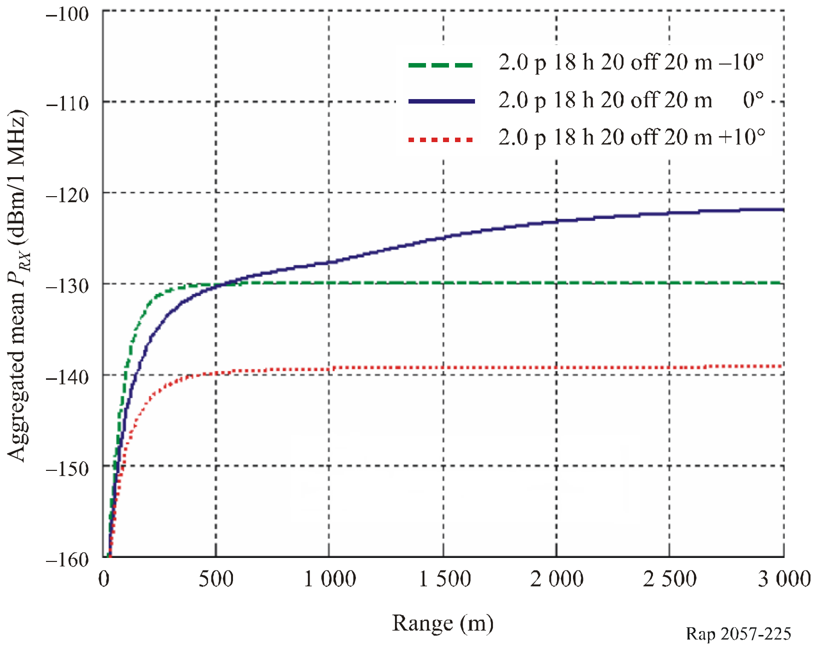


FIGURE 225

Scenario 2: Comparison of different alignment angles of FS-link with respect to road



1.5.8.3 FWA CS Central square scenario – Aggregate interference

It has already been shown in above sections that the worst aggregate interference does not arise when there is very high density of cars (e.g. during traffic jamming); this because of the shielding from preceding cars that is more effective. Worst case of aggregate interference comes from medium density traffic when many cars are still on the road but their spacing is in the order of few tens of metres and each one tend to be in LoS with the victim antenna.

For the same reason, the original scenario of “urban central square” (Fig. 205) has been extended for considering also a “suburban roundabout” where lesser density of cars might be balanced by a farther potential length of the lanes in visibility.

For this evaluation we have supposed lanes with cars spacing increasing with the distance from the roundabout of an amount sufficient for rendering the shielding of preceding car ineffective. Besides simplifying the simulation, this also represents the physical situation of the speed lowering as close cars came to the roundabout.

Figs. 226 and 227 show the principle and the values for the car spacing used in the simulation (using straight lanes only), while Fig. 228 shows the interference aggregation of a single lane.

It is also worth noting that results are valid also when roads do not enter straight into the roundabout; they might bend around, however, any car will still show the FS station two radar devices, whichever is its orientation. The sensible distance between cars also prevents, in average, lateral shielding. In addition, would the lanes bend, the cars remain closer than in the straight case examined and more cars are possible within the same radius.

FIGURE 226

Distance between cars (principle)

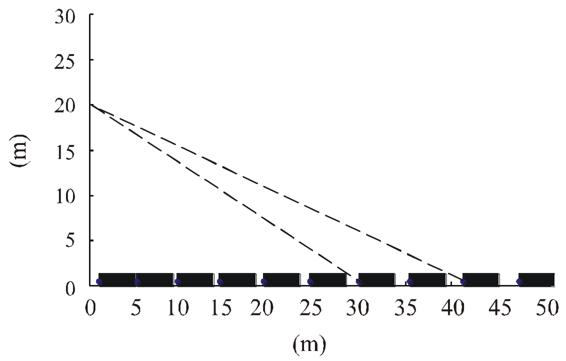


FIGURE 227

Distance between cars (value)

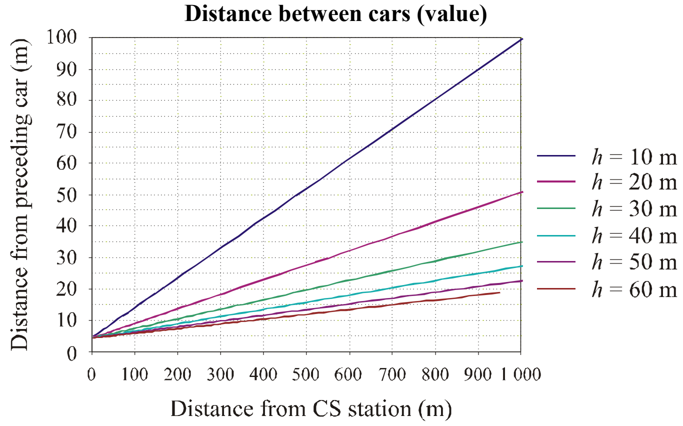


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FIGURE 228

Single lane aggregate interference (FWA CS victim)

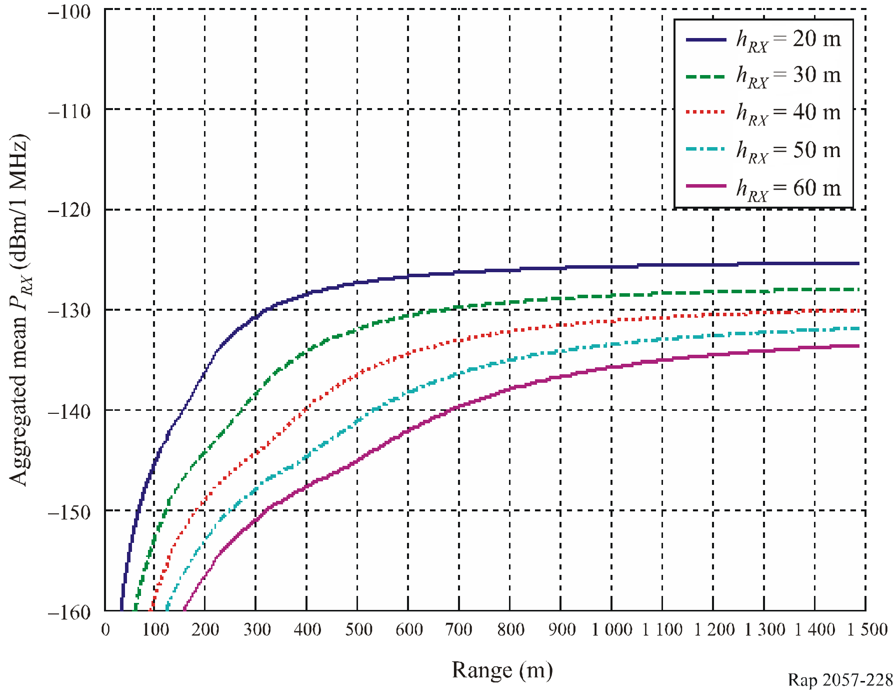


Figure 228 shows the aggregation of "single lane" only; the scenario assumes a number of three convergent roads each with three lanes per direction. In this situation of medium traffic situation, the density of cars in both directions might be nearly the same; therefore, an upper bound of lanes, affecting the integration, is 3 × 3 × 2 = 18 lanes.

The upper bound of the aggregation is then 10 log 18 = 12.5 dB higher than data in Fig. 228:

Upper-bound aggregate level (dBm) = Fig. 228 data + 12.5

Provided that SRR sensors are expected to be distributed around the car and they have no particular azimuth directivity, in both cases, neither the angle between the directions of FS link and of the road nor the FS antenna "offsets" from the road have any impact on the results. The only FS parameter counting is the antenna height and the potential queue length.

However, Fig. 228 does not take into account mitigations like rain correlation (due to the relatively shorter interfering path), clutter losses and sprays.

Similarly to the discussion made for the P-P link along a major road in previous paragraphs, the relevant parameters (namely antenna height, queue length and additional mitigations) might be argued for their worst cases.

With the same arguments for choosing them, it might be seen that similar conclusions might be derived:

– using the same approach as for the deployment case 1 (for the P-P case) it might be assumed that with SRR e.i.r.p. density of –41.3 dBm/MHz the objectives could be exceeded by up to ~13 dB (for the 18 lanes scenario).

– with the same approach as for the deployment case 2 (for the P-P case), excluding the lower antenna case and queue lengths less than few hundreds meters and using the same 19 dB of additional mitigation shown in Table 104, the objectives could be met with some margin.

Appearing even slightly favourable than the P-P case previously studied, this scenario is not considered in more detail for drawing final conclusions.

1.5.9 Test results

A summary of a test campaign to determine the effect of SRR 24 GHz on the error performance objectives BER of FS receiver is given in Annex 7 of this Report.

These results have mainly allowed determining that the peak interference power from the SRR devices within a 50 MHz bandwidth should also be limited. A value of the peak power limit (e.i.r.p.) within 50 MHz bandwidth of no more than 42 dB higher than the mean interference limit within 1 MHz bandwidth can be derived from the measurement results.

Therefore, for a –41.3 dBm/MHz e.i.r.p. mean density limit, the peak power density limit, according to the protection objectives, should be:

$$I_{Peak} \leq 0 \text{ dBm/50 MHz}$$

In case different mean e.i.r.p. density limits might be recommended, the peak e.i.r.p. density should be modified accordingly.

1.5.10 Conclusions

The above study, while evaluating a number of potentially impacting aggregation scenarios, has shown that the case in § 1.5.8.2 of FS P-P link parallel to a major road or highway is ~7 dB worse than the FS P-MP FWA link; therefore the final conclusions are based on the FS P-P link scenario.

The above studies have shown that the SRR emission limits, for not impacting on FS, strongly depend on external circumstances that are in any case of imprecise or even unpredictable nature.

Deployment Case 1 study

From the FS Deployment Case 1 study, which might be of interest for countries where the deployment of P-P links, with low FS receiver antenna height, is frequent along high traffic density roads, and extensive use of these bands for FS links in mobile network infrastructure may occur, an average SRR e.i.r.p. power emission limit of at least –50 dBm/MHz is necessary; however, where the joint concurrence probability of the more severe deployment situations (i.e., lower FS antenna heights closer to a road) is considered, an e.i.r.p. density limit of –60 dBm/MHz is necessary for long term interference avoidance.

Deployment Case 2 study

The FS Deployment Case 2 study, which might be of interest for countries where less stringent infrastructural requirements regarding the FS receiver height and distance to the road might prevail, the SRR e.i.r.p. power emission limit of –41.3 dBm/MHz may be considered appropriate when other mitigation factors (unpredictable but anyhow, in most cases, present), depicted in Table 104, are taken into account. This will, however, increase the risk of interference from SRR to the FS in case those more unfavourable circumstances might occur.

Further considerations

It should also be noted that, besides sharing requirements with co-primary services, there are no internationally adopted limitations for the deployment and use of FS systems in their primary allocated bands; risky deployment situations, even if presently considered not existing in some Administrations, might occur at a later stage, unless appropriate guidance will be given for future FS use and deployment. Therefore, the recommended limits would also depend on the degree of risk that Administrations wish to take on the probability of incurring interference in their assumed reasonable worst case and on possible measures taken for minimising that risk also in the future.

Finally, attention should be given to the "single car" contribution studied in § 1.5.8.1 showing that, with an unfavourable (which, nevertheless, could happen) placement of a car (e.g. when a small portion of busy road would cross, with any angle, the FS P-P link direction in full LoS of its antenna), the given interference is very close or, in case of lower antenna heights (≤ 20 m), is already exceeding the objective, giving small or no room for any aggregation.

Appendix 1
to Annex 2

Evaluation of mitigation factors K_B and K_{LoS}

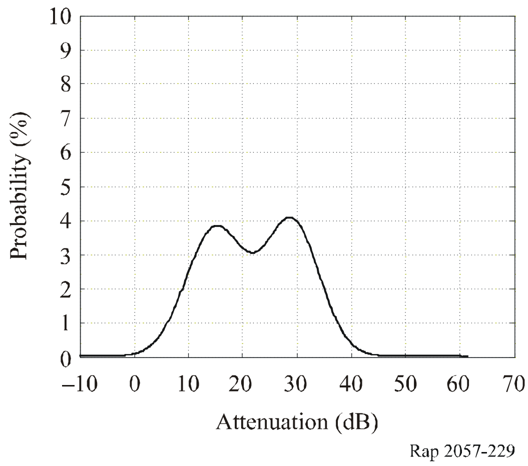
1 K_B factor

1.1 Evaluation

For the Milan study in a previous contribution we have derived a typical indoor to outdoor attenuation distribution probability from convolution of penetration losses probability described in Recommendation ITU-R P.1411 and the indoor path losses using the two slope Siwiak model adopted for UWB indoor propagation. The resulting probability density is summarized in Fig. 229.

FIGURE 229

Probability density of the joint attenuation functions



The above graph shows the probability in term of attenuation in decibels; for defining an average attenuation to be applied to the whole UWB population with the scope of further aggregating their power, we should:

– transform the attenuation probability into a power ratio probability;
– evaluate the mean value of that power ratio.

The statistical variable $Atten_{(dB)}$ in Fig. 229 is described by the formula:

$$A_{dB} = -10 \cdot \log_{10}(a)$$

where (a) is the power ratio.

The mean value of (a) is then derived as: $\bar{a}$ = 0.034207 = 14.66 dB

1.1.2 K_B conclusions

Even if not far from the above result, the present assumption K_B = 10 dB seems a bit underestimated if considered over a large distribution of different building typology. Considering also that many cases will experience also floors trespassing (not specifically addressed in this analysis), we could still conservative say that: K_B = 13 dB

For single building entry (i.e. for scenario 3a) K_B = 10 dB would be conservatively maintained.

2 K_{LoS} factor

2.1 Evaluation

In § 1.3.3.3.2.2, over Milan building of height distribution, a Monte-Carlo analysis of a LoS/NLoS probability distribution has been made as function of building distance and floor number in both urban and suburban areas. The Milan scenario in Fig. 152 presents also the floors number distribution derived from the building height distribution.

Using the above data it is possible to statistically define a "mean value" of the LoS probability as function only of the distance from victim FS station as follows.

– Available data are limited to 20 floors. Considering that from the building height statistic the occurrence of buildings higher than 20 floors is 0.073% in urban and 0.038% in suburban, respectively, we could disregard their possible contribution to this analysis.

– A mean $P_{LoS}(D)$ can be defined from LoS probability data and floors number probability with the following formula:

$$< P_{LoS}(D) > = \sum_{i=1}^{20} prob\_floor(i) \cdot prob_{LoS}(i, D)$$

– The $< P_{NLoS}(D) > = 1 - < P_{NLoS}(D) >$ is evaluated as shown in Fig. 230.

The "generic scenario" integration is made, weighting the power contribution of each UWB entry for its probability of average NLoS probability (e.g. when NLoS probability is 0.9 the power contribution is reduced of 90%). Results for P-P aggregation in urban and suburban areas with victim FS antenna height of 45 and 60 m are shown in Fig. 230.

FIGURE 230

NLoS probability vs.distance

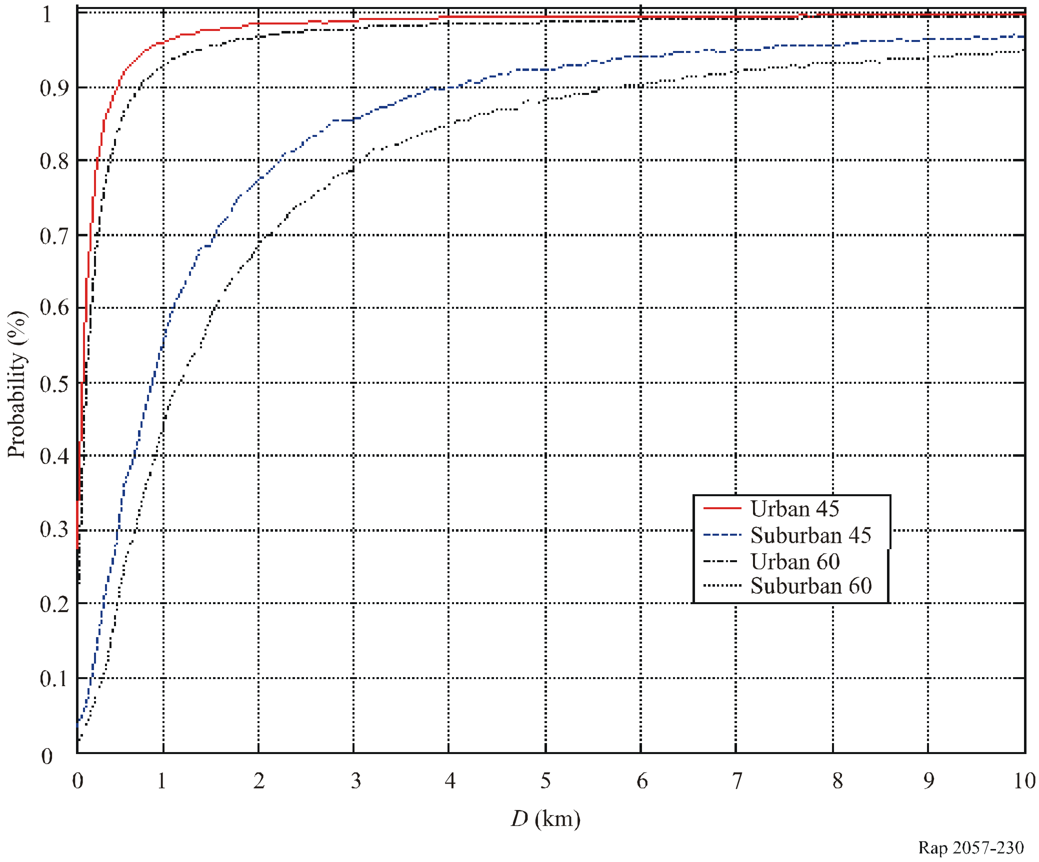
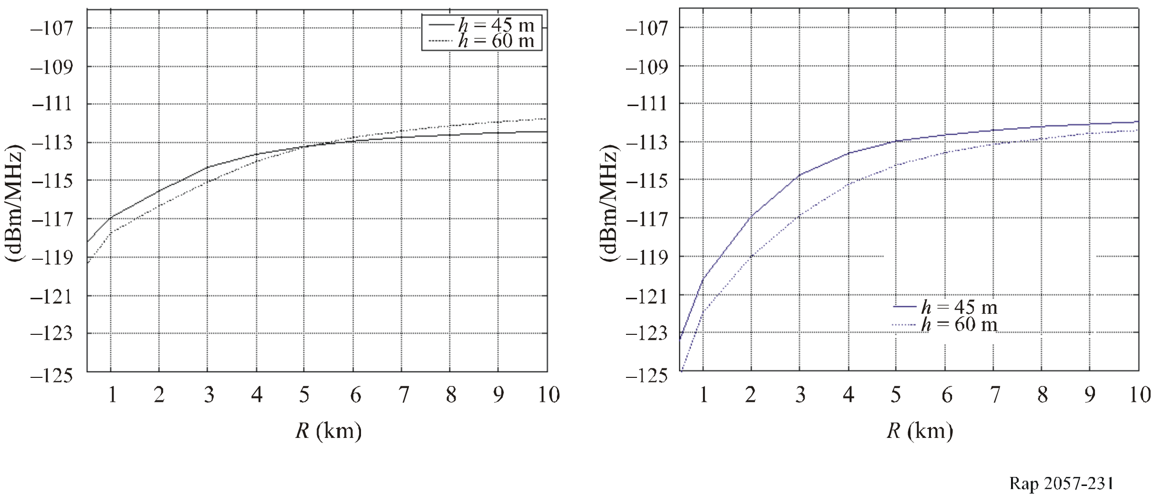


FIGURE 231

P-P urban and suburban scenario aggregation (with LoS/NLoS evaluation)



P-P urban (10,000 UWB/km²) P-P suburban (1,000 UWB/km²)

Comparing the results of h = 60 m with the equivalent results presented for 100% LoS situation in Fig. 163 § 1.3.3.1, the only difference could be related to the addition here of a K_{LoS} factor. However a number of considerations should be made:

– The difference over a 10 km radius area is:

112 – 81 = 31 dB (urban area)

112 – 91 = 21 dB (suburban area)

– As logically expected, the potential reduction eliminating the NLoS cases is not constant but higher in urban rather than suburban areas.

– The difference could not be directly assumed as K_{LoS} value because:
  – The value is quite large and the assumption made for "generic evaluation" that NLoS devices contribution could be disregarded is no longer valid.
  – The evaluation is made on a very specific case and the variations, in particular for suburban cases, might be large.

– Nevertheless, the difference from the 5 dB presently assumed seems too large for it being justified.

2.1.1 K_{LoS} conclusions

From the above results, it looks clear that the major contribution would come from the large majority of NLoS devices.

For a tentative conservative conclusion we would start form the asymptotic contribution of LoS devices (Fig. 231); assuming that the large majority (~ 99.8% in urban and 95% in suburban) of NLoS UWB devices would in this case contribute with 17 dB higher aggregation (e.g. + 27 dB for higher NLoS UWB number but –10 dB lower for their NLoS propagation) for urban and 7 dB (e.g. + 13 dB for higher NLoS UWB number and –6 dB lower for their moderate NLoS propagation) than that here evaluated for LoS devices only. With this assumption the K_{LoS} factor may be assumed as:

$$K_{loS} = 31 - 27 + 10 = 14 \text{ dB} \quad \text{(urban area)}$$

$$K_{LoS} = 21 - 13 + 6 = 14 \text{ dB} \quad \text{(suburban area)}$$

Appendix 2
to Annex 2

One practical test for evaluating reflection impact

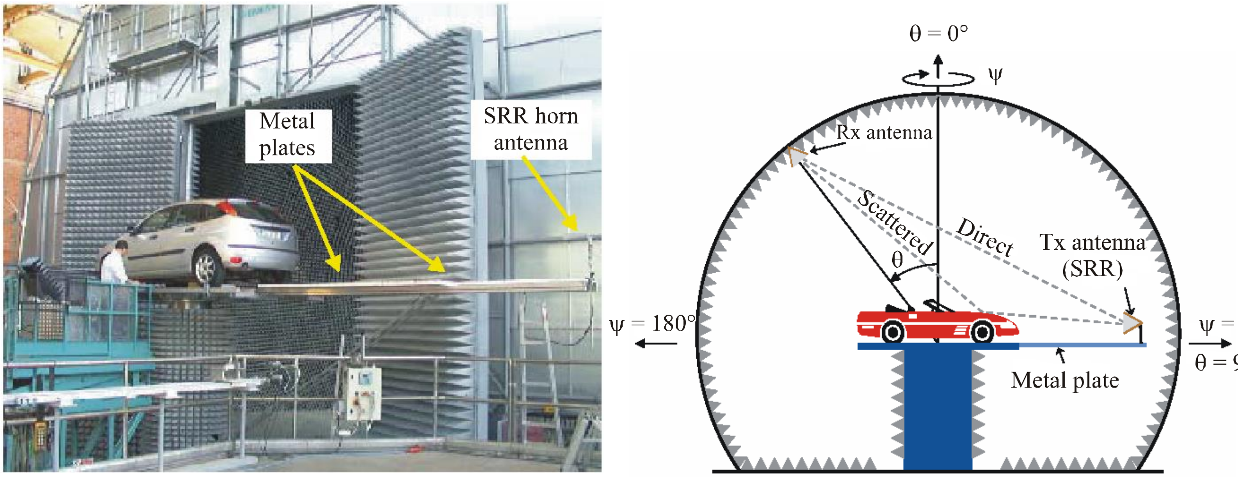
The reflection/diffraction caused by surrounding vehicles has the potential to increase (or under some other circumstances also decrease) the interference from SRR to the FS stations.

As an example, the backward SRR devices emissions may reflect on the front of the following vehicle and be redirected towards the victim antenna and hence add to the aggregate interference caused by direct LoS path emissions.

The expected reflection coefficient for a passenger car was determined in a test campaign made at the Joint Research Centre in Ispra, Italy in 2002 (see Fig. 232 and accompanying photograph of the test set up).

FIGURE 232

Coupling parameter measurements for a passenger car, conducted at the Joint Research Centre ISPRA, Italy



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The measured mean polarimetric coupling coefficient for frontside and rearward illumination is listed in Table 107:

TABLE 107

Mean coupling coefficient for H- and V-polarization of a passenger car

Mean coupling coefficient	H-polarization (dB)	V-polarization (dB)
Front illumination	–22.9	–22.9
Rear illumination	–28.6	–24.2

With the coupling coefficient given in Table 107 the effects of reflection and diffraction of surrounding vehicles can be calculated. Important is the additional interference power increase with respect to the existing LoS emission power.

Because the reflected power is attenuated by the mean coupling coefficient compared to the emitted power in the LoS direction, this power is 22.9 dB lower than the power directly emitted in the LoS direction.

The absolute increase of the interference power in dB can be calculated with the following formula:

$$\Delta I = 10 \log_{10}\left(1 + 10^{\frac{C_{ref}}{10}}\right)$$

where:

ΔI: absolute increase of the interference power (dB)

C_{ref}: mean coupling coefficient (dB).

For a one-time reflection scattered back in the same direction as the direct LoS interference power an absolute increase of the LoS interference power of 0.022 dB results for a C_{ref} of –22.9 dB.

Multipath reflections that are scattered many times between two cars before they leave in the LoS direction will have an even lower mean coupling coefficient and can be disregarded.

Finally, a large number of all the reflections will leave in another direction than the direct LoS and do not contribute to any interference increase.

Annex 3

Studies related to the impact of devices using ultra-wideband technology on systems operating within the fixed-satellite service

1 FSS earth stations characteristics

Please refer to Annex 8 for the FSS system characteristics.

2 UWB interference into FSS uplinks

This section summarizes different studies dealing with the uplink case that have been submitted to Radiocommunication TG 1/8. All studies were based on the GSO satellite based simplified summation methodology to calculate the aggregate interference and used the FSS protection criterion (I/N = –20 dB) given in Recommendation ITU-R S.1432.

This methodology is based on the calculation of the interference by aggregating the emission of the UWB devices located in the satellite receive antenna beam. The nature of the interference coming from UWB devices is assumed to be noise-like.

A number of studies were performed using a UWB emission level of – 41.3 dBm/MHz, and have been conducted in the frequency range of 6 GHz and 28 GHz considering free space propagation.

Table 108 presents the summary of the studies based on this methodology for typical FSS uplinks. For each study, the maximum number of active UWB devices over an area in order to protect the satellite receiver is given.

TABLE 108

Summary of results of FSS uplink studies for various frequency bands based on the GSO satellite based simplified summation methodology

Study	Satellite assumptions	UWB assumptions	Maximum density of active UWB devices for I/N = –20 dB protection criterion
Study 1: 8/14/30 GHz uplink	T = 500 K Global beam Ant. gain G_{SAT} ≈ 10 log ($4\pi r^2/s$)	100% outdoor Uniformly distributed Free-space loss	8 active UWB/km^2 @ 8 GHz 2 551 active UWB/km^2 @ 14 GHz 11 715 active UWB/km^2 @ 30 GHz
Study 2: 6 GHz uplink	T = 500 K Zone, spot beam Antenna beamwidth = 2º to 12º Satellite ant. gain = 25.6 to 41.2 dBi	50% indoor Uniformly distributed over the beam Free-space loss Roof loss: 8.5 dB	10 active UWB/km^2 (equivalent to 12 329 000 active UWB devices at 2º to 534 164 000 active devices at 12º)
Study 3: 6 GHz uplink	T = 1 000 K Elliptical (Europe) zone beam Rec. ITU-R S.672 Ant. gain towards horizon = 14.5 dBi to –10 dBi at elevations = 5° to ≥ 48° respectively	50% indoor Uniformly distributed No Clutter Free-space loss 10 dB building loss	25 active UWB/km^2 for UWB devices in 70% of area 40 active UWB/km^2 for UWB devices in 40% of area 33 active UWB/km^2 for UWB devices in 10% of area
Study 4: 6 GHz uplink	Zone Beam (Europe) T = 100 K Ant. gain towards horizon = 14.5 dBi to –10 dBi at elevations = 5 to ≥ 48 respectively	95% outdoor Randomly distributed Free-space loss 10 dB building loss	20 active UWB/km^2 (equivalent to 34 000 000 UWB over the beam)
Study 5: 6 GHz uplink	T = 675 K Zone beam (N America) Satellite ant. gain (G_{SAT}) = 34 dBi Clear air loss = 0.1 dB	100% outdoor Uniformly distributed Free-space loss	100 300 000 UWB devices over the beam (equivalent to approx 7 devices/km^2 over 15 m/km^2)
Study 6: 6 GHz uplink	T = 700 K Zone beam, coverage radius 3 000 km Satellite ant. gain (G_{SAT}) = 25 dBi Rec. ITU-R S.672 with L_s = –20 dB	Uniformly distributed Free-space loss plus range of 0-50 dB roof/clutter loss (0 dB corresponds to 100% outdoor)	400 000 000 UWB devices over the beam for 100% outdoor (equivalent to approx 14 devices/km^2 over 28 m/km^2)
Study 7: 28 GHz uplink	T = 728 K Zone beam (N America) Satellite ant. gain (G_{SAT}) = 46.4 dBi Clear air loss = 0.5 dB	100% outdoor Uniformly distributed Free-space loss	152 480 000 UWB devices over the beam (equivalent to approx 11 devices/km^2 over 15 m/km^2)

For the MSS feeder links of GSO FSS systems, the aggregate methodology is also used in addition to the GSO satellite based aggregate methodology. In these cases, a combination of 80% indoor and 20% outdoor distribution of UWB devices is assumed. Moreover the characteristics used are the MSS feeder links presented in Annex 8. In Table 109 a summary of results based on GSO satellite based simplified summation aggregate methodology is given. In comparison, in Table 110, a summary of results based on the airborne aggregate methodology is given.

TABLE 109

Summary of aggregate interference levels from multiple UWB emitters into GSO MSS System 1 and System 2 satellite receiver for different emitter densities in C band (based on GSO simplified summation aggregate methodology)

Parameters	System-1	System-2	Units
Beam/band (6.5 GHz or 1.6 GHz)	G-C Band	G-C Band	
Boltzmann's constant (k)	–198.6	–198.6	dBm/kHz
System noise temperature (*T*)	891	501	K
Bandwidth, *B*	32.7	150	MHz
Thermal noise, *N*	–93.96	–89.84	dBm
I/*N* (1% criterion)	–20	–20	dB
I_{max}	–113.96	–109.84	dBm
United States mask/slope mask			
Indoor/outdoor	0.80:0.20	0.80:0.20	
Average e.i.r.p. of the UWB device	–41.3	–41.3	dBm/MHz
Factor to take into account combination of *I*/*D* & *O*/*D* devices	–5.528	–5.528	dB
d (based on Appendix 8 Annex-II dis formula)	39 220	39 220	km
Frequency (*F*)	6.5	6.5	GHz
Absorption loss	0	0	dB
B	32.7	150	MHz
Gain of sat receive antenna (EoC)	16.5	17	dBi
Number of emitters (N) (millions)	1	1	
I AGG	–155.81	–148.70	dBm
Area	2.17E+08	2.17E+08	km^2
Emitter density (units/m^2)	4.61E-09	4.61E-09	units/m^2
I AGG with 0.00001 emitter/m^2	–122.45	–115.33	dBm
I AGG with 0.0001 emitter/m^2	–112.45	–105.33	dBm
I AGG with 0.001 emitter/m^2	–102.45	–95.33	dBm
I AGG with 0.01 emitter/m^2	–92.45	–85.33	dBm
I AGG with 0.1 emitter/m^2	–82.45	–75.33	dBm
I AGG with 1 emitter/m^2	–72.45	–65.33	dBm
Emitter density limit required to meet the criterion with 100% activity factor	0.000071	0.000035	units/m^2
Emitter density limit required to meet the criterion with 4% activity factor	0.00177	0.00088	units/m^2
Emitter density limit required to meet the criterion with 4% activity factor	1 766	885	units/m^2
Required UWB PSD emission limit in dBm/MHz to ensure compatability. Density of active UWB transmitters/km^2.			
1	–41.30	–41.3	dBm/MHz
10	–41.30	–41.3	dBm/MHz
100	–42.81	–45.8	dBm/MHz
1 000	–52.81	–55.8	dBm/MHz
10 000	–62.81	–65.8	dBm/MHz

TABLE 110

Summary of aggregate interference levels from multiple UWB emitters into GSO MSS System 1 and System 2 satellite receiver for different emitter densities in C band (based on airborne aggregate methodology)

Parameters	System-1	System-2	Units
Beam/Frequency band	GI-C Band	GI-C Band	
Boltzmann's constant (k)	–198.6	–198.6	dBm/kHz
System noise temperature (*T*)	891	501	K
Bandwidth	32.7	150	MHz
N	–93.96	–89.84	dBm
I/*N* (1% criterion)	–20	–20	dB
I_{max}	–113.96	–109.84	dBm
G_r – Gain of sat receive antenna			
Peak	20.5	22	dBi
Edge of coverage	16.5	17	dBi
Radius of the observed zone	5 878	5 878	km
Average e.i.r.p. of the transmitting device	–41.3	–41.3	dBm/MHz
Indoor/Outdoor	0.80:0.20	0.80:0.20	
UWB Emitter density emitters/m^2 (emitters/km^2) with 100% activity factor			
0.00001 [10]	–125.25	–118.13	dBm
0.0001 [100]	–115.25	–108.13	dBm
0.001 [1000]	–105.25	–98.13	dBm
0.01 [10,000]	–95.25	–88.13	dBm
0.1 [100,000]	–85.25	–78.13	dBm
1 [1,000,000]	–75.25	–68.13	dBm
Emitter density limit required to meet the criterion with 100% activity factor	0.000134	0.000067	emitters/m^2
Emitter density limit required to meet the criterion with 4% activity factor	0.003357	0.00169	emitters/m^2
Emitter density limit required to meet the criterion with 4% activity factor	3 357	1 686	emitters/m^2
Required UWB PSD emission limit in dBm/MHz to ensure compatability. Density of active UWB transmitters/km^2.			
1	–41.30	–41.3	dBm/MHz
10	–41.30	–41.3	dBm/MHz
100	–41.30	–43.0	dBm/MHz
1 000	–50.0	–53.0	dBm/MHz
10 000	–60.0	–63.0	dBm/MHz

Depending on the assumptions made in the studies, the maximum number of UWB devices that ensures the FSS protection varies between 10 and 100 active UWB/km^2.

This value depends on the type of satellite receiver (a zone beam is more sensitive than a global one), the building loss taken into account and the indoor/outdoor proportion of UWB.

Moreover, the maximum number of active UWB devices given is an average through a large area (for example Europe). That means that, as there are some sea areas or low density areas, this number can be considered higher in some location.

Therefore, taking into account the methodologies and parameters used, the studies show that a large deployment of UWB devices would not create an exceedence of the protection criterion of the FSS uplinks.

Conclusions (Earth-to-space)

The results of the various studies indicate that the aggregate interference into the satellite receiver is unlikely to be problematic for a protection criterion of I/N = –20 dB and a UWB device e.i.r.p. density of –41.3 dBm/MHz.

3 UWB interference into FSS downlinks

Radiocommunication TG 1/8 considered a number of studies that had addressed interference from UWB devices into FSS downlinks. This section summarizes those studies, and draws conclusions on the potential impact on FSS systems.

3.1 Single interferer

A study considered the case of single-entry interference potential from UWB systems into FSS receivers (feeder links for the MSS).

Using the systems parameters for MSS feeder links, the impact of a single UWB device into an MSS feeder link in the FSS was simulated. The propagation was modelled using a combination of generic UWB propagation model with log-normal shadow fading with mean value of 2.21 dB, smooth earth diffraction model (Recommendation ITU-R P.526) and clutter model as given in Recommendation ITU-R P.452). The physical arrangement simulated was as follows:

TABLE 111

UWB and MSS feeder link earth station analysis parameters

Parameter	Value
Protection criteria	I/N = –20 dB (average (RMS) interference power)
Antenna height	10 m
Antenna elevation angle	10º
UWB device height	2 m
Measurement bandwidth	1 MHz

The results calculated for average emissions from a non-dithered UWB signal were as follows:

TABLE 112

Non-dithered UWB signal into an MSS feeder link earth station (UWB height 2 m)

PRF (MHz)	BWCF (dB)	Max acceptable UWB e.i.r.p. at 10 m distance (dBm/MHz)		Separation distance (m) for UWB e.i.r.p. = –41.3 dBm/MHz rms	
		System 1	System 2	System 1	System 2
0.001 to 1.0	16.02	–62.25	–63.56	501	592.5
10	6.02	–52.25	–53.56	117	146
100	0.00	–46.23	–47.54	23.8	39.8
500	0.00	–46.23	–47.54	23.8	39.8

The results calculated for average emissions from a dithered UWB signal were as follows:

TABLE 113

Dithered UWB signal into an MSS feeder link earth station (UWB height 2 m)

PRF (MHz)	BWCF (dB)	Max acceptable UWB e.i.r.p. at 10 m distance (dBm/MHz)		Separation distance (m) for UWB e.i.r.p. = –41.3 dBm/MHz rms	
		System 1	System 2	System 1	System 2
0.001 to 500	16.02	–62.25	–63.56	501	592.5

Similarly, an analysis was made of the impact of peak power UWB emissions, using the same characteristics for the MSS feeder link. The results for non-dithered UWB signal analysis were as follows:

TABLE 114

Non-dithered UWB signal into MSS feeder link earth station (UWB height 2 m)

PRF (MHz)	BWCF (dB)	Max acceptable UWB e.i.r.p. at 10 m distance (dBm/MHz)		Separation distance (m) for UWB e.i.r.p. = –41.3 dBm/MHz rms	
		System 1	System 2	System 1	System 2
0.001	69.03	–115.26	–116.57	8.965	9.68
0.01	59.03	–105.26	–106.57	4.125	4.685
0.1	49.03	–95.26	–96.57	1.02	1.294
1	39.03	–85.26	–86.57	0.85	0.99
10	18.98	–65.21	–66.52	0.728	0.856
100	0.00	–46.23	–47.54	0.0238	0.0398
500	0.00	–46.23	–47.54	0.0238	0.0398

The results for dithered UWB signals under the same conditions were as follows:

TABLE 115

Dithered UWB signal into MSS feeder link earth station (UWB height 2 m)

PRF (MHz)	BWCF (dB)	Max acceptable UWB e.i.r.p. at 10 m distance (dBm/MHz)		Separation distance (m) for UWB e.i.r.p. = –41.3 dBm/MHz rms	
		System 1	System 2	System 1	System 2
0.001	69.03	–115.26	–116.57	8.965	9.68
0.01	59.03	–105.26	–106.57	4.125	4.685
0.1	49.03	–95.26	–96.57	1.02	1.294
1	39.03	–85.26	–86.57	0.85	0.99
10	29.03	–75.26	–76.57	0.728	0.94
100	19.03	–65.26	–66.57	0.0238	0.862
500	16.02	–62.25	–63.56	0.0238	0.5925

The following conclusions can be drawn from the results of the impact analysis with regard to interference from single UWB emitter with assumed PRF not less than 1 MHz:

– Separation distances (single entry)
  – A minimum separation distance ranging from 39.8 m to 600 m, depending on the PRF, is required for interference from average power UWB emissions.
  – A minimum separation distance ranging from 39.8 m to 990 m, depending on the PRF, is required for interference from peak power non-dithered emissions.
  – A minimum separation distance ranging from 592 m to 990 m, depending on the PRF, is required for interference from peak power dithered non-dithered emissions.
– Maximum permissible e.i.r.p. density in 1 MHz bandwidth at 10 m distance
  – The maximum permissible e.i.r.p. density is equal to –63.56 dBm/MHz for average power emissions (both non dithered and dithered).
  – The maximum permissible e.i.r.p. density is equal to –86.57 dBm/MHz for peak power emissions (both non dithered and dithered).

3.2 Aggregate interference

Several studies addressed the case of the impact of an aggregate UWB population on FSS earth station reception. This section summarizes those studies, giving results on the aggregate interference into FSS earth station receiver, and also giving results on possible mitigation methods and their impact on the aggregate interference from UWB devices.

3.2.1 Interference power density to noise ratio from UWB systems into FSS earth station receiver

The different studies enable to calculate the *I*/*N* into an FSS earth station, from a population of UWB devices (each with e.i.r.p. density –41.3 dBm/MHz) randomly distributed around the FSS receiver, following several types of UWB deployments. Some relevant *I*/*N* ratio values for different deployment scenarios, derived from the various studies, are compared in Table 116.

TABLE 116

Results from various FSS downlink studies presented in terms of calculated *I*/*N*

Study	Antenna elevation (degrees)	Antenna	Simulation methodology	Propagation model	Proportion of devices assumed indoors (%)	Resulting *I*/*N* for approx. 1 000 active UWB devices km^{-2} (dB)	Resulting *I*/*N* for approx. active UWB devices km^{-2} (dB)
1	6	9 m Rec. ITU-R S.465	Satellite downlink methodology Uniform distribution 10 km radius	Free-space loss($1/r^2$) 2-15 dB building attenuation No allowance for further shadowing	90	0.6	–6.4
2	33	4.8 m Rec. ITU-R S.465	Satellite downlink methodology Uniform distribution 3 km radius	Rec. ITU-R P.452-11 (flat terrain, e.g. $1/r^2$) 10-15 dB building attenuation No allowance for further shadowing	80	13	5.2
3	15	9 m AP7	Satellite downlink methodology Uniform distribution 20 km radius	$1/r^2$: free-space loss $1/r^3$: foliage $1/r^4$: walls, obstacle 10 dB clutter loss 10 dB building attenuation for indoor devices	100	0	N/A
4	5	3 m Rec. ITU-R S.465	Satellite downlink methodology Uniform distribution 5 km radius	$1/r^2$: free space loss $1/r^3$: foliage $1/r^4$: walls, obstacle	90	N/A	1.2[(1)]
5	5	4.5 m Rec. ITU-R S.465	Uniform distribution 5 km radius	$1/r^2$: free space loss $1/r^3$: foliage $1/r^4$: walls, obstacle	50	N/A	7.5[(1)]

(1) Density of devices = 127.3 active devices/km^2.

These calculations used FSS characteristics given in Annex 8.

One possible reason for the diversity between simulations may be the differences in propagation modelling and in particular the weighting of the propagation exponent's $1/r^2$, $1/r^3$, $1/r^4$. Nevertheless, all the scenarios were considered as valid, and in all cases, the *I*/*N* ratio of –20 dB is exceeded.

Complementing those results, one study made a series of sensitivity analyses, and noted the following:

– The density of outdoor devices has a much larger impact on the aggregate interference effects than does the density of indoor devices.
– The height of deployment, aperture and elevation angles of the FSS earth station antenna seemed to make only small differences (~1 to 2 dB) to the overall aggregate interference effect.
– An exclusion zone around the FSS antenna, within which no UWB devices may operate, may have a significant effect on the aggregate interference effect. (However, the size of such a zone may have to extend to several hundred metres in order to ensure protection.)
– The aggregate effects of UWB devices operating more than a few kilometres from the FSS antenna would be negligible.

More generally, most of the studies confirm that the results depend mainly on the type of UWB deployment chosen (density, and indoor and outdoor proportion).

3.2.2 Means to mitigate the impact of aggregate UWB emissions

In most of the scenarios, the I/N ratio value is from –12 dB to 13 dB depending on the UWB deployment scenario. Those values exceed the –20 dB I/N threshold. Thus, three factors, which offer some mitigation of the impact of UWB emissions into the FSS, are considered in the following sections.

3.2.2.1 Exclusion zone

Three studies summarized here considered the impact of an exclusion zone that would enable the I/N ratio of –20 dB. For practical reasons, this exclusion zone around the FSS earth station is delimited by a circle.

In the case of Study 1 it concludes that a separation distance larger than 2 km is needed to avoid interference from UWB devices in the case of N = 1 000 devices/km^2 even if the elevation angle is assumed to be 30° and the indoor ratio is to be assumed 90%. If the density of active devices is N = 100 devices/km^2, the separation distance required is 500-3 000 m.

In the case of Study 2, Table 117 presents the results on the minimum radius of the exclusion zone that would ensure a I/N ratio of –20 dB for different scenarios in the case of a flat terrain database.

TABLE 117

Exclusion zone (m) for the flat terrain model

FSS antenna diameter (m)	Indoor/ outdoor proportion (%)	Density of active UWB transmitter (/km^2)	Number of tries	Indoor attenuation of 10 dB		Indoor attenuation of 15 dB	
				Exclusion zone (radius (m))	*I*/*N* ratio (dB)	Exclusion zone (radius (m))	*I*/*N* ratio (dB)
4.8	80/20	5	500	750	–20.36	700	–20.72
	80/20	50	500	2 200	–20.01	2 100	–20.19
	80/20	500	500	2 880	–20.62	2 800	–20.03

This study also gives the results, as an example, on the minimum radius of the exclusion zone that would ensure the *I*/*N* ratio of –20 dB in the case of a real terrain database representing a C-band Teleport at Bercenay-en-othe (France) located in a rural area. The results below of this example confirm the above values.

TABLE 118

Exclusion zone (m) for Bercenay-en-othe terrain database

FSS antenna diameter (m)	Indoor/ outdoor proportion (%)	Density of active UWB transmitter (/km^2)	Number of tries	Indoor attenuation of 10 dB		Indoor attenuation of 15 dB	
				Exclusion zone (radius (m))	*I*/*N* ratio (dB)	Exclusion zone (radius (m))	*I*/*N* ratio (dB)
4.8	80/20	5	500	950	–20.26	950	–20.63

More generally, for this Study 2, and for a free-space loss situation (without taking account any obstacles), the determined exclusion zone, which enables the *I*/*N* ratio of –20 dB in the downlink direction, is around 2 km, depending on which scenario is taking into account.

In the case of Study 3, the sensitivity to separation of the earth station from the population of UWB devices was simulated. Noting that an earth station may be located some distance from the population of UWB devices, the simulation was repeated with different exclusion zones, up to 200 m between the victim antenna and the nearest UWB device. The results show that, in all cases, the *I*/*N* = –20 dB level is exceeded. However, it is noted that the separation distance decreases the degree of interference exceedence – for example, a 50 m exclusion zone decreases the interference by more than 3 dB at the 10% exceedence level.

The studies, on various scenarios, have indicated that the aggregate effect of populations of UWB devices would exceed the *I*/*N* ratio of –20 dB unless there were significant separation distances (1-3 km) between the population of UWB devices and the FSS earth station.

3.2.2.2 Reduction of the UWB density

In Study 3, the sensitivity of interference to the density of UWB devices was simulated. From the reference case of 100 UWB hotspots and 2 million residential dwellings, the following variations were modelled: 50 hotspots and 1 million residences; 100 hotspots and 1.5 million residences; 150 hotspots and 2 million residences. In this case, the results give that the permissible *I*/*N* thresholds were exceeded in every case. The simulation demonstrated that the density of UWB hotspots has only a small effect on the aggregate interference received by the victim. Note that the difference between the reference case (100 hotspots and 2 million residences) and the last case (150 hotspots and 2 millions residences) is negligible – this indicates that the impact of hotspots may be small compared to the aggregate effect of the (more distributed) residential usage of UWB.

3.2.2.3 Reduction of the UWB e.i.r.p. level

Due to the unlicensed and uncoordinated aspects of UWB devices, it may not be practical to establish such an exclusion zone of 1 to 3 km or to reduce the UWB density. However if UWB emissions are reduced, the exclusion zone may be reduced to a practicable distance.

Study 2 proposes some practical exclusion zones whose size may vary according to the location. Examples are shown in Table 119.

TABLE 119

Type	Exclusion zone (m)
Rural	100
Sub-urban	50
Urban	10

Consequently, taking into account these types of possible exclusion zones, Tables 120 and 121 present the level of UWB e.i.r.p. that could ensure the *I*/*N* ratio of –20 dB, with the assumptions of Study 2.

TABLE 120

UWB e.i.r.p. levels for the flat terrain model

FSS antenna diameter (m)	Indoor/ outdoor proportion (%)	UWB density (/km²)	Activity factor (%)	Density of active UWB transmitter (/km²)	Number of tries	Indoor attenuation of 10 dB			Indoor attenuation of 15 dB		
						Exclusion zone (radius (m))	UWB e.i.r.p. level (dBm/MHz)	*I*/*N* ratio (dB)	Exclusion zone (radius (m))	UWB e.i.r.p. level (dBm/MHz)	*I*/*N* ratio (dB)
4.8	80/20	100	5	5	500	100	–53	–20.89	100	–52	–20.13
	80/20	1 000	5	50	500	50	–63	–20.43	50	–61.8	–20.19
	80/20	10 000	5	500	500	10	–77	–20.49	10	–75	–20.11

TABLE 121

UWB e.i.r.p. levels for the Bercenay-en-Othe terrain database

FSS antenna diameter (m)	Indoor/ outdoor proportion (%)	UWB density (/km²)	Activity factor (%)	Density of active UWB transmitter (/km²)	Number of tries	Indoor attenuation of 10 dB			Indoor attenuation of 15 dB		
						Exclusion zone (radius (m))	UWB e.i.r.p. level (dBm/MHz)	*I*/*N* ratio (dB)	Exclusion zone (radius (m))	UWB e.i.r.p. level (dBm/MHz)	*I*/*N* ratio (dB)
4.8	80/20	100	5	5	500	100	–69	–20.08	100	–68.3	–20.37

Those results show that a reduction of the UWB e.i.r.p. compared to the –41.3 dBm/MHz is necessary to meet the *I*/*N* level of –20 dB. The range of this reduction is from 10 to 35 dB for the various cases studied. For the case of Bercenay-en-othe (France) located in a rural area and with a realistic terrain database, a reduced UWB e.i.r.p. value of around −69 dBm/MHz would be adequate to ensure the *I*/*N* ratio of –20 dB in this teleport of Bercenay-en-Othe. This case remains an example and is not representative of all cases, but confirms the results presented before.

Study 2 gives the maximum permissible UWB e.i.r.p. levels, based on flat terrain, in order to achieve the *I*/*N* ratio of –20 dB into the FSS.

– −53 dBm/MHz in a rural area;

– −63 dBm/MHz in a semi-urban area;

– −77 dBm/MHz in an urban area.

3.2.3 Further studies

After consideration of the results above, three additional studies were submitted to further clarify the impact of some variables.

3.2.3.1 Urban office block scenario

A study was also conducted in order to verify whether the urban area limit of –77 dBm/MHz was adequate to cover the situations where the receive FSS station was located in city centres where UWB devices would be deployed in multi-story office buildings. An example of such a scenario is shown in Fig. 233. This study assumed the FSS earth station antenna located on top of a building housing 40 offices and having on each side a building housing twice as many offices. Each office was assumed to be 10 m × 15 m × 5 m in dimensions and accommodate 6 workers, which would use computers and peripherals interconnected by UWB devices, a total of 6 UWB devices per office worker.

In the scenario depicted, the number of UWB devices within the three office blocks nearest to the FSS earth station antenna would be (80 + 40 + 80) × 36 = 7 200, in an area of only (60 × 80) = 4 800 m^2 on the Earth's surface – i.e. less than 1/200th of a square kilometre. (Fig. 234 shows the physical scenario as modelled.)

The following assumptions were also made:

– UWB activity factor: 5%.

– Average FSS earth station antenna gain: 0 dBi.

– $1/r^2$ free-space loss with 10 dB of additional loss per barrier (walls, ceilings) between the UWB device and the FSS earth station antenna.

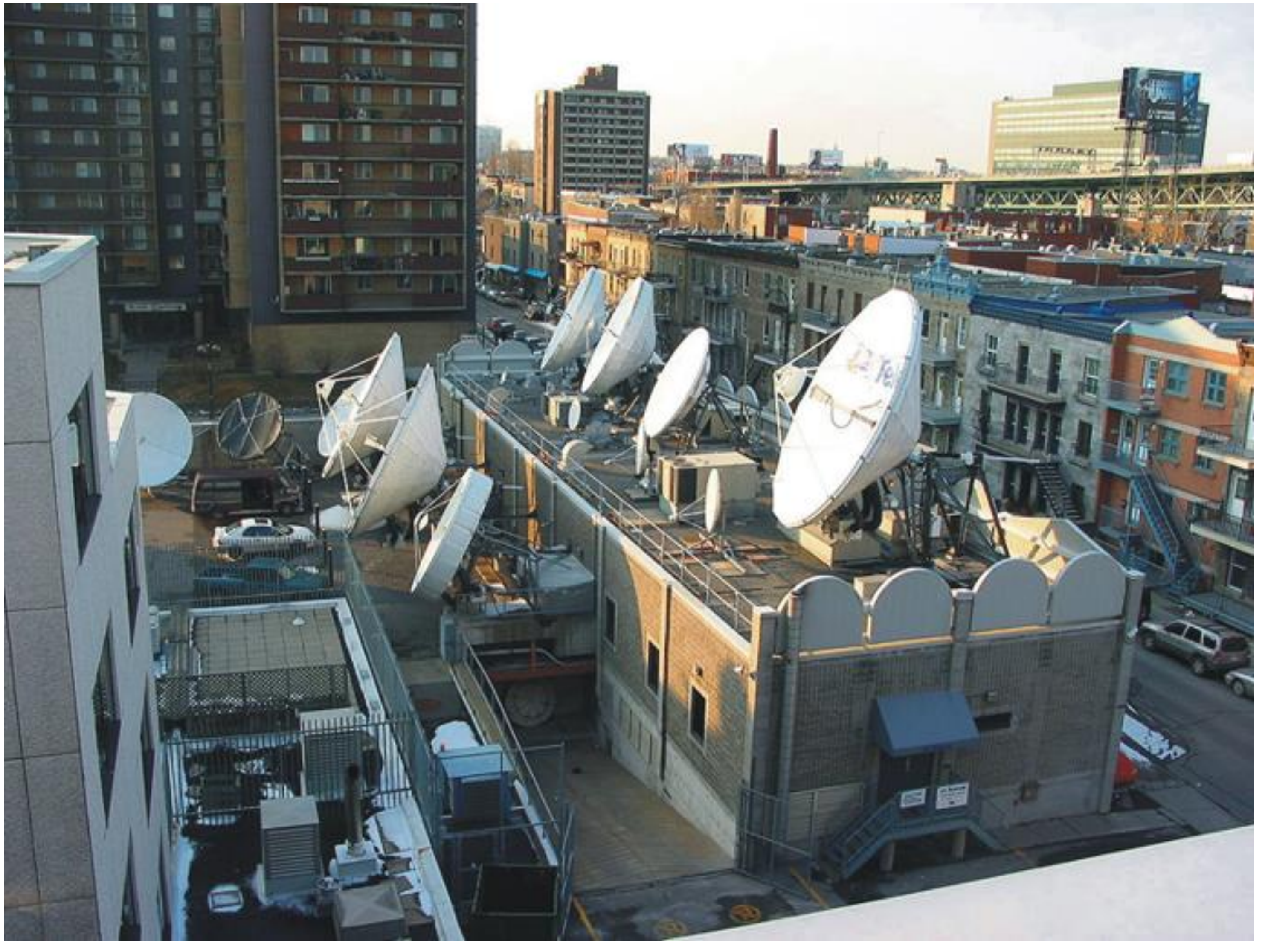
– Frequency band: 4 GHz.

– Protection criterion: –20 dB *I*/*N*.

– Antenna array effect of the electrical wiring in the building: ignored.

FIGURE 233

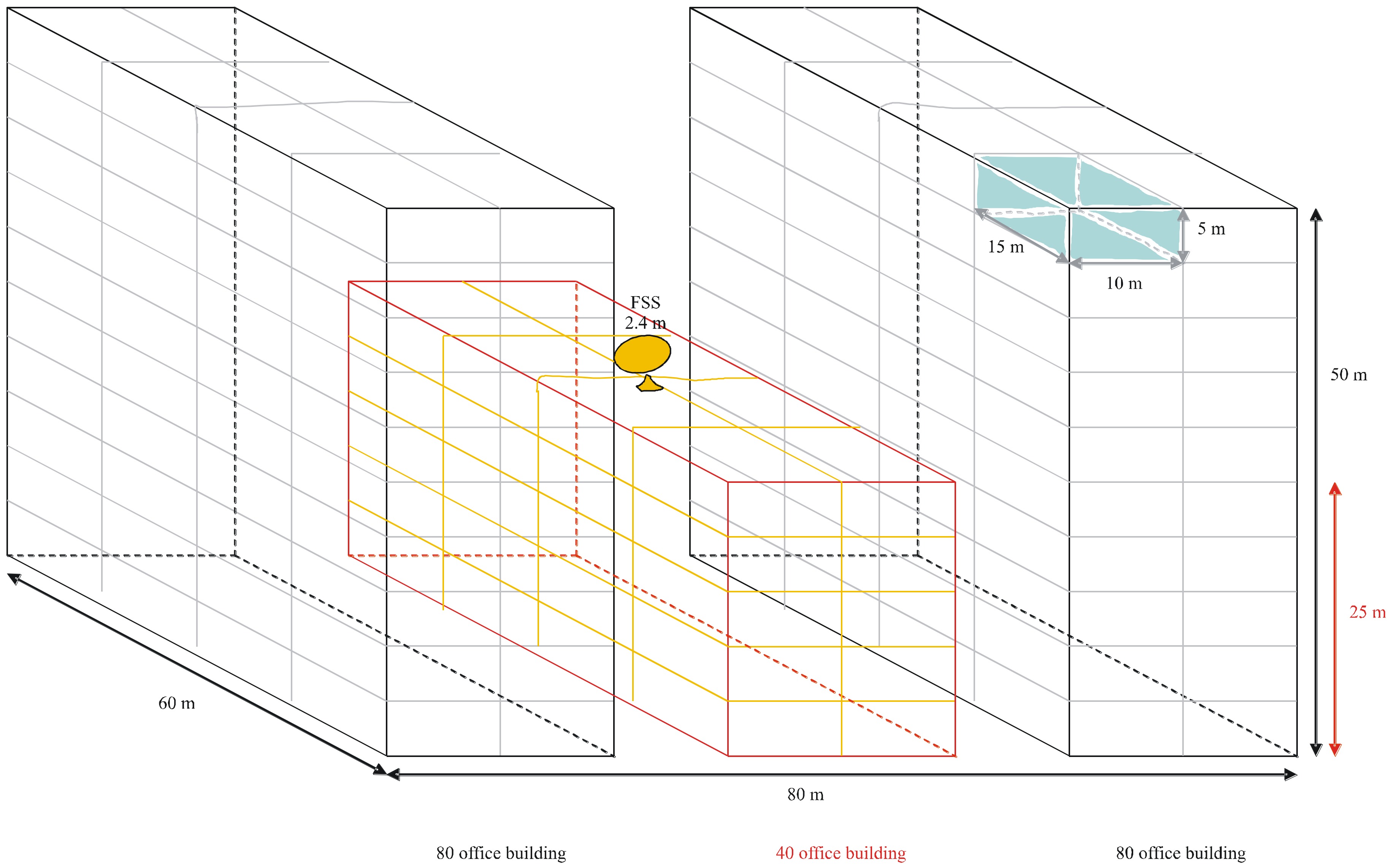
The "office block scenario" illustrating the reality of earth stations located in an area of multi-story buildings



Rap 2057-233

FIGURE 234

Example office block scenario



Rap 2057-234

The study concluded that, for protection of the FSS earth station against the interference from these UWB devices alone, the maximum permissible UWB e.i.r.p. level should be –76.6 dBW/MHz, a value which is comparable to that derived for the urban area scenario.

3.2.3.2 Impact of physical environment

In order to take into account the impact of obstacles over links and to assess the associated attenuation, it is proposed to consider different obstacles and different types of paths combining these obstacles and thus the relevant attenuations.

The following section presents first the different types of obstacles taken into account in the simulation whose results are listed in this Annex.

Obstacles

Five types of obstacles are considered: theses different obstacles are characterized by attenuation in addition to the free space loss, and described as follows:

– Wall (Recommendation ITU-R P.1238-3), uniform distribution of incidence angles of the waves emitted by UWB devices on the walls.

– Windows (Recommendation ITU-R P.1238-3), uniform distribution of incidence angles of the waves emitted by UWB devices on the glass.

– Trees (Recommendation ITU-R P.833-4), uniform distribution from 2 to 40 dB for rural, from 2 to 25 dB for suburban, from 2 to 10 dB for urban.

– External obstacles (Recommendation ITU-R P.452-11), uniform distribution of attenuation from 10 to 20 dB.

– Obstructions (Recommendation ITU-R P.526), uniform distribution of attenuation from 20 to 100 dB (this is valid for indoor and outdoor UWB devices).

Model and characterization of different scenarios

A path between a UWB device and the FSS receiver earth station may encounter different type of obstacles. Taking into account the obstacles defined above, ten categories of path are defined:

– path (1) : free space only

– path (2) : free space + wall attenuation

– path (3) : free space + window attenuation

– path (4) : free space + wall attenuation + external obstacle attenuation

– path (5) : free space + window attenuation + external obstacle attenuation

– path (6) : free space + wall attenuation + trees attenuation

– path (7) : free space + window attenuation + trees attenuation

– path (8) : free space + obstruction attenuation

– path (9) : free space + external obstacle attenuation

– path (10): free space + trees attenuation.

Different types of distributions

In the simulation zone, it is assumed that each of the simulated path falls into one or another defined paths above. Moreover, each scenario (rural, suburban and urban) was not modelled by the same path distribution, due to the fact that the environments differ from one to another (e.g. more dense vegetation in a rural environment, more building obstruction in a urban scenario etc.). Therefore, it is proposed to consider the following type of distribution which are detailed on Table 122.

– "Type 0" considers only free space propagation and indoor attenuation for UWB devices located indoor. In this distribution case, activity factor is assumed of 1% and 5%.
– "Type 1" proposes a distribution of the different paths among all the UWB devices, aiming at representing a realistic environment, as presented in the table below. In this distribution case, activity factor is assumed of 1% and 5%.
– "Type 2" proposes the same type of distribution as "Type 1" case, but consider an activity factor of 1 to 5% for indoor UWB devices and of 0.02% for outdoor devices.
– "Type 3" proposes another distribution based only on indoor UWB devices.

TABLE 122

Different types of distributions of attenuations

Distributions		**Path 1 FSL**	**Path 2 FSL + window**	**Path 3 FSL + wall**	**Path 4 FSL + window + ext. ob.**	**Path 5 FSL + wall + ext. ob.**	**Path 6 FSL + window + trees**	**Path 7 FSL + wall + trees**	**Path 8 FSL + obstruction**	**Path 9 FSL + ext. ob.**	**Path10 FSL + trees**
Rural	**Type 0**	20%	20%	60%	0%	0%	0%	0%	0%	0%	0%
	Type 1	2%	1%	4%	1%	4%	3%	7%	65%	8%	5%
	Type 2	2%	1%	4%	1%	4%	3%	7%	65%	8%	5%
	Type 3	0%	3%	8%	1%	3%	4%	11%	70%	0%	0%
suburban	**Type 0**	20%	20%	60%	0%	0%	0%	0%	0%	0%	0%
	Type 1	1%	1%	3%	2%	7%	1%	3%	70%	8%	4%
	Type 2	1%	1%	3%	2%	7%	1%	3%	70%	8%	4%
	Type 3	0%	1%	4%	4%	11%	1%	4%	75%	9%	0%
Urban	**Type 0**	20%	20%	60%	0%	0%	0%	0%	0%	0%	0%
	Type 1	2%	1%	4%	1%	6%	1%	1%	75%	7%	2%
	Type 2	2%	1%	4%	1%	6%	1%	1%	75%	7%	2%
	Type 3	0%	2%	4%	4%	8%	1%	1%	80%	0%	0%

Results

Table 123 gives the results of the simulations with the distributions presented above.

TABLE 123

Results for the various distributions in terms of (i) *I*/*N* for a UWB e.i.r.p. of –41.3 dBm/MHz and (ii) for UWB e.i.r.p. in order to achieve the *I*/*N* value of –20 dB

	Distribution of attenuation			**Type 0**		**Type 1**		**Type 2**		**Type 3**	
	Indoor/outdoor proportion			**80/20**		**80/20**		**80/20**		**100/0**	
	UWB density (/km²)	**Exclusion zone (m)**	**Activity factor (%)**	***I*/*N* (dB) for a e.i.r.p. of –41.3 dBm/MHz**	**e.i.r.p. (dBm/MHz) for *I*/*N* = –20 dB**	***I*/*N* (dB) for a e.i.r.p. of –41.3 dBm/MHz**	**e.i.r.p. (dBm/MHz) for *I*/*N* = –20 dB**	***I*/*N* (dB) for a e.i.r.p. of –41.3 dBm/MHz**	**e.i.r.p. (dBm/MHz) for *I*/*N* = –20 dB**	***I*/*N* (dB) for a e.i.r.p. of –41.3 dBm/MHz**	**e.i.r.p. (dBm/MHz) for *I*/*N* = –20 dB**
Rural	100	100	1	–12.8	–49.2	–16.2	–44.0	–20.6	–41.2	–18.3	–42.4
Suburban	1 000	50	1	–2.6	–58.5	–9.1	–52.5	–13.9	–47.3	–12	–49.1

Urban	10 000	10	1	11.1	–72.1	4.8	–66.0	1.9	–63.3	0.5	–61.9
Rural	100	100	5	–8.2	–53.3	–13.6	–47.2	–16.7	–44.7	–16.5	–45.0
Suburban	1 000	50	5	2.5	–64.0	–5.4	–56.0	–8.6	–52.6	–9.2	–-52.0
Urban	10 000	10	5	16.9	–77.9	9.2	–70.1	3.03	–64.5	4.4	–65.5

NOTE 1 – Type 0: Free-space + attenuation for wall and windows.

Type 1: Distribution of various attenuations added to free-space.

Type 2: Distribution of various attenuations added to free-space/An activity factor of 1 or 5% for indoor devices and 0.02% for outdoor devices.

Type 3: Distribution of various attenuations added to free-space/All devices are indoor.

The results show that as more obstacles are introduced and numbers of outdoor UWB devices are reduced, there is a reduction in the calculated *I*/*N*. But the reduction varies between different scenarios. Indeed, for the rural case, the *I*/*N* value decreases 4 dB. However there is a decrease of the *I*/*N* value for the suburban and the urban case from 6 to 8 dB.

Comparing the results for the two different activity factors, a lower value for this parameter decreases the *I*/*N* value and thus improves the sharing situation.

The reduction of the activity factor for outdoor devices (Type 2) or the consideration of only indoor UWB devices (Type 3) enable a decrease of the *I*/*N* values from 3 dB to 6 dB compared to Type 1 results. Therefore, considering a small amount of outdoor active UWB devices improve the sharing situation between a UWB population and a FSS receiving earth station.

Moreover, considering the FSS downlink band 4.5-4.8 GHz, the results for this band show a very slight difference compared to the band 3.6-4.2 GHz. Thus, it is possible to consider that results given in the band 3.6-4.2 GHz are also valid for the band 4.5-4.8 GHz.

3.2.3.3 Application of integral methodology

The third additional study applied the integral methodology to the 4 GHz, upper 6 GHz, and 12 GHz FSS satellite downlink frequency bands. This methodology (documented in Annex 2 of the Rec. ITU-R SM.1757) comprises a simple equation qualified as an “aggregate model applicable for a terrestrial device located at the centre of a zone defined by minimum and maximum radii using free space propagation” in which an average aggregate interference per unit bandwidth is calculated and stated as being “valid in the case of omnidirectional emissions and free space propagation”. The means by which the Integral methodology was used to compute a maximum UWB device e.i.r.p. density is detailed below:

In the integral methodology the aggregate interference power at the earth station receiver input is computed as:

$$A = 2\alpha\ \eta\ \rho\ \pi \ln (R_1/R_0)$$

where:

- A: aggregate interference power (W)
- η: fraction of the time that each emitter is transmitting
- ρ: average density of emitters (emitters/m^2)
- R_1: maximum radius of the observed zone (m)
- R_0: minimum radius of the observed zone (m)

and

$$\alpha = e.i.r.p.\ (\lambda/4\ \pi)^2\ G_r$$

where:

e.i..r.p.: average effective isotropic radiated power of the UWB device (W per nit bandwidth)

λ: wavelength (m)

G_r: victim receiver gain.

To account for attenuation of emissions from devices located indoors, the free space propagation result A is multiplied by the factor μ to establish $A' = \mu A$:

where:

$$\mu = (f_0 + a\, f_i)$$

and

f_0: fraction of UWB devices that are transmitting out of doors

f_i: fraction of UWB devices that are transmitting indoors

a: attenuation, expressed as a the fraction, of the indoor UWB signal that penetrates walls to the out of doors

$(f_0 + f_i)$: unity.

To calculate the parameter "e.i.r.p." defined above, for a stated bandwidth, such that a required protection ratio (I/N) for the victim service receive antenna is not exceeded, the value A' is equated to k T B*(I/N), where:

k: Boltzman's constant

T: system noise temperature of the earth station (K)

I/N: protection ratio (e.g. 0.01) of the victim receive system

B: bandwidth (Hz) over which the UWB power density is averaged, typically taken as 1 MHz.

In the integral methodology, a single value for victim earth station antenna gain G_r must be entered. In the aggregate case where UWB device emissions may occur from a variety of off-axis angles relative to the earth station antenna, an estimate of the aggregate impact can be obtained by applying the Integral methodology with the average victim receiver gain of 0 dBi.

Table 124 provides a summary of the input parameters and results of the application of the integral methodology to each of the bands for two deployment scenarios, urban and suburban.

TABLE 124

Application of integral methodology to the 4 GHz and upper 6 GHz FSS downlink bands to calculate maximum UWB e.i.r.p. density with stated parameters

		4 GHz		**Upper 6 GHz**	
Parameter		**Urban**	**Suburban**	**Urban**	**Suburban**
Frequency, c/λ	(GHz)	3.7	3.7	6.9	6.9
Indoor/outdoor UWB ratio, f_i/f_0	(%)	80/20	80/20	80/20	80/20
UWB device density, ρ	(/km^2)	10 000	1 000	10 000	1 000
Exclusion zone, R_0	(m)	20	40	20	40
Maximum radius of study, R_1	(km)	5	10	5	10
Indoor-to-outdoor attenuation, a	(dB)	10	10	10	10
UWB activity factor, η	(%)	5	5	5	5

Number of simultaneously active devices		500	50	500	50
Effective ES antenna gain, G_r	(dBi)	0	0	0	0
System noise temperature	(K)	100	100	128	128
I/*N* protection criterion	(dB)	–20	–20	–20	–20
Calculated maximum UWB e.i.r.p. density	(dBm/MHz)	–71.7	–61.7	–65.2	–55.2

This study also applied the integral methodology to the 12 GHz satellite downlink frequency band, which is allocated to FSS and BSS depending on the band segment and Region. Results for the suburban (50 active devices/km^2, 40 m exclusion zone, 10 km study radius) and urban (500 active devices/km^2, 20 m exclusion zone, 5 km study radius) scenarios, with common parameters of 11.7 GHz frequency, 80/20% indoor/outdoor ratio, 90 K noise temperature, and 1% protection criterion, give maximum UWB device e.i.r.p. densities of –52.1 dBm/MHz and –62.1 dBm/MHz respectively. However, the services that are typically deployed in the 12 GHz band (i.e. DTH or VSAT systems) employ earth station receive antennas that may be mounted on residences or other smaller buildings, where UWB devices may be deployed in close proximity to the antennas, and are thus likely more susceptible to single entry interference than to the aggregate interference computed with the integral methodology. Thus these aggregate results are included here for information only but have not been validated by more realistic single entry studies that would likely indicate a requirement for lower UWB e.i.r.p. densities to protect the services. This principle that single entry interference is likely more the determining factor than aggregate interference to determine the maximum UWB e.i.r.p. device density to protect a service is expected also to be true for the 17 GHz downlink band, which is allocated to BSS (17.3-17.8 GHz in Region 2) and FSS (17.3-17.7 GHz in Region 1).

3.3 Conclusion for FSS downlink

The aggregate effect of a population of UWB devices on the FSS in the downlink direction mainly depends on the type of UWB deployment, the density of devices using UWB technology and the relative proportions of indoor and outdoor use.

The studies have shown that, in most of the cases, this aggregate effect cannot adequately provide the *I*/*N* level of –20 dB into FSS earth station receivers without mitigating the aggregate interference from UWB devices operating at an e.i.r.p. level of –41.3 dBm/MHz. This mitigation may require a significant minimum separation distance between the population of UWB devices and FSS earth station of as much as 1-3 km, or a limit in the density of devices using UWB technology.

Given practical considerations, and the existing deployment of FSS earth stations, it may not be possible to achieve such exclusion zone distances of 1-3 km in many cases, and in order to achieve the *I*/*N* ratio of –20 dB in the band, with assumed practical exclusion zones (100 m rural/50 m semi-urban/10 m urban), it seems to be more appropriate to propose a reduction of the e.i.r.p. density levels of UWB devices in order to achieve the *I*/*N* ratio of –20 dB into the FSS.

The results of the studies suggest a range of possible e.i.r.p. density values for devices using UWB technology, depending upon the assumptions made for FSS deployment and for operation of UWB devices. For an FSS earth station located in an urban area, the range is –77 to –61.9 dBm/MHz; for the same deployment in a suburban area, this range is –63 to –47.3 dBm/MHz; and in a rural area, this range is –53 to –41.2 dBm/MHz. However, it would be impractical for devices using UWB technology to adjust their e.i.r.p. density depending on their location. Furthermore, the applications anticipated for UWB devices suggest a much higher likelihood of urban deployment. Therefore, a single value consistent with the urban scenario seems most appropriate in the bands 3.4-4.2 GHz and 4.5-4.8 GHz.

4 Conclusions for FSS studies (uplink and downlink)

The results of aggregate studies for the Earth-to-space direction (uplink) indicate that the FSS protection criterion of no more than 1% aggregate interference into the satellite receiver will be met provided that the maximum UWB device e.i.r.p. density does not exceed – 41.3 dBm/MHz.

In respect of the FSS feeder links (downlink) for MSS, the following conclusions were drawn assuming a single UWB emitter with PRF not less than 1 MHz:

- Separation distances (single entry)
  - A minimum separation distance ranging from 39.8 m to 600 m, depending on the PRF, is required for interference from average power UWB emissions.
  - A minimum separation distance ranging from 39.8 m to 990 m, depending on the PRF, is required for interference from peak power non-dithered emissions.
  - A minimum separation distance ranging from 592 m to 990 m, depending on the PRF, is required for interference from peak power dithered non-dithered emissions.
- Maximum permissible e.i.r.p. density in 1 MHz bandwidth at 10 m distance
  - The maximum permissible e.i.r.p. density is equal to –63.56 dBm/MHz for average power emissions (both non dithered and dithered).
  - The maximum permissible e.i.r.p. density is equal to –86.57 dBm/MHz for peak power emissions (both non dithered and dithered).

The results of aggregate studies for the space-to-Earth direction (downlink) are summarized in Table 125. The right-most three columns of the table indicate the maximum UWB device emission level allowed in order that the FSS protection criterion of no more than 1% aggregate interference into the earth station receiver is maintained.

TABLE 125

Summary of results of space-to Earth studies

Study	Antenna elevation (degrees)	Antenna	Simulation zone	Propagation model	Proportion of devices assumed indoors (%)	Maximum UWB emission level (dBm/MHz) to achieve an *I*/*N* of – 20 dB		
						1000 active UWB devices/km^{-2}	100 active UWB devices/km^{-2}	10 active UWB devices/ km^{-2}
1 *(3.7 GHz)*	6	9 m Rec. ITU-R S.465 *T* = 100 K	Uniform distribution 10 km radius	Free-space loss (1/r^2) 2-15 dB building attenuation No allowance for further shadowing	90	–61.9(1)	–54.9(1)	N/A
2 *(3.7 GHz)*	33	4.8 m Rec. ITU-R S.465 *T* = 100 K	Uniform distribution 3 km radius with exclusions zones (10 m to 100 m)	Rec. ITU-R P.452-11 (flat terrain, e.g. 1/r^2) 10-15 dB building attenuation No allowance for further shadowing	80	–77(2a)	–63(2b)	–53(2c)
3 *(3.7 GHz)*	15	9 m AP7 *T* = 100 K	Uniform distribution 20 km radius with 10 m exclusion zone	1/r^2: free-space loss 1/r^3: foliage 1/r^4: walls, obstacle 10 dB clutter loss 10 dB building attenuation	100	–61.3(1)	N/A	N/A
4 *(3.7 GHz)*	5	3 m Rec. ITU-R S.465 *T* = 100 K	Uniform distribution 5 km radius	1/r^2:free space loss 1/r^3: foliage 1/r^4: walls, obstacle	90	N/A	–61.3(1)	N/A
5 *(3.7 GHz)*	5-15	4.5 m *T* = 100 K	Uniform distribution 5 km radius	1/r^2: free space loss 1/r^3: foliage 1/r^4: walls, obstacle	50	N/A	–59.8(1)	N/A
6 *(3.7 GHz)*	(3)	(3) *T* = 100 K	Office block "hotspot" 80 m × 60 m area	1/r^2: free space loss plus 10 dB per partition (wall, floor etc)	100	–76.6(4)	–	–
7 *(3.7 GHz, 4.6 GHz)*	33	4.8 m Rec. ITU-R S.465 *T* = 100 K	Uniform distribution 3 km radius with exclusions zones (10 m to 100 m)	Rec. ITU-R P.452-11 (flat terrain, e.g. 1/r^2) Plus additional allowances for obstructions, diffractions, shadowing etc.	80	–70.1 to –63.3	–56 to –47.3	–47.2 to –41.2
					100	–65.5 to –61.9	–52 to –49.1	–45 to –42.4
8 *(3.7 GHz)*	(3)	(3) *T* = 100 K	Integral methodology 5 km radius/ 20 m exclusion and 10 km radius/40 m exclusion	1/r^2: free space loss plus 10 dB indoor-to-outdoor attenuation	80	–71.7	–61.7	–
8 *(6.9 GHz)*	(3)	(3) *T* = 100 K	Integral methodology 5 km radius/20 m exclusion and 10 km radius/ 40 m exclusion	1/r^2: free space loss plus 10 dB indoor-to-outdoor attenuation	80	–65.2	–55.2	–

(1) These values are linearly extrapolated from the study results.

(2a), (2b), (2c) The UWB device densities used were 500, 50 and 5 respectively.

(3) An antenna gain of 0 dBi was assumed for all directions of interference.

(4) This study assumed a density of 72 000 active UWB devices/km^2 in the hotspot.

Four of the studies documented above were conducted with the approach of using the FSS protection criterion of I/N = –20 dB as an input variable so that the resulting maximum UWB device emission level was an output. The other four studies took the approach of using a UWB device emission level as an input so that a resulting I/N was calculated; however, the results were linearly extrapolate results to approximate the situation to meet the I/N = –20 dB protection criterion. The extrapolated results are consistent with the other results.

The results therefore suggest a range of possible e.i.r.p. density values for devices using UWB technology, depending upon the assumptions made for FSS deployment and for operation of UWB devices. For an FSS earth station located in an urban area, the range is –77 to –61.9 dBm/MHz; for the same deployment in a suburban area, this range is –63 to –47.3 dBm/MHz; and in a rural area, this range is –53 to –41.2 dBm/MHz. However, it would be impractical for devices using UWB technology to adjust their e.i.r.p. density depending on their location. Furthermore, the applications anticipated for UWB devices suggest a much higher likelihood of urban deployment. Therefore, a single value consistent with the urban scenario seems most appropriate in the bands 3.4-4.2 GHz and 4.5-4.8 GHz.

Annex 4

Studies related to the impact of devices using ultra-wideband technology on systems operating within the mobile-satellite service and the radionavigation satellite service

1 Mobile-satellite service (MSS)

1.1 Search and rescue systems

1.1.1 Computation of the protection distances for the band 1 544-1 545 MHz for the LEO case

TABLE 126

Computation of the protection distance for a maximum radius of 10 km

Density of active UWB transmitters/km^2	Required UWB e.i.r.p. density (dBm/MHz) outdoor and indoor = –75	Required UWB e.i.r.p. density (dBm/MHz) outdoor and indoor = –85	Required UWB e.i.r.p. density (dBm/MHz) outdoor = –75 indoor = –65	Required UWB e.i.r.p. density (dBm/MHz) outdoor = –85 indoor = –75
1	10 m	10 m	10 m	10 m
10	10 m	10 m	10 m	10 m
100	10 m	10 m	10 m	10 m
1 000	10 m	10 m	10 m	10 m
10 000	100 m	10 m	3 km	10 m

1.1.2 Computation of the protection distances for the band 1 544-1 545 MHz for the GSO case

TABLE 127

Computation of the protection distance for a maximum radius of 10 km

Density of active UWB transmitters/km^2	Required UWB e.i.r.p. density (dBm/MHz) outdoor and indoor = –75	Required UWB e.i.r.p. density (dBm/MHz) outdoor and indoor = –85	Required UWB e.i.r.p. density (dBm/MHz) outdoor = –75 indoor = –65	Required UWB e.i.r.p. density (dBm/MHz) outdoor = –85 indoor = –75
1	10 m	10 m	10 m	10 m
10	10 m	10 m	100 m	10 m
100	1 km	10 m	5.5 km	100 m
1 000	8 km	1 km	9.5 km	5.5 km
10 000	9.8 km	8 km	9.95 km	9.5 km

1.1.3 Results of the interference analysis for the band 406-406.1 MHz

TABLE 128

Density of active UWB transmitters/km^2	Required UWB e.i.r.p. (both indoor and outdoor) density (dBm/MHz)	Required UWB e.i.r.p. density (dBm/MHz)	
		Outdoor density (dBm/MHz)	Indoor density (dBm/MHz)
1	–30	–38	–28
10	–40	–48	–38
100	–50	–58	–48
1 000	–60	–68	–58
10 000	–70	–78	–68

1.1.4 1 544-1 545 MHz (space-to-Earth)

The COSPAS/SARSAT (C/S) system provides distress alert and location information to appropriate public safety rescue authorities for maritime, aviation and land users in distress. The band 1 544-1 545 MHz is a space-to-Earth link to LEOLUTs (non-GSO local user terminal: earth station for non-GSO satellites) and GEOLUTs (GSO local user terminal: earth station for GSO satellites) for the two kinds of satellites (LEO and GSO). This band is limited to distress and safety operations only. For the C/S system, this band is used for feeder links of satellites needed to relay the emissions of satellite emergency position indicating radio beacons to earth stations. There are currently about 39 C/S earth stations or LEOLUT located in more than 20 countries in the world.

In the LEO case, the power spectral density (psd) that must not be exceeded at the ground station level is –203.2 dBW/Hz. For the GSO case, the limit is much more stringent (because of a lower S/N ratio) and becomes –223.5 dBW/Hz. In both cases, the psd is valid after the ground station antenna. Therefore, in the hereunder calculations, the ground antenna gain has to be taken into account.

The maximum antenna gain of the ground station is 31 dBi for the LEO case (3 m antenna dish, θ_{3dB} = 4.5°) and 35 dBi for the GSO case (5 m antenna dish, θ_{3dB} = 2.7°).

1.1.4.1 Rationale for the interference criteria in the band 1 544-1 545 MHz applicable for the Cospas/Sarsat system

Interferers in the band 1 544-1 545 MHz must not degrade the final $(E_b/N_0)_T$ by more than 0.4 dB. The required $(E_b/N_0)_T$ without any margin is 9.6 dB for a required BER of 10^{-5}. This implies that the C/I must be > 20 dB. With a degradation of 0.4 dB, the BER becomes 2.3×10^{-5}. As the minimum received power at the ground level for a 406 MHz beacon is –151.2 dBW, the maximum admissible level of interferers in the band 1 544-1 545 MHz is –151.2 dBW – 20 dB = –171.2 dBW. As the bandwidth of a 406 MHz beacon equals 1 600 Hz, therefore, the interference criteria becomes –203.2 dBW/Hz. Such criteria is equivalent to a psd of –113.2 dBm/MHz for the LEO case. For the GSO case, the criteria becomes –133.2 dBm/MHz.

According to Recommendation ITU-R M.1731, the protection criteria for Cospas-Sarsat local user terminals in the band 1 544-1 545 MHz concerning the LEO satellites is–207.5 dB(W/Hz) for one type of satellite channel and –204.7 dB(W/Hz) for another type of satellite channel. Concerning the GSO satellites, the corresponding protection criteria is –209.7 dB(W/Hz).

1.1.4.2 Interference analysis

The aggregate case uses the Integral method and computes the minimum radius R_0 for a given maximum radius R_1 and for various average densities/km^2. Tables 129 and 130 provide the corresponding protection distances for the LEO and GSO cases.

For the LEO case, in order to take into account more realistic situations, the fixed gain of the antenna gain of the C/S which is directional because the ground station is tracking a LEO satellite in azimuth and in elevation, is replaced with an average gain in the horizontal plane between the main lobe and the first side lobes, that is to say 21 dBi for the LEO.

For the GSO case, the antenna is not moving and always looking at the satellite. Depending on the latitude of the ground station a 10 dB decrease of the antenna gain provides a 25 dBi antenna gain for the GSO ground station: most of the interference is seen through the side lobes of the antenna.

In Table 129, two cases are considered: indoor use and outdoor use. For the case of indoor use, an average building attenuation of 9 dB is used in the aggregate model only. According to Recommendation ITU-R P.1238-2 and to the paper "The indoor radio Propagation Channel" (Proc. of the IEEE, Vol. 81, No. 7, July 1993 by Homayoun Hashemi), it appears that such an indoor attenuation is conservative and is able to cover most cases.

TABLE 129

Interference analysis between UWB devices and a Cospas/Sarsat ground station in the band 1 544-1 545 MHz for a LEO satellite

Frequency		1 544	MHz				
		UWB density	UWB spectrum mask	United States Mask – outdoor	United States Mask – indoor	Outdoor slope mask	Indoor slope mask
		(UWB/m^2)	e.i.r.p. limit (dBm/MHz)	–75	–75	–87.6	–77.6
LEO case		100	Protection distance	10 m	10 m	10 m	10 m
		1 000	Protection distance	10 m	10 m	10 m	10 m
		10 000	Protection distance	2 000 m	10 m	10 m	10 m
Aggregate interference calculation							
e.i.r.p.	–75	dBm/MHz	UWB e.i.r.p. limit	–75	–75	–87.6	–77.6
L	0.19	m	Wavelength α = e.i.r.p. . $(\lambda/4\pi)^2$. G_r				
G	21	dBi	Average antenna gain	21	21	21	21
α	–90.21	dBm/MHz		–90.21	–90.21	–102.81	–92.81
H	4%	%	Activity factor	4%	4%	4%	4%
R	10 000	UWB/km^2	UWB density	10 000	10 000	10 000	10 000
R_0	2	km	Minimum radius used for aggregate interference	2	0.01	0.01	0.01
R_1	10	km	Maximum radius	10	10	10	10
A	–124.1	dBm/MHz	$A = 2\alpha\eta\rho\pi\ln(R_1/R_0)$	–114.1	–107.8	–120.4	–110.4
		dB	Indoor/outdoor attenuation	0	9	0	9
	20%	%	% Outdoor	20%	20%	20%	20%
	80%	%	% Indoor	80%	80%	80%	80%
		dBm/MHz	Aggregate interference	–114.1	–116.8	–120.4	–119.4
	–113.2	dBm/MHz	PSD protection level	–113.2	–113.2	–113.2	–113.2
		dB	Margin for aggregate interference	0.9	3.6	7.2	6.2
R_0		km	Minimum radius used for aggregate interference for both indoor and outdoor UWB devices	0.1		0.01	
		dBm/MHz	Aggregate interference for both indoor and outdoor UWB devices	–114.8		–119.6	
		dB	Margin for aggregate interference for both indoor and outdoor UWB devices	1.6		6.4	

TABLE 130

Interference analysis between UWB devices and a Cospas/Sarsat ground station in the band 1 544-1 545 MHz for a GSO satellite

Frequency		1 544	MHz				
		UWB density	UWB spectrum mask	United States Mask – outdoor	United States Mask – indoor	CEPT outdoor slope mask	CEPT indoor slope mask
		(UWB/m^2)	e.i.r.p. limit (dBm/MHz)	–75	–75	–87.6	–77.6
GSO case		100	Protection distance	5 000 m	100 m	10 m	10 m
		1 000	Protection distance	9 300 m	6 000 m	3 000 m	4 000 m
Aggregate interference calculation							
e.i.r.p.	–75	dBm/MHz	UWB e.i.r.p. limit	–75	–75	–87.6	–77.6
l	0.19	m	Wavelength	0.19	0.19	0.19	0.19
G	25	dBi	Average antenna gain	25	25	25	25
α	–86.21	dBm/MHz	α = e.i.r.p. . $(\lambda/4\pi)^2$. G_r	–86.21	–86.21	–98.81	–88.81
h	4%	%	Activity factor	4%	4%	4%	4%
r	1 000	UWB/km^2	UWB density	1 000	1 000	1 000	1 000
R_0	2	km	Minimum radius used for aggregate interference	9.3	6	3	4
R_1	10	km	Maximum radius	10	10	10	10
A	–130.1	dBm/MHz	$A = 2\alpha\eta\rho\pi\ln(R_1/R_0)$	–133.6	–125.1	–134.0	–125.2
		dB	Indoor/outdoor attenuation	0	9	0	9
	20%	%	% Outdoor	20%	20%	20%	20%
	80%	%	% Indoor	80%	80%	80%	80%
		dBm/MHz	Aggregate interference	–133.6	–134.1	–134.0	–134.2
	–133.2	dBm/MHz	PSD protection level	–133.2	–133.2	–133.2	–133.2
		dB	Margin for aggregate interference	0.4	0.9	0.8	1.0
R_0		km	Minimum radius used for aggregate interference for both indoor and outdoor UWB devices	0.01		8	
		dBm/MHz	Aggregate interference for both indoor and outdoor UWB devices	–119.0		–140.5	
		dB	Margin for aggregate interference for both indoor and outdoor UWB devices	–14.2		7.3	

The band 1 535-1 559 MHz is allocated to MSS (space-to-Earth) with the band 1 544-1 545 MHz limited to distress and safety communications under RR No. 5.356, and the above calculations have shown that a protection distance is required around each ground station.

Therefore, due to the fact the characteristics of the UWB deployment are not correctly known, it is recommended that attention must be paid to the band 1 544-1 545 MHz and that the UWB devices must avoid such band in order not to cause any interference to the ground stations.

1.1.5 406-406.1 MHz (Earth-to-space)

The band 406-406.1 MHz is an uplink band (Earth-to-space) for EPIRB (Emergency Power Indicator Radio Beacon) or distress beacons that are active when somebody is in a distress situation. The signal is relayed by LEO satellites (850 km) and also by GSO satellites. On board the LEO satellite, the maximum spfd due to OoB emissions or other emissions than distress beacons must not exceed –198.6 dBW/m^2 Hz (Recommendation ITU-R M.1478, which takes into account an antenna gain of 3.9 dBi). This spfd is equivalent to a maximum admissible noise density of –210.1 dBW/Hz or –120.1 dBm/MHz.

In Table 131, in the aggregate case, the building attenuation is taken around 5 dB.

TABLE 131

Interference analysis between UWB and EPIRB at 406 MHz

Frequency	406	MHz			
Wavelength	0.74	m			
Protection criteria (Rec. ITU-R M.1478)	–198.6	dBW/Hz/m^2	At the antenna level		
Satellite antenna gain	3.9	dBi			
Minimum elevation angle at the ground station	5	degrees			
Maximum interference level	–120.1	dBm/MHz	At the receiver level		
Parameter		United States mask (outdoor)	United States mask (indoor)	Slope mask (outdoor)	Slope mask (indoor)
Maximum e.i.r.p. (power spectral density) of a single UWB device	dBm/MHz	–41.3	–41.3	–138.1	–128.1
Distance UWB – Satellite receiver (km) at the nadir	km	850	850	850	850
Space attenuation (dB)	dB	143	143	143	143
Satellite antenna gain (dBi)	dBi	3.9	3.9	3.9	3.9
Received power at the MSS in 1 MHz bandwidth (dBm)	dBm/MHz	–181	–181	–277	–267
Threshold (dBm/MHz)	dBm/MHz	–120.1	–120.1	–120.1	–120.1
Margin with a single UWB device (dB)	dB	60.5	60.5	157.3	147.3
Activity factor (%)	%	4%	4%	4%	4%
% Outdoor	%	20%	20%	20%	20%
% Indoor	%	80%	80%	80%	80%
Indoor/outdoor attenuation (dB)	dB	0	5	0	5
Half geocentric angle	degrees	23.47	23.47	23.47	23.47
Size of the satellite footprint: radius in km for a minimum ground station elevation angle of 5° assuming a flat earth	km	2 613	2 613	2 613	2 613

TABLE 131 (*end*)

Maximum UWB density/km^2 corresponding to the above MSS footprint	UWB/km^2	1.30	4.10	6×10^9	2×10^9
Received power of a single UWB device at the MSS receiver in 1 MHz bandwidth (dBm) for both indoor and outdoor usage	dBm/MHz	–184.00		–273.00	
Maximum UWB density/km^2 corresponding to the above MSS footprint for both indoor and outdoor usage	UWB/km^2	2.86		2×10^9	
Maximum UWB density/km^2 corresponding to the above MSS footprint using the NTIA aggregation method	UWB/km^2	5.72	18.10	2.74×10^{10}	8.66×10^9
Maximum UWB density/km^2 corresponding to the above MSS footprint for both indoor and outdoor usage using the NTIA aggregation method	UWB/km^2	12.63		1×10^{10}	

According to RR No. 5.267, any emission capable of causing harmful interference to the authorized uses of the band 406-406.1 MHz is prohibited.

When a single UWB device is operating with the e.i.r.p. expressed above, the receiver on board the MSS satellite would not be affected. However, Table 131 shows that, depending on the applied spectrum mask, very small or much larger densities can be reached without causing interference. Therefore, specific care should be given to this band which is fundamental to satellite search and rescue.

1.2 Mobile-satellite services – Service links of GSO MSS systems

1.2.1 Introduction

The ultra-wideband concept is based upon the transmission of signals of very low power over a large bandwidth. The use of very short duration pulses or other modulation techniques leads to the signals being spread over a very bandwidth that may overlap frequency bands allocated to radio services such as the MSS. Therefore, there is a potential to cause interference to MSS systems. In particular, there is a potential to cause interference to the existing GSO mobile satellite systems like Inmarsat-3 satellite system as well as to the planned GSO MSS systems like Inmarsat-4 satellite system.

1.2.2 Scenarios of interference from UWB systems into service links of GSO MSS systems

There following interference scenarios are to be considered from UWB systems into service links of GSO MSS systems.

TABLE 132

Scenarios of interference from UWB systems into service links of GSO MSS systems

Mode	Direction	Frequency band (MHz)	Description
Scenario-A (1.5 GHz) Scenario-A (2.185 GHz)	Service downlink	1 525-1 559 2 170-2 200	Single UWB emitter interference into a single MES terminal and Aggregate interference into aeronautical MES terminals from multiple UWB emitters Single and aggregate UWB emitter interference into a single hand-held MES terminal
Scenario-B (1.6 GHz)	Service uplink	1 626.5–1 660.5	Aggregate interference into satellite receiver from multiple UWB emitters

1.2.3 Maximum permissible interference levels

A criterion of 1% is assumed for GSO MSS systems operating in 1.5/1.6 GHz and 2.185 GHz frequency bands. In addition, a criterion of 10% is also assumed for GSO MSS systems operating 2.185 GHz frequency band.

The maximum permissible interference levels into two typical GSO MES terminals operating in 1.5 GHz frequency band (in the downlink direction) (Scenario A) are given in Table 133.

TABLE 133

Maximum permissible interference levels for Scenario A (1.5 GHz) interference analysis (all MES terminals including aeronautical MES terminals)

Parameter	Symbol	Type-1 Terminal	Type-2 Terminal	Units
System noise temperature	T_S	355	316	K
IF bandwidth	B_{IF}	200	60	kHz
Maximum permissible interference level	I_{MAX}	–140.09	–145.82	dBm

The generic characteristics of MSS hand-held receivers operating in 2.185 GHz frequency band are given in Table 134.

TABLE 134

Generic characteristics of MSS handheld receivers in the band 2 170-2 200 MHz

System	S-DMB
Bandwidth per carrier	4.84 MHz
NF	9 dB
Receiver antenna height	1.5 m

The maximum permissible interference levels of MES terminals of non-GSO MSS systems operating in 2.185 GHz band are given in Table 135.

TABLE 135

Maximum permissible level for the interference analysis

Parameter	Earth station	Earth station	Units
Frequency band	2 170-2 200 (downlink)	2 170-2 200 (downlink)	MHz
System noise temp	158	158	K
Reference bandwidth	30 000 (maximum)	1.4 (minimum)	kHz
Max permissible level in terms of the average UWB emission	–121.9 (dBm/30 MHz)	–165.2 (dBm/1.4 kHz)	dBm
Max permissible level in terms of the peak UWB emission	–99.1(dBm/30 MHz)	N/A	dBm

The maximum permissible interference levels into two GSO MSS satellite receivers in the uplink direction (Scenario-B) are given in Table 136.

TABLE 136

Maximum permissible interference levels into GSO MSS satellites for Scenario B impact analysis (1.6 GHz)

Parameter	System-1	System-1	System-2	System-2	Units
Beam	Global	Spot	Global	Narrow Spot	
System noise temperature	562	708	501	501	K
Bandwidth	34	34	34	34	MHz
Maximum permissible interference level	–115.79	–114.78	–116.29	–116.29	dBm

1.2.4 Victim receiver antenna characteristics

The following antenna radiation patterns are used to arrive at the victim MES receiver terminal antenna gain towards the UWB transmitter (Tables 137 and 138). A gain of 0 dBi is used for MSS hand-held terminals operating in 2.185 GHz.

TABLE 137

Type-1 MES terminal antenna radiation pattern

Gain pattern (dB)	Off-axis angle (degrees)
17	$\theta \leq 13$
14	$13 < \theta \leq 21$
$G = 44 - 25 \log \theta$	$21 < \theta \leq 76$
$G = -3$ dBi	$\theta > 76$

TABLE 138

Type-2 MES terminal antenna radiation pattern

Gain pattern (dB)	Off-axis angle (degrees)
18.0	$0 < \theta \leq 30$
$41 - 25 \log(\theta)$	$30 < \theta \leq 63$
–4.0	$\theta > 63$

1.2.5 Reference UWB emission levels

The following reference emission levels are used for the interfering UWB transmitters (Tables 139 and 140).

TABLE 139

Scenario A (1.5 GHz) interference analysis

United States mask	–75.3	dBm/MHz	@ 1 542 MHz
Slope-*I*/*D* mask	–77.7	dBm/MHz	@ 1 542 MHz
Slope-*O*/*D* mask	–87.7	dBm/MHz	@ 1 542 MHz

TABLE 140

Scenario B interference analysis

United States mask – Indoor devices	–53.3	dBm/MHz	@ 1 642.5 MHz
United States mask – Outdoor devices	–63.3	dBm/MHz	@ 1 642.5 MHz
Slope-*I*/*D* mask	–75.3	dBm/MHz	@ 1 642.5 MHz
Slope-*O*/*D* mask	–85.3	dBm/MHz	@ 1 642.5 MHz

1.2.6 Propagation models for the interference analysis

Free-space propagation model is used in the aggregate interference calculations for the following interference scenarios.

– Scenario A (Aggregate interference from multiple UWB emitters into aero MES terminal in the service downlink).

– Scenario B (Aggregate interference from multiple UWB emitters into satellite receiver in the service uplink).

Both free-space propagation model and Recommendation ITU-R P.1411 model are used for Scenario A interference analysis with regard to land MES terminals. Free-space propagation model is used for MES stations in the rural areas. Recommendation ITU-R P.1411-1 model is used for MES terminals in urban areas for interference from UWB devices with peak power emissions and very low PRF.

Free-space propagation model is also used for the MSS hand-held terminals operating in the in-door environment at 2.185 GHz frequency band. This model is also used for MES terminals of non-GSO MSS systems operating in 2.185 GHz band.

1.2.7 Categories of victim receivers

Interference Scenario A (1.5 GHz) in the service downlink

Type-1 and Type-2 land-based MES terminals are considered under Category A victim receiver for which the dominant mode of interference is single-entry interference.

Type-1 and Type-2 aero MES terminals are considered under Category C victim receiver for which the dominant mode of interference is aggregate interference from a large-scale area.

Interference Scenario B (1.6 GHz) in the service uplink

System-1 and System-2 satellite receivers are considered under Category C victim receiver for which the dominant part of interference is aggregate interference from a large scale area.

1.2.8 Deployment scenario for aggregate interference analysis

The following assumptions are used for the aggregate interference analysis:

– Percentage of active UWB transmitters: 4%

– Percentage of outdoor devices: 20%

– The density of UWB transmitters: 10 devices/km^2.

1.2.9 Other assumptions

The following assumptions have been made in the interference analysis of single UWB device in Interference Scenario A (downlink):

– UWB transmit and receive antennas are isotropic with unity gains (0 dBi).

– UWB devices transmit at defined power levels, e.i.r.p. per a measurement reference bandwidth (BW_{REF}), and these powers accumulate in the victim receiver.

– When the victim receiver has an IF bandwidth (BW_{RX}) different from the reference measurement bandwidth of the e.i.r.p. of the UWB transmitter (BW_{REF}), a bandwidth correction factor (BWCF) should be considered to normalize the average (r.m.s.) power level in a 1 MHz bandwidth, and to provide a correction for the UWB signal average (r.m.s.) power level ($BWCF_A$) or peak power level ($BWCF_P$) at the victim receiver IF output in dB.

For non-dithered UWB emissions, the BWCF for average power, $BWCF_A$, in units of dB, is given by the following expressions:

$BWCF_A = 0$, for $B_{RX} \leq PRF$ and $B_{REF} < PRF$;

$BWCF_A = 10 \log (PRF/B_{REF})$, for $B_{RX} \leq PRF$ and $B_{REF} \geq PRF$;

$BWCF_A = 10 \log (B_{RX}/PRF)$, for $PRF \leq B_{RX}$ and $B_{REF} < PRF$;

$BWCF_A = 10 \log (B_{RX}/B_{REF})$, for $PRF \leq B_{RX}$ and $B_{REF} \geq PRF$.

For non-dithered UWB emissions, the BWCF for peak power, $BWCF_P$, in units of dB, is given by the following expressions:

$BWCF_P = 0$, for $B_{RX} \leq 0.45\ PRF$ and $B_{REF} < PRF$;

$BWCF_P = 10 \log (PRF/B_{REF})$, for $B_{RX} \leq 0.45\ PRF$ and $B_{REF} \geq PRF$;

$BWCF_P = 20 \log \{B_{RX}/(0.45\ PRF)\}$, for $0.45\ PRF \leq B_{RX}$ and $B_{REF} < PRF$;

$BWCF_P = 10 \log \{(B_{RX})^2/(0.2\ PRF\ B_{REF})\}$, for $0.45\ PRF \leq B_{RX}$ and $B_{REF} \geq PRF$.

where *PRF* is the pulse repetition frequency of the UWB device.

For dithered UWB emissions, the BWCF for average power, $BWCF_A$, in units of dB, is given by the following expressions:

$BWCF_A = 10 \log (B_{RX}/B_{REF})$, for any value of B_{RX} and B_{REF}.

For dithered UWB emissions, the BWCF for peak power, $BWCF_P$, in units of dB, is given by the following expressions:

$BWCF_P = 10 \log \{(B_{RX})^2 /(0.2\ PRF\ B_{REF})\}$, for $0.2\ PRF < B_{RX}$ and any B_{REF}.

For $BRX \leq 0.2\ PRF$, the UWB signal time waveform at the filter output with bandwidth B_{RX} will be noise-like and consequently, average (RMS) power is more appropriate than peak power to assess receiver performance degradation. Therefore, to determine $BWCF_P$ for $B_{RX} \leq 0.2\ PRF$, the equation $BWCF_A = 10 \log (B_{RX}/B_{REF})$ should be used for any value of B_{RX} and B_{REF}.

1.2.10 Results of the interference analysis – Scenario A (1.5 GHz)

1.2.10.1 Land-based MES terminals

The link budget methodology as explained in § 1.2.1 of Annex 2 of Recommendation ITU-R SM.1757 is used to arrive at the separation distances required to maintain the protection criteria of the victim MES terminals from the UWB reference emission levels. Two types of MES terminals have been considered in the analysis. Table 141 gives the summary of separation distances required for Type-1 terminals. Similarly Table 142 gives the summary of separation distances required for Type-2 terminals.

The maximum permissible UWB emission levels at 20 m distance are obtained for different PRFs. These levels are then compared with the emission level requirement standards of FCC and CEPT. The last two columns of Tables 141 and 142 give separation distances where the UWB emission e.i.r.p. levels equals –75.3 dBm/MHz (United States mask limit), and –87.7 dBm/MHz (slope mask outdoor limit). With respect to the proposed slope mask indoor limit, if a building penetration loss of 10 dB is assumed, the results will be identical to the outdoor case.

Separation distances

Type-1 MES terminal

The following separation distances are required for UWB devices with PRF varying from 1 kHz to 500 MHz.

– Separation distances varying from 14 m to 132 m are required for non-dithered average UWB signals.
– Separation distances varying from 32 m to 1 860 m are required for non-dithered peak UWB signals in non-urban areas.
– Separation distances varying from 74 m to 269 m are required for non-dithered peak UWB signals in urban areas.
– Separation distances varying from 14 m to 59 m are required for dithered average UWB signals.
– Separation distances varying from 14 m to 1 860 m are required for dithered peak UWB signals in non-urban areas.
– Separation distances varying from 74 m to 269 m are required for dithered peak UWB signals in urban areas.

Type-2 MES terminal

The following separation distances are required for UWB devices with PRF varying from 1 kHz to 500 MHz.

– Separation distances varying from 17 m to 286 m are required for non-dithered average UWB signals.

– Separation distances varying from 29 m to 1 211 m are required for non-dithered peak UWB signals in non-urban areas.
– Separation distances varying from 65 m to 217 m are required for non-dithered peak UWB signals in urban areas.
– Separation distances varying from 17 m to 70 m are required for dithered average UWB signals.
– Separation distances varying from 29 m to 1 211 m are required for dithered peak UWB signals in non-urban areas.
– Separation distances varying from 65 m to 217 m are required for dithered peak UWB signals in urban areas.

TABLE 141

Type-1 MES terminal

PRF (MHz)	BWCF (dB)	Max permitted UWB e.i.r.p.@ 20 m	Delta reference level (dB) with respect to United States mask limit	Delta reference level (dB) with respect to CEPT mask limit	Distance (m) where permitted UWB e.i.r.p. equals United States mask limit		Distance (m) where permitted UWB e.i.r.p. equals slope mask limit	
Non-dithered signals – Average – UWB terminal height = 2 m								
0.1	–6.99	–84.66	–9.36	3.04	58.8(1)		14.1(1)	
1 to 500	0.00	–91.65	–16.35	–3.95	132(1)		32(1)	
Non-dithered signals – Peak – UWB terminal height = 2 m								
0.001	23.01	–114.66	–39.36	–26.96	1 860(1)	269(2)	446(1)	132(2)
0.01	13.01	–104.66	–29.36	–16.96	588(1)	151(2)	141(1)	74(2)
0.1	3.01	–94.66	–19.36	–6.96	186(1)	85(2)	45(1)	
1 to 500	0.00	–91.65	–16.35	–3.95	132(1)		32(1)	
Dithered signals – Average – UWB terminal height = 2 m								
0.001 to 500	–6.99	–84.66	–9.36	3.04	59(1)		14(1)	
Dithered signals – Peak – UWB terminal height = 2 m								
0.001	23.01	–114.66	–39.36	–26.96	1 860(1)	269(2)	446(1)	132(2)
0.01	13.01	–104.66	–29.36	–16.96	588(1)	151(2)	141(1)	74(2)
0.1	3.01	–94.66	–19.36	–6.96	186(1)	85(2)	45(1)	
1 to 500	–6.99	–84.66	–9.36	3.04	59(1)		14(1)	

(1) Separation distance outside the urban area with free-space propagation model.

(2) Separation distance inside the urban area with Recommendation ITU-R P.1411-1 propagation model.

TABLE 142

Type-2 MES terminal

PRF (MHz)	BWCF (dB)	Max permitted UWB e.i.r.p. @ 20 m	Delta reference level (dB) with respect to United States mask limit	Delta reference level (dB) with respect to CEPT mask limit	Distance (m) where permitted UWB e.i.r.p. equals United States mask limit		Distance (m) where permitted UWB e.i.r.p. equals slope mask limit	
Non-dithered signals – Average – UWB terminal height = 2 m								
0.001 to 0.01	–12.22	–86.17	–10.87	1.53	70(1)		17(1)	
0.1	–10.00	–88.39	–13.09	–0.69	90(1)		22(1)	
1 to 500	0.00	–98.39	–23.09	–10.69	286(1)		69(1)	
Non-dithered signals – Peak – UWB terminal height = 2 m								
0.001	12.55	–110.94	–35.64	–23.24	1 211(1)	217(2)	291(1)	106(2)
0.01	2.55	–100.94	–25.64	–13.24	383(1)	122(2)	92(1)	65(2)
0.1	–7.45	–90.94	–15.64	–3.24	121(1)	69(2)	29(1)	
1 to 500	0.00	–98.39	–23.09	–10.69	286(1)		69(1)	
Dithered signals – Average – UWB terminal height = 2 m								
0.001 to 500	–12.22	–86.17	–10.87	1.53	70(1)		17(1)	
Dithered signals – Peak – UWB terminal height = 2 m								
0.001	12.55	–110.94	–35.64	–23.24	1 211(1)	217(2)	291(1)	106(2)
0.01	2.55	–100.94	–25.64	–13.24	383(1)	122(2)	92(1)	65(2)
0.1	–7.45	–90.94	–15.64	–3.24	121(1)	69(2)	29(1)	
1 to 500	–12.22	–86.17	–10.87	1.53	70(1)		17(1)	

(1) Separation distance outside the urban area with free-space propagation model.

(2) Separation distance inside the urban area with Recommendation ITU-R P.1411-1 propagation model.

1.2.10.2 Results of the interference analysis – Aero MES terminals

The airborne aggregate interference methodology as explained in § 1.3.5 of Annex 2 of Recommendation ITU-R SM.1757 is used to estimate the aggregate interference from multiple UWB emitters into aeronautical MES terminals in the downlink direction. An United States mask limit of –75.3 dBm/MHz is used in the analysis. Three different altitudes – high (10 000 m), medium (3 000 m) and low (100 m) are assumed for the aero MES terminals. Different combinations of indoor/outdoor UWB transmitters are used in the analysis. Two different types of aero MES terminals have been considered in the analysis. The results of the compatibility analysis are given in Table 143.

TABLE 143

	High altitude		Medium altitude		Low altitude	
Parameter	Type-1	Type-2	Type-1	Type-2	Type-1	Type-2
Beam/frequency band	L Band	L Band	L Band	L Band	L Band	L Band
Boltzmann's constant (*k*)	–198.6	–198.6	–198.6	–198.6	–198.6	–198.6
System noise temperature (*T*)	355	316	355	316	355	316
Bandwidth	0.2	0.06	0.2	0.06	0.2	0.06
N	–120.09	–125.82	–120.09	–125.82	–120.09	–125.82
I/*N* (1% criterion)	–20	–20	–20	–20	–20	–20
I_{max}	–140.09	–145.82	–140.09	–145.82	–140.09	–145.82
Rx gain of aero MES terminal	0	0	0	0	0	0
Altitude of the aero MES terminal	10 000	10 000	3 000	3 000	100	100
Radius of the observed zone	467	467	417	417	394	394
Indoor/*outdoor*	0.80:0.20	0.80:0.20	0.80:0.20	0.80:0.20	0.80:0.20	0.80:0.20
Average e.i.r.p. of the transmitting device	–75.3	–75.3	–75.3	–75.3	–75.3	–75.3
UWB emitter density emitters/m^2 (emitters/km^2) with 100% activity factor						
0.00001 [10]	–160.20	–165.43	–159.11	–164.34	–156.86	–162.09
0.0001 [100]	–150.20	–155.43	–149.11	–154.34	–146.86	–152.09
0.001 [1 000]	–140.20	–145.43	–139.11	–144.34	–136.86	–142.09
0.01 [10 000]	–130.20	–135.43	–129.11	–134.34	–126.86	–132.09
0.1 [100 000]	–120.20	–125.43	–119.11	–124.34	–116.86	–122.09
1 [1 000 000]	–110.20	–115.43	–109.11	–114.34	–106.86	–112.09
Emitter density limit required to meet the criterion with 100% activity factor	0.001025	0.000914	0.000798	0.000711	0.000475	0.000424
Emitter density limit required to meet the criterion with 4% activity factor	0.02563	0.02285	0.01995	0.01778	0.01188	0.01059
Emitter density limit required to meet the criterion with 4% activity factor	25 629	22 853	19 950	17 780	11 878	10 591
Required UWB PSD emission limit (dBm/MHz) to ensure compatibility						
Density of active UWB transmitters/km^2						
1	–75.30	–75.30	–75.30	–75.30	–75.30	–75.30
10	–75.30	–75.30	–75.30	–75.30	–75.30	–75.30
100	–75.30	–75.30	–75.30	–75.30	–75.30	–75.30
1 000	–75.30	–75.69	–76.28	–76.78	–78.53	–78.03
10 000	–85.19	–85.69	–86.28	–86.78	–88.53	–98.03

1.2.10.3 Results of the interference analysis – Hand-held MES terminals (Scenario A: 2.185 GHz)

Different interference scenarios have been considered for assessing interference. Results are listed below, considering free-space loss propagation in an indoor environment:

TABLE 144

Results of the interference study for the band 2 170-2 200 MHz

Minimum distance (m)	Number of interferers	Maximum e.i.r.p. (dBm/MHz)	
		***I/N* = –20 dB**	***I/N* = –10 dB**
0.3	1	–96.2	–86.2
0.5	1	–91.8	–81.8
1	1	–85.8	–75.8
	3	–90.6	–80.6
3	3	–81.0	–71.0
10	3	–70.6	–60.6
	10	–75.8	–65.8

Table 144 shows that in the case of single-entry interference, minimum separation distance of about 36 cm leads to a maximum e.i.r.p. density of –85 dBm/MHz, which is the value needed also to protect terrestrial IMT-2000 in the adjacent band 2 110-2 170 MHz.

In the case of multiple entry interference, minimum separation distance of 3 m, when considering three potential interferers leads to a value of –81 dBm/MHz for the 1% degradation criteria, and –71 dBm/MHz for the 10% degradation criteria, which shows that the value of –85 dBm/MHz would be also suitable in that case.

1.2.10.4 Results of the interference analysis – MES terminals of non-GSO MSS systems in 2.2 GHz band

The results of the interference study are summarized in Table 145.

TABLE 145

Maximum permitted e.i.r.p. of the UWB device

Parameter	Average	Peak	Units
Max permissible level per MHz	–136.7	–128.7	dBm/MHz
Propagation path loss	30.4	30.4	dB
Max permitted e.i.r.p. of the UWB device (aggregate value)	–106.3	–98.3	dBm/MHz
Max permitted e.i.r.p. of the UWB device (aggregate value) in terms of the reference bandwidth	–91.6 (dBm/30 MHz) –134.8 (dBm/1.4 kHz)	–68.7 (dBm/30 MHz) Not available for the reference bandwidth of 1.4 kHz)	dBm

1.2.11 Results of the interference analysis – GSO MSS satellite receiver (Scenario B)

In Scenario B, it is more appropriate to do interference analysis between UWB emitters and satellite receiver based on aggregate interference from many UWB emitters into a satellite receiver, as the satellite receiver can receive interference from many UWB emitters within the coverage area of the satellite receive antenna beam. In § 1.2.11.1, results based on airborne aggregate interference model (§ 1.3.5 of Annex 2 of Recommendation ITU-R SM.1757) are presented. In § 1.2.11.2, results based on simplified summation methodology for GSO satellite uplinks (§ 1.3.4.1.2 of Annex 2 of Recommendation ITU-R SM.1757) are presented.

1.2.11.1 Summary of results of interference analysis based on airborne aggregate interference model

The results of interference computations for interference into satellite receiver from UWB emitters within the coverage area of service link global beam are given in Table 145 for System-1 and System-2.

1.2.11.2 Summary of results of interference analysis based on simplified summation methodology for GSO satellite uplinks

The results of interference computations for interference into satellite receiver from UWB emitters within the coverage area of service link global beam are given in Tables 146 and 147 for System-1 and System-2 satellites respectively.

TABLE 146

Summary of aggregate interference levels from multiple UWB emitters into GSO MSS satellite receiver for different emitter densities – Scenario B (1.6 GHz)

Parameter	**System-1**		**System-2**		**Units**
Beam/frequency band	GI – L Band	Spot – L Band	GI – L Band	NS – L Band	
Boltzmann’s constant (*k*)	–198.6	–198.6	–198.6	–198.6	dBm/k/Hz
System noise temperature (*T*)	562	708	501	501	k
Bandwidth	34	34	34	34	MHz
N	–95.79	–94.78	–96.29	–96.29	dBm
I/*N* (1% criterion)	–20	–20	–20	–20	dB
I_{max}	–115.79	–114.78	–116.29	–116.29	dBm
Gr – Gain of satellite Rx antenna					
Peak	18.5	27	22	41	dBi
Edge of coverage	16	23	17	37	dBi
Radius of the observed zone	5 878	2 086	5 278	416	km
Indoor/outdoor	0.80:0.20	0.80:0.20	0.80:0.20	0.80:0.20	
Average e.i.r.p. of the transmitting device (indoor)	–75.28	–75.28	–75.28	–75.28	dBm/MHz
Factor to take into account combination of I/D&O/D devices and building loss	–10 000	–10 000	–10 000	–10 000	dB
UWB emitter density (emitters/m^2*)*	Aggregate interface		Aggregate interface		

TABLE 146 (*end*)

Parameter	**System-1**		**System-2**		**Units**
0.00001 [10]	–142.09	–143.52	–141.09	–143.45	dBm
0.0001 [100]	–132.09	–133.52	–131.09	–133.45	dBm
0.001 [1 000]	–122.09	–123.52	–121.09	–123.45	dBm
0.01 [10 000]	–112.09	–113.52	–111.09	–113.45	dBm
0.1 [100 000]	–102.09	–103.52	–101.09	–103.45	dBm
1 [1 000 000]	–92.09	–93.52	–91.09	–93.45	dBm
Emitter density limit required to meet the criterion with 100% activity factor	0.004266	0.0077482	0.003019	0.005200	emitters/m^2
Emitter density limit required to meet the criterion with 4% activity factor	0.10664	0.18704	0.07546	0.13000	emitters/m^2
Emitter density limit required to meet the criterion with 4% activity factor	106 639	187 042	75 464	129 998	emitters/m^2
Required UWB PSD emission limit (dBm/MHz) to ensure compatibility					
Density of active UWB transmitters/km^2					
1	–75.28	–75.28	–75.28	–75.28	dBm/MHz
10	–75.28	–75.28	–75.28	–75.28	dBm/MHz
100	–75.28	–75.28	–75.28	–75.28	dBm/MHz
1 000	–75.28	–75.28	–75.28	–75.28	dBm/MHz
10 000	–78.982	–76.54	–80.482	–78.12	dBm/MHz

TABLE 147

Summary of aggregate interference levels from multiple UWB emitters into GSO MSS System-1 satellite receiver – Scenario B (1.6 GHz)

Parameter	**System-1**				**Units**
Beam	Global	Global	Spot	Spot	
Boltzmann's constant (k)	–198.6	–198.6	–198.6	–198.6	dBm/K/Hz
System noise temperature (T)	562	562	708	708	K
Bandwidth (B)	34	34	34	34	MHz
Thermal noise (N)	–95.79	–95.79	–94.78	–94.78	dBm
I/N (1% criterion)	–20	–20	–20	–20	dB
I_{max}	–115.79	–115.79	–114.78	–114.78	dBm
United States mask/slope mask limit	United States mask	Slope mask	United States mask	Slope mask	

TABLE 147 (*end*)

Parameter	**System-1**				**Units**
Indoor/outdoor	0.80:0.20	0.80:0.20	0.80:0.20	0.80:0.20	
Average e.i.r.p. of the UWB device (indoor)	–53.30	–75.28	–53.30	–75.28	dBm/MHz
Factor to take into account combination of *I*/*D*&*O*/*D* devices and building loss	–10 000	–10 000	–10 000	–10 000	dB
d (based on Appendix 8, Annex-II dis formula)	39 220	39 220	39 220	39 220	km
Frenquency (*F*)	1.6435	1.6435	1.6435	1.6435	GHz
Absorption loss	0	0	0	0	dB
B	34	34	34	34	MHz
Gain of satellite receive antenna (EoC)	16	16	23	23	dBi
Number of emitters (*N*) in millions	1	1	1	1	
I AGG	–160.67	–182.65	–153.67	–175.65	dBm
Area	2.17×10^8	2.17×10^8	2.74×10^7	2.74×10^7	km^2
Emitter density (units/m^2)	4.61×10^9	4.61×10^9	3.66×10^8	3.66×10^8	units/m^2
I AGG with 0.00001 emitter/m^2	–127.30	–149.28	–129.30	–151.28	dBm
I AGG with 0.0001 emitter/m^2	–117.30	–139.28	–119.30	–141.28	dBm
I AGG with 0.001 emitter/m^2	–107.30	–129.28	–109.30	–131.28	dBm
I AGG with 0.01 emitter/m^2	–97.30	–119.28	–99.30	–121.28	dBm
I AGG with 0.1 emitter/m^2	–87.30	–109.28	–89.30	–111.28	dBm
I AGG with 1 emitter/m^2	–77.30	–99.28	–79.30	–101.28	dBm
Emitter density limit required to meet the criterion with 100% activity factor	0.000142	0.022330	0.000283	0.044668	emitters/m^2
Emitter density limit required to meet the criterion with 4% activity factor	0.00354	0.55825	0.00708	1.11670	emitters/m^2
Emitter density limit required to meet the criterion with 4% activity factor	3 539	558 250	7 075	1 116 700	emitters/km^2
Required UWB PSD emission limit (dBm/MHz) to ensure compatibility					
Density of active UWB transmitters/km^2					
1	–53.3	–75.28	–53.3	–75.28	dBm/MHz
10	–53.3	–75.28	–53.3	–75.28	dBm/MHz
100	–53.3	–75.28	–53.3	–75.28	dBm/MHz
1 000	–61.79	–75.28	–58.78	–75.28	dBm/MHz
10 000	–71.79	–75.28	–68.78	–75.28	dBm/MHz

TABLE 148

Summary of aggregate interference levels from multiple UWB emitters into GSO MSS System-2 satellite receiver – Scenario B (1.6 GHz)

Parameter	**System-2**						**Units**
Beam	Global	Global	Wide Spot	Wide Spot	N Spot	N spot	
Boltzmann’s constant (*k*)	–198.6	–198.6	–198.6	–198.6	–198.6	–198.6	dBm/K/Hz
System noise temperature (*T*)	501	501	501	501	501	501	K
Bandwidth (*B*)	34	34	34	34	34	34	MHz
Theme noise (*N*)	–96.29	–96.29	–96.29	–96.29	–96.29	–96.29	dBm
I/*N* (1% criterion)	–20	–20	–20	–20	–20	–20	dB
I_{max}	–116.29	–116.29	–116.29	–116.29	–116.29	–116.29	dBm
United States mask/slope mask limit	United States mask	Slope mask	United States mask	Slope mask	United States mask	Slope mask	
Indoor/outdoor	0.80:0.20	0.80:0.20	0.80:0.20	0.80:0.20	0.80:0.20	0.80:0.20	
Average e.i.r.p. of the UWB device (indoor)	–53.30	–75.28	–53.30	–75.28	–53.30	–75.28	dBm/MHz
Factor to take into account combination of *I*/*D*&*O*/*D* devices and building loss	–10 000	–10 000	–10 000	–10 000	–10 000	–10 000	dB
d (based on Appendix 8, Annex-II dis formula)	39 220	39 220	39 220	39 220	39 220	39 220	km
Frenquency (*F*)	1.6435	1.6435	1.6435	1.6435	1.6435	1.6435	GHz
Absorption loss	0	0	0	0	0	0	dB
B	34	34	34	34	34	34	MHz
Gain of satellite receive antenna (EoC)	17	17	21.5	21.5	37	37	dBi
Number of emitters (*N*) in millions	1	1	1	1	1	1	
I AGG	–159.67	–181.65	–155.17	–177.15	–139.67	–161.65	dBm
Area	2.17×10^8	2.17×10^8	8.68×10^6	8.68×10^6	1.09×10^6	1.09×10^6	km^2
Emitter density (units/m^2)	4.61×10^9	4.61×10^9	1.15×10^7	1.15×10^7	9.21×10^7	9.21×10^7	units/m^2
I AGG with 0.00001 emitter/m^2	–126.30	–148.28	–135.78	–157.76	–129.31	–151.29	dBm
I AGG with 0.0001 emitter/m^2	–116.30	–138.28	–125.78	–147.76	–119.31	–141.29	dBm
I AGG with 0.001 emitter/m^2	–106.30	–128.28	–115.78	–137.76	–109.31	–131.29	dBm
I AGG with 0.01 emitter/m^2	–96.30	–118.28	–105.78	–127.76	–99.31	–121.29	dBm
I AGG with 0.1 emitter/m^2	–86.30	–108.28	–95.78	–117.76	–89.31	–111.29	dBm
I AGG with 1 emitter/m^2	–76.30	–98.28	–85.78	–107.76	–79.31	–101.29	dBm
Emitter density limit required to meet the criterion with 100% activity factor	0.000100	0.015812	0.000889	0.140281	0.000200	0.031623	emitters/m^2
Emitter density limit required to meet the criterion with 4% activity factor	0.00251	0.39531	0.02223	3.50703	0.00501	0.79057	emitters/m^2

TABLE 148 (*end*)

Parameter	**System-2**						**Units**
Emitter density limit required to meet the criterion with 4% activity factor	2 506	395 312	22 230	3 507 034	5 011	790 569	emitters/km^2
Required UWB PSD emission limit (dBm/MHz) to ensure compatibility							
Density of active UWB transmitters/km^2							
1	–53.3	–75.28	–53.3	–75.28	–53.3	–75.28	dBm/MHz
10	–53.3	–75.28	–53.3	–75.28	–53.3	–75.28	dBm/MHz
100	–53.3	–75.28	–53.3	–75.28	–53.3	–75.28	dBm/MHz
1 000	–63.29	–75.28	–53.81	–75.28	–60.28	–75.28	dBm/MHz
10 000	–73.29	–75.28	–63.81	–75.28	–70.28	–75.28	dBm/MHz

1.2.12 Conclusions

The interference analysis is performed between UWB devices and two GSO MSS satellite systems. Two scenarios of interference have been considered. These are interference from a single UWB device into Type-1/Type-2 MES terminal and aggregate interference from multiple UWB emitters into aero Type-1 and Type-2 MES terminals (Scenario A (downlink)) and aggregate interference from multiple UWB transmitters into two GSO MSS satellite receivers in service link band (Scenario B (uplink)).

The aggregate interference analysis is performed with 4% activity factor and 20% of UWB devices deployed outside.

1.2.12.1 Downlink

1.2.12.1.1 Land-based MES terminals operating at 1.5 GHz band

The following conclusions can be drawn from the results of the interference analysis with regard to interference from single UWB emitter with PRF not less than 1 MHz into MES terminal in Mode 2. These conclusions are based on the analysis of only two typical GSO MES terminals. The separation distances and aggregate interference levels will vary for other types of GSO MES terminals.

Type-1 terminal

Separation distances

– A minimum separation distance ranging from 14 m to 132 m, depending on the PRF, is required for interference from average power UWB emissions.

– A minimum separation distance ranging from 32 m to 132 m, depending on the PRF, is required for peak power UWB emissions in non-urban and urban areas.

Maximum permissible e.i.r.p. density in 1 MHz at 20 m distance

– The permissible e.i.r.p. density is equal to –91.65 dBm/MHz from non-dithered emissions with PRF not less than 1 MHz.

– The permissible e.i.r.p. density is equal to –84.66 dBm/MHz from dithered emissions with PRF not less than 1 MHz.

There is a potential for interference in all these cases.

Type-2 MES terminal

Separation distances

– A minimum separation distance ranging from 17 m to 286 m, depending on the PRF, is required for both average power and peak UWB emissions.

Maximum permissible e.i.r.p. density in 1 MHz at 20 m distance

– The permissible e.i.r.p. density is equal to –98.39 dBm/MHz from non-dithered emissions with PRF not less than 1 MHz.

– The permissible e.i.r.p. density is equal to –86.17 dBm/MHz from dithered emissions with PRF not less than 1 MHz.

There is a potential for interference in all these cases.

1.2.12.1.2 Hand-held MES terminals operating in 2 185 GHz band

A maximum permissible e.i.r.p density of –85 dBm/MHz is required to protect hand-held MES terminals operating in the frequency band 2 170-2 200 MHz.

1.2.12.1.3 MES terminals of non-GSO MSS systems operating in 2 185 GHz band

A maximum permissible average e.i.r.p density of –106.3 dBm/MHz and peak e.i.r.p density of –98.3 dBm/MHz are required to protect MES terminals of non-GSO MSS systems.

The following conclusions can be drawn from the results of the interference analysis with regard to aggregate interference from multiple UWB emitters in Scenario A.

1.2.12.1.4 Aero MES terminals

The results of the interference analysis indicate that the aggregate interference into the aeronautical MES terminal is unlikely to be problematic. The acceptable UWB emitter density to meet the interference criteria depends on the ratio of indoor devices to outdoor devices and as well as on their activity factor. With 4% activity factor and 80% indoor UWB devices, the following emitter densities/km^2 are required in order to meet the required interference criteria.

Type-1 Aero terminal

High altitude: 25 629 emitters/km^2

Medium altitude: 19 950 emitters/km^2

Low altitude: 11 878 emitters/km^2

Type-2 Aero terminal

High altitude: 22 853 emitters/km^2

Medium altitude: 17 780 emitters/km^2

Low altitude: 10 591 emitters/km^2

1.2.12.1.5 Maritime MES terminals

It is expected that there may not be a problem with regard to interference from single UWB device into a maritime MES terminal deployed on board the ships in international waters under interference Scenario A.

1.2.12.2 Uplink

The results indicate that the aggregate interference into the satellite receiver is unlikely to be problematic.

The feasibility of sharing between UWB devices and MSS networks depends on the expected number of UWB devices and the regulations for their deployment.

2 Radionavigation satellite service

2.1 Introduction

Radionavigation satellite systems (RNSS) are particular systems to which very careful consideration is afforded in the development of appropriate protection criteria to preclude interference from UWB-based unlicensed services.

Two overriding issues encountered in developing UWB protection requirements applicable to RNSS receivers were:

– the low signal levels available to terrestrial-based RNSS receivers;

– uncertainties associated with potential mobile UWB-to-mobile RNSS interference interactions.

As a result of the RNSS signals, the signal power at the surface of the Earth is very low. In addition, RNSS receivers, particularly those for use in mobile applications, employ small antenna sub-systems with characteristics inferior to the relatively large directional antennas typically used to receive satellite downlink signals.

Since UWB technology is proposed to be developed, interference interactions involving mobile applications of both UWB and RNSS technologies must be considered.

This paper summarizes the link budget analyses and those special circumstances considered in the development of UWB-specific criteria to ensure protection to existing and future RNSS receivers.

Regarding RNSS receivers, several ITU-R M series Recommendations have already been suggested as the basis to be used in the studies, but do not cover the RNSS systems evolutions, neither Galileo system current design and characteristics, nor foreseen GPS modernization program (new signals and characteristics).

The Recommendations are the following ones:

– Rec. ITU-R M.1088 – Considerations for sharing with systems of other services operating in the bands allocated to the radionavigation-satellite service

– Rec. ITU-R M.1317 – Considerations for sharing between systems of other services operating in bands allocated to the radionavigation-satellite and aeronautical radionavigation services and the global navigation satellite system (GLONASS-M)

– Rec. ITU-R M.1477 – Technical and performance characteristics of current and planned radionavigation-satellite service (space-to-Earth) and aeronautical radionavigation service receivers to be considered in interference studies in the band 1 559-1 610 MHz

– Rec. ITU-R M.1479 – Technical characteristics and performance requirements of current and planned radionavigation-satellite service (space-to-space) receivers to be considered in interference studies in the frequency bands 1 215-1 260 MHz and 1 559-1 610 MHz

– Rec. ITU-R M.1318 – Interference protection evaluation model for the radionavigation-satellite service in the 1 559-1 610 MHz band.

Looking at UWB interferences, depending on UWB type of applications (imaging, vehicular radars, communications, positioning) the impact on RNSS receiver might be different.

The interference effects upon RNSS receivers are classified as pulse-like, noise-like and CW-like transmissions and the RNSS receivers are not equally tolerant to each. GPS measurement campaigns done during the United States rulemaking process actually shown these different effects. The same classification is forecast for the Galileo receivers.

In addition, the class and the degree of UWB RFI impact is observed to depend on UWB signal characteristics such as pulse repetition frequency (PRF), waveform and modulation in relation to the RNSS receiver bandwidth, not only RF bandwidth (1 MHz magnitude) but also after correlation process bandwidth (less than 1 kHz magnitude).

Depending on the periodicity of the PRF, on the type of modulation (pulse amplitude modulation, pulse position modulation, on-off keying, bi-phase modulation), the UWB spectrum shape will be different. In some cases, it will produce many spectral lines where in other cases it could be considered as a continuous spectrum. The impact on the RNSS receiver will be very different.

For RNSS concerns, the two main types of UWB applications, namely those requiring high data rate and the others requiring low data rate, would then have mainly two different jamming expected effects:

– a noise floor increasing effect from the communications devices, degrading continuously RNSS receivers performance if they are sharing the RNSS band;
– an intermittent CW-like interference (loss of lock on satellites signal during tracking or interminable acquisition time), from the others devices (positioning, or radar/imaging). These latter effects need to be carefully studied.

2.1.1 Noise-like effect

For the noise-like effect only, classical link budget analysis is sufficient to propose appropriate regulations based on the Galileo system which seems to offer sufficient protection to RNSS receivers.

2.1.2 CW-like effect

RNSS receivers can also experience CW-like interference effects due to power concentrations in UWB frequency spectrums when periodical signals are used. Indeed, some UWB devices, foreseen for localization or Radar applications, could transmit periodic signal. The impact of the CW-like is fully presented and proposes adequate regulation for such UWB signal.

When the receiver loses lock onto the RNSS signal, it experiences a large phase and code error, resulting in the loss of the entire power of the navigation signal component, creating a positioning discontinuity. In the worst conditions, it can give hazardous misleading information on the user positioning. In these conditions, the power measured in the lock detection block is thus only due to the interferer, and is similar to the power that would have the useful signal without interferer. Consequently, the lock detection block is not able to detect that the receiver is tracking the interferer, rather than the useful signal.

This effect explains why commercial low cost receivers are very susceptible to CW interference: the loss of lock is not detected and the ranging measurement of jammed satellites is used to compute the position (in absence of receiver autonomous integrity monitoring (RAIM) algorithm or when only a few satellites are available). Indeed, receivers generally experience a large positioning error, as reported in lot of interference tests. As an example, it has been reported positioning errors in the order of several kilometres before the loss of lock detection.

For those reasons, CW interference can compromise the positioning integrity or the navigation service continuity, and must be considered as a critical event.

The signal loss of lock, the interferer tracking, and the large position error are rather known effects of CW interferers on RNSS receivers. However, all the parameters which enter in conjunction to cause one effect or the other have not, up to now, been clearly characterized.

It is needed to characterize the UWB (PRF, periodicity, modulation, etc.) and to assess the impact of each type of UWB on RNSS receivers.

In addition, depending on the GNSS application, the acquisition and tracking thresholds may be different and may lead to different protection levels.

Looking at the CW-like effect interference on RNSS GPS receivers, United States defined an additional limit in any 1 kHz bandwidth. This limit is 10 dB below the one proposed in 1 MHz: such a limit has been retained in the United States rules. Concerning GALILEO, a similar regulation proposes appropriate limit in any 1 kHz bandwidth, based on extensive and detailed theoretical analysis.

2.2 The global positioning system (GPS)

2.2.1 GPS usage

GPS came into existence as a satellite-based radionavigation service, and while this is still maintained as its core functionality, advancements in circuit miniaturization and computational capabilities have led to a revolution in innovative new technologies enabled by GPS receivers. Over the past decade, these new GPS-based services have experienced rapid growth in both the commercial and non-commercial markets worldwide. This promises to be a continuing market trend over the foreseeable future.

A complete listing of existing and potential applications of GPS technology is beyond the scope of this paper; however, the following list is representative of the applications considered in assessing the potential for interference to GPS receivers from the introduction of UWB on an unlicensed basis[52].

2.2.1.1 Aviation applications

GPS-aided aeronautical precision and non-precision approaches, instrumented landings and en-route navigation operations.

2.2.1.2 Maritime applications

The use of GPS to aid in navigation challenges associated with operations in constricted waterways, harbours, docks, and locks.

2.2.1.3 Railway applications

GPS is being used to implement positive train control (PTC) in efforts to improve traffic efficiency.

2.2.1.4 Emergency services applications

GPS is being used as a solution for providing location data from E-911 calls placed with a wireless handset. Many public safety first responders (police, fire, rescue, etc,) now utilize GPS for navigation and position location functions associated with their routine and emergency responsibilities.

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[52] NTIA Special Publications 01-45 and 01-47, "*Assessment of compatibility between ultrawideband (UWB) systems and global positioning system (GPS) receivers*," (Report and Addendum), 2001, (http://www.ntia.doc.gov/osmhome/reports.html).

2.2.1.5 Surveying and geographic information systems (GIS)

GPS is used extensively in surveying and mapping operations. High-grade systems are often capable of utilizing both the GPS standard positioning service (SPS) and the precise positioning service (PPS) to achieve very high accuracy.

2.2.1.6 Precision machine control

GPS has become integral in providing navigational control to mechanized operations such as precision agriculture. GPS also enables automated robotic systems designed to replace human workers in extremely hazardous environments.

2.2.2 GPS signal characteristics

The following provides a brief description of the existing and future GPS signals available for use in civil-based GPS applications.

2.2.2.1 GPS L1

The GPS L1 signal is centred on a frequency of 1 575.42 MHz with a registered bandwidth of 24 MHz (1 575.42 ± 12 MHz). As such, the L1 signal is completely contained within the 1 559-1 610 MHz frequency band allocated on a co-primary basis to the aeronautical radio navigation service (ARNS) and the radionavigation satellite service (RNSS).

The GPS L1 signal provides an SPS, a PPS, and a navigation message. The L1 carrier is modulated with a coarse acquisition (C/A) code to provide the SPS and is the only signal presently guaranteed to be available to civil users of GPS. The L1 carrier is also modulated with a longer precision (P) code, in phase-quadrature with the C/A-code, to provide the PPS. The minimum signal level at the surface of the Earth is specified as –130 dBm for the GPS L1 C/A-code signal.

2.2.2.2 GPS L2

The GPS L2 signal is transmitted on a centre frequency of 1 227.60 MHz with a registered bandwidth of 24 MHz (1 227.60 ± 12 MHz). Currently, only the P-code (unencrypted) or Y-code (encrypted) is modulated onto the GPS L2 carrier. Ongoing GPS modernization efforts include the addition of a new civil signal (L2C) in phase-quadrature with the GPS L2 carrier, providing an additional channel for civil utilization of the SPS.

2.2.2.3 GPS L5

The implementation of a new GPS signal, denoted L5, is also part of the ongoing GPS modernization effort. WRC-2000 provided a co-primary allocation to RNSS in the 1 164-1 215 MHz segment of the 960-1 215 MHz ARNS frequency band. GPS L5 will be transmitted on 1 176.45 MHz with a registered bandwidth of 24 MHz (1 176.45 ± 12 MHz). The new GPS L5 signal has been specifically designed to support aviation applications. However, based on the observed escalation of communications applications utilizing GPS L1, it can be anticipated that similar applications will also develop utilizing the L5 signal, once it becomes available.

2.2.3 Technical and performance characteristics of RNSS (space-to-Earth) systems and augmentation systems

Recommendation ITU-R M.1477 contains four annexes that describe various RNSS receivers that are recommended for use in interference analyses involving the RNSS in the band 1 559-1 610 MHz. Recommendation ITU-R M.1477 also recommends that a 6 dB safety margin, as discussed in Annex 5 to the Recommendation, be applied for the protection of the safety-of-life aspects and applications of RNSS and ARNS, when performing such interference analyses.

Table 1 of Recommendation ITU-R M.1477 describes a civil navigation GPS aeronautical receiver that is designed to provide category I precision approach guidance. This receiver must meet the requirements of a satellite-based augmentation system (SBAS) specification. It must track both GPS satellites and SBAS satellites, which have GPS-like codes and transmit at the same centre frequency of 1 575.42 MHz. The SBAS signal is modulated with data using a symbol rate of 500 bits/s, which is then decoded with a convolutional decoding scheme to output information at a rate of 250 bits/s. Land vehicle and marine navigation receivers are designed to provide metre-level guidance, using differential corrections obtained from any of a number of GPS augmentation systems, including SBASs, radiobeacon networks, or other local area broadcasts that use one of several frequencies from HF to UHF. Their characteristics described in Table 149 apply as well to these types of receivers. As noted in footnote[53] to this table, the interference thresholds identified already take into account the effects of GPS intra-system interference based on random code analysis. The threshold values must account for all other aggregate interference.

TABLE 149

SBAS air navigation receiver, Category I precision approach operations

L1 carrier centre frequency	1 575.42 MHz
C/A code chip rate	1.023 Mbit/s
Navigation data rate, GPS	50 bit/s
Navigation data rate, SBAS, with FEC, rate 1/2	500 symbols/s
Word error rate (1 word = 250 information bits)	10^{-3} per s
Minimum received power level at antenna input, SBAS	–161 dBW
Minimum antenna gain towards satellite at 5° elevation	–4.5 dBic
Maximum antenna gain in upper hemisphere	+7 dBic
Assumed antenna gain in lower hemisphere	–10 dBic
Maximum pre-correlation filter 3 dB bandwidth(1)	±16.5 MHz
Receiver noise figure	4.4 dB
RF pulse overload recovery time	25×10^{-6} s
Receiver aggregate wideband interference threshold in track mode(2), (3)	–140.5 dB(W/MHz)
Receiver aggregate wideband interference threshold in acquisition mode(2), (3)	–146.5 dB(W/MHz)
Receiver aggregate narrow-band interference threshold in track mode(2), (3)	–150.5 dBW
Receiver aggregate narrow-band interference threshold in acquisition mode(2), (3)	–156.5 dBW

(1) A more stringent pre-correlator filter may be needed to protect receiver operations from adjacent band RF emissions.

(2) The interference threshold already takes into account the effects of GPS intra-system interference-based on random code analysis. See § 2. The threshold must account for all other aggregate interference. The applicability of a safety margin is discussed in Annex 5.

(3) Wideband interference has a bandwidth in the range 100 kHz to 1 MHz; narrow-band interference has a bandwidth less than or equal to 700 Hz. For other bandwidths, refer to Fig. 1.

[53] Table 149 si a reproduction of Table 1 of Recommendation ITU-R M.1477.

Table 2[54] of Recommendation ITU-R M.1477 describes an air navigation receiver designed to provide Category II/III precision approach guidance. It must meet the requirements of a ground-based augmentation system (GBAS). It must track GPS satellites and pseudolites. Pseudolites are ground-based transmitters, which emit a signal having the characteristics of GPS, but utilizing different spreading codes. There are wideband and narrow-band pseudolites currently under consideration. Wideband pseudolites emit a code similar to the Y code, thus the signal has the spectral characteristics of the Y code. The pseudolites are pulsed with a duty cycle of less than 4%. The narrow-band pseudolites emit a signal having C/A code characteristics, offset from the L1 (L1 band is at 1 559-1 610 MHz) centre frequency by ±10.23 MHz. They are pulsed, with a duty cycle of about 9%.

TABLE 150

GBAS air navigation receiver, Category II/III precision approach operations

L1 carrier, wideband pseudolite frequency	1 575.42 MHz
Narrow-band pseudolite carrier frequency	L1 ± 10.23 MHz
C/A code, narrow-band pseudolite chip rate	1.023 Mbit/s
Wideband pseudolite code chip rate	1.023 Mbit/s
Navigation data rate, GPS	50 bit/s
Minimum received C/A code power level at antenna input	–161 dBW
Minimum average wideband pseudolite power level at antenna input	–140 dBW
Minimum average narrow-band pseudolite power level at antenna input	–140 dBW
Minimum antenna gain towards pseudolite	–21 dBic
Minimum antenna gain towards GPS satellite at 5° elevation	–4.5 dBic
Maximum antenna gain in upper hemisphere	+7 dBic
Maximum pre-correlation filter, 3 dB bandwidth(1)	±16.5 MHz
Receiver noise figure	4.4 dB
RF pulse overload recovery time	25×10^{-6} s
Receiver aggregate wideband interference threshold in track mode(2), (3)	–140.5 dB(W/MHz)
Receiver aggregate wideband interference threshold in acquisition mode(2), (3)	–146.5 dB(W/MHz)
Receiver aggregate narrow-band interference threshold in track mode(2), (3)	–150.5 dBW
Receiver aggregate narrow-band interference threshold in acquisition mode(2), (3)	–156.5 dBW

(1) A more stringent pre-correlator filter may be needed to protect receiver operations from adjacent band RF emissions.

(2) The interference threshold already takes into account the effects of GPS intra-system interference-based on random code analysis. See § 2. The threshold must account for all other aggregate interference. The applicability of a safety margin is discussed in Annex 5.

(3) Wideband interference has a bandwidth in the range 100 kHz to 1 MHz; narrow-band interference has a bandwidth less than or equal to 700 Hz. For other bandwidths, refer to Fig. 1.

[54] Table 150 is a reproduction of Table 2 of Recommendation ITU-R M.1477.

Table 3[55] of Recommendation ITU-R M.1477 describes a ground-based receiver, which is used in SBAS operations to determine ionospheric delays. It is also used in non-SBAS ground applications. This receiver uses a semi-codeless technique that exploits a unique feature of the GPS architecture whereby the L1 and L2 (L2 band is at 1 215-1 260 MHz) Y code signals are cross-correlated to provide a measurement of signal delay at L2, thus making it possible to determine the signal delay due to the ionosphere. The cross-correlation scheme is made possible by the fact that the GPS L1 and L2 signals have identical codes. This receiver must acquire and track both GPS and SBAS satellites at L1. Semi-codeless receivers are more sensitive to interference because they operate without benefit of knowing the Y code.

TABLE 151

SBAS ground network receiver, semi-codeless(1)

L1 carrier frequency	1 575.42 MHz
L2 carrier frequency	1 227.6 MHz
C/A code chip rate	1.023 Mbit/s
Y-code chip rate	10.23 Mbit/s
Navigation data rate, GPS	50 bit/s
Navigation data rate, SBAS, with FEC, rate 1/2	250 bit/s
Word error rate (1 word = 250 information bits)	10^{-3} per s
Minimum carrier power at antenna input (L1/CA)	–160 dBW
Minimum carrier power at antenna input (L1/Y)	–163 dBW
Minimum carrier power at antenna input (L2/Y)	–166 dBW
Minimum antenna gain towards satellite at 5° elevation	–4.5 dBic
Maximum antenna gain	+7 dBic
Maximum pre-correlation filter 3 dB bandwidth(2)	±16.5 MHz
Receiver noise figure	4.4 dB
RF pulse overload recovery time	25×10^{-6} s
Receiver aggregate wideband interference threshold in the Y-code track mode(3), (4)	–146.5 dB(W/MHz)
Receiver aggregate wideband interference threshold in acquisition mode(3), (4)	–146.5 dB(W/MHz)
Receiver aggregate narrow-band interference threshold in the Y-code track mode(3), (4)	–154.5 dBW
Receiver aggregate narrow-band interference threshold in acquisition mode(3), (4)	–156.5 dBW

(1) These receivers serve critical roles at SBAS ground stations at known fixed locations. Hence appropriate physical buffer zones should exist around such receivers. This Table also represents the characteristics of non-SBAS GPS semi-codeless receivers.

(2) A more stringent pre-correlator filter may be needed to protect receiver operations from adjacent band RF emissions.

(3) The interference threshold already takes into account the effects of GPS intra-system interference-based on random code analysis. See § 2. The threshold must account for all other aggregate interference. The applicability of a safety margin is discussed in Annex 5.

(4) Wideband interference has a bandwidth in the range 100 kHz to 1 MHz; narrow-band interference has a bandwidth less than or equal to 700 Hz. For other bandwidths, refer to Fig. 1.

55 Table 151 is reproduction of Table 3 of Recommendation ITU-R M.1477.

This Report will not repeat the above process for the numerous other types of RNSS receiver technical and performance characteristics covered in Annexes 2, 3, and 4 to Recommendation ITU-R M.1477. More details about the GPS system are given in Recommendation ITU-R M.1477. For details about the other RNSS systems that are described in Annexes 2, 3, and 4 to Recommendation ITU-R M.1477, and for the discussion of the aeronautical safety margin in Annex 5 to Recommendation ITU-R M.1477.

As Recommendation ITU-R M.1477 expressly states, the maximum interference levels in each of the tables do not refer to the allowable level of interference, but rather to the interference levels that manufacturers must design equipment to withstand, while still meeting performance requirements. The total allowable level of interference from known sources must be significantly below this value, namely by the safety margin (see Annex 5 to the Recommendation). This is to allow for variations in receiver performance and unknown sources of interference.

Radiocommunication TG 1/8 is also to take into account that the assessment of potential compatibility of UWB devices with RNSS systems and augmentation systems is to be conducted under the premise that UWB devices will operate, if at all, on a strictly non-interference basis. This means that UWB devices would not be entitled to as generous an interference allowance for purposes of compatibility assessment as, for example, would a device or system in a potentially co-primary service system.

Although Recommendation ITU-R M.1477 was generally developed for the 1 559-1 610 MHz band, it is, for purposes of the assessment of potential compatibility to be overseen by Radiocommunication TG 1/8, generally descriptive of the technical and performance characteristics of RNSS (space-to-Earth) systems and augmentation systems that operate or are planned for operation in the 1 164-1 215 MHz and 1 215-1 300 MHz bands. Deviations from this general proposition can be dealt with on an ad hoc basis as the studies progress.

2.2.4 Emissions limitations and associated technical requirements on UWB devices in order to protect RNSS systems and augmentation systems in the 1 165-1 215 MHz, 1 215-1 300 MHz, and 1 559-1 610 MHz bands

The following are the emission limitations and associated technical requirements that one administration has imposed on UWB devices in order to ensure the protection of the Global Positioning System. There are additional requirements for UWB devices that are not reproduced here, as they do not directly relate to the protection of RNSS systems and augmentation systems.

A Technical requirements for ground penetrating radars and wall imaging systems

1 The UWB bandwidth of an imaging system operating must be below 10.6 GHz.

2 Operation is limited to GPRs and wall imaging systems operated for purposes associated with law enforcement, fire fighting, emergency rescue, scientific research, commercial mining, or construction.

   a) Parties operating this equipment must be eligible for licensing under rules set out for this purpose.

   b) The operation of imaging systems under this section requires coordination, as set out in these rules.

3 A GPR that is designed to be operated while being hand-held and a wall imaging system shall contain a manually operated switch that causes the transmitter to cease operation within 10 s of being released by the operator. In lieu of a switch located on the imaging system, it is permissible to operate an imaging system by remote control provided the imaging system ceases transmission within 10 s of the remote switch being released by the operator.

4 The general emissions limits applicable to all UWB devices with emissions at or below 960 MHz are as follows:

Emissions (quasi-peak-detected) below 960 MHz

Frequency (MHz)	Field strength (μV/m)	Measurement distance (m)
0.009-0.490	2 400/*F* (kHz)	300
0.490-1.705	2 400/*F* (kHz)	30
1.705-30.000	30	30
30.000-88.000	100	3
88.000-216.000	150	3
216.000-960.000	200	3

NOTE 1 – *F* (kHz) is the frequency in kHz.

5 The radiated emissions above 960 MHz from a GPR or wall imaging system shall not exceed the following average limits when measured using a resolution bandwidth of 1 MHz:

Frequency (MHz)	e.i.r.p. (dBm)
960-1610	–65.3
1 610-1 990	–53.3
1 990-3 100	–51.3
3 100-10 600	–41.3
Above 10 600	–51.3

6 In addition to the radiated emission limits specified in the Table in paragraph 4) of this section, UWB transmitters operating under the provisions of this section shall not exceed the following average limits when measured using a resolution bandwidth of no less than 1 kHz:

Frequency (MHz)	e.i.r.p. (dBm)
1 164-1 240	–75.3
1 559-1 610	–75.3

7 For UWB devices where the frequency at which the highest radiated emission occurs, f_M, is above 960 MHz, there is a limit on the peak level of the emissions contained within a 50 MHz bandwidth centred on f_M. That limit is 0 dBm e.i.r.p. The United States rules contain a procedure pursuant to which it is acceptable to employ a different resolution bandwidth, and a correspondingly different peak emission limit.

B Technical requirements for through-wall imaging systems

1 The UWB bandwidth of an imaging system operating under the provisions of this section must be below 960 MHz or the centre frequency, f_C, and the frequency at which the highest radiated emission occurs, f_M, must be contained between 1 990 MHz and 10 600 MHz.

2 Operation under the provisions of this section is limited to through-wall imaging systems operated by law enforcement, emergency rescue or firefighting organizations that are under the authority of a local or state government.

3 For through-wall imaging systems operating with the UWB bandwidth below 960 MHz:

a) Parties operating this equipment must be eligible for licensing under rules set out for this purpose.

b) The operation of these imaging systems requires coordination, as set out in these rules.

c) The imaging system shall contain a manually operated switch that causes the transmitter to cease operation within 10 s of being released by the operator. In lieu of a switch located on the imaging system, it is permissible to operate an imaging system by remote control provided the imaging system ceases transmission within 10 s of the remote switch being released by the operator.

d) The general emissions limits applicable to all UWB devices with emissions at or below 960 MHz are as follows:

Emissions (quasi-peak-detected) below 960 MHz

Frequency (MHz)	**Field strength (μV/m)**	**Measurement distance (m)**
0.009-0.490	2 400/*F*(kHz)	300
0.490-1.705	2 400/*F*(kHz)	30
1.705-30.000	30	30
30.000-88.000	100	3
88.000-216.000	150	3
216.000-960.000	200	3

e) The radiated emissions above 960 MHz shall not exceed the following average limits when measured using a resolution bandwidth of 1 MHz:

Frequency (MHz)	**e.i.r.p. (dBm)**
960-1 610	–65.3
1 610-1 990	–53.3
Above 1 990	–51.3

f) In addition to the radiated emission limits specified in the table in paragraph d) of this section, emissions from these imaging systems shall not exceed the following average limits when measured using a resolution bandwidth of no less than 1 kHz:

Frequency (MHz)	**e.i.r.p. (dBm)**
1 164-1 240	–75.3
1 559-1 610	–75.3

4) For equipment operating with f_C and f_M between 1 990 MHz and 10 600 MHz:

a) Parties operating this equipment must hold a licence issued by the Federal Communications Commission to operate a transmitter in the Public Safety Radio Pool. The licence may be held by the organization for which the UWB operator works on a paid or volunteer basis.

b) This equipment may be operated only for law enforcement applications, the providing of emergency services, and necessary training operations.

c) The general emissions limits applicable to all UWB devices with emissions at or below 960 MHz are as follows:

Emissions (quasi-peak-detected) below 960 MHz

Frequency (MHz)	Field strength (µV/m)	Measurement distance (m)
0.009-0.490	2 400/*F*(kHz)	300
0.490-1.705	2 400/*F*(kHz)	30
1.705-30.000	30	30
30.000-88.000	100	3
88.000-216.000	150	3
216.000-960.000	200	3

d) The radiated emissions above 960 MHz shall not exceed the following average limits when measured using a resolution bandwidth of 1 MHz:

Frequency (MHz)	e.i.r.p. (dBm)
960-1 610	–46.3
1 610-10 600	–41.3
Above 10 600	–51.3

e) In addition to the radiated emission limits specified in paragraph 4) c) of this section, emissions from these imaging systems shall not exceed the following average limits when measured using a resolution bandwidth of no less than 1 kHz:

Frequency (MHz)	e.i.r.p. (dBm)
1 164-1 240	–56.3
1 559-1 610	–56.3

f) There is a limit on the peak level of the emissions contained within a 50 MHz bandwidth centred on the frequency at which the highest radiated emission occurs, f_M. That limit is 0 dBm e.i.r.p. The United States rules contain a procedure pursuant to which it is acceptable to employ a different resolution bandwidth, and a correspondingly different peak emission limit.

g) Through-wall imaging systems operating under the provisions of this section shall bear the following or similar statement in a conspicuous location on the device: "Operation of this device is restricted to law enforcement, emergency rescue and firefighter personnel. Operation by any other party is a violation of United States Federal Law, per 47 USC 301, and could subject the operator to serious legal penalties."

C Technical requirements for surveillance systems

1 The UWB bandwidth of an imaging system operating under the provisions of this section must be contained between 1 990 MHz and 10,600 MHz.

2 Operation under the provisions of this section is limited to fixed surveillance systems operated by law enforcement, fire or emergency rescue organizations or by manufacturers licensees, petroleum licensees or power licensees.

a) Parties operating under the provisions of this section must be eligible for licensing under rules set out for this purpose.

b) The operation of imaging systems under this section requires coordination, as required by these rules.

3 The general emissions limits applicable to all UWB devices with emissions at or below 960 MHz are as follows:

Emissions (quasi-peak-detected) below 960 MHz

Frequency (MHz)	Field strength (μV/m)	Measurement distance (m)
0.009-0.490	2 400/*F*(kHz)	300
0.490-1.705	2 400/*F*(kHz)	30
1.705-30.000	30	30
30.000-88.000	100	3
88.000-216.000	150	3
216.000-960.000	200	3

4 The radiated emissions above 960 MHz from a device operating under the provisions of this section shall not exceed the following average limits when measured using a resolution bandwidth of 1 MHz:

Frequency (MHz)	e.i.r.p. (dBm)
960-1 610	–53.3
1 610-1 990	–51.3
1 990-10 600	–41.3
Above 10 600	–51.3

5 In addition to the radiated emission limits specified in the Table above, UWB transmitters operating under the provisions of this section shall not exceed the following average limits when measured using a resolution bandwidth of no less than 1 kHz:

Frequency (MHz)	e.i.r.p. (dBm)
1 164-1 240	–63.3
1 559-1 610	–63.3

6 There is a limit on the peak level of the emissions contained within a 50 MHz bandwidth centered on the frequency at which the highest radiated emission occurs, f_M. That limit is 0 dBm e.i.r.p. The United States rules contain a procedure pursuant to which it is acceptable to employ a different resolution bandwidth, and a correspondingly different peak emission limit.

7 Imaging systems operating under the provisions of this section shall bear the following or similar statement in a conspicuous location on the device: “Operation of this device is restricted to law enforcement, fire and rescue officials, public utilities, and industrial entities. Operation by any other party is a violation of United States Federal Law, per 47 USC 301, and could subject the operator to serious legal penalties.”

D Technical requirements for medical imaging use

1 The UWB bandwidth of an imaging system operating under the provisions of this section must be contained between 3 100 MHz and 10,600 MHz.

2 Operation under the provisions of this section is limited to medical imaging systems used at the direction of, or under the supervision of, a licensed health care practitioner. The operation of imaging systems under this section requires coordination, as detailed in these rules.

3 A medical imaging system shall contain a manually operated switch that causes the transmitter to cease operation within 10 s of being released by the operator. In lieu of a switch located on the imaging system, it is permissible to operate an imaging system by remote control provided the imaging system ceases transmission within 10 s of the remote switch being released by the operator.

4 The general emissions limits applicable to all UWB devices with emissions at or below 960 MHz are as follows:

Emissions (quasi-peak-detected) below 960 MHz

Frequency (MHz)	Field strength (μV/m)	Measurement distance (m)
0.009-0.490	2 400/*F*(kHz)	300
0.490-1.705	2 400/*F*(kHz)	30
1.705-30.000	30	30
30.000-88.000	100	3
88.000-216.000	150	3
216.000-960.000	200	3

5 The radiated emissions above 960 MHz from a device operating under the provisions of this section shall not exceed the following average limits when measured using a resolution bandwidth of 1 MHz:

Frequency (MHz)	**e.i.r.p. (dBm)**
960-1 610	–65.3
1 610-1 990	–53.3
1 990-3 100	–51.3
3 100-10 600	–41.3
Above 10 600	–51.3

6 In addition to the radiated emission limits specified in the Table above, UWB transmitters operating under the provisions of this section shall not exceed the following average limits when measured using a resolution bandwidth of no less than 1 kHz:

Frequency (MHz)	**e.i.r.p. (dBm)**
1 164-1 240	–75.3
1 559-1 610	–75.3

7 There is a limit on the peak level of the emissions contained within a 50 MHz bandwidth centered on the frequency at which the highest radiated emission occurs, f_M. That limit is 0 dBm e.i.r.p. The United States rules contain a procedure pursuant to which it is acceptable to employ a different resolution bandwidth, and a correspondingly different peak emission limit.

E Technical requirements for vehicular radar systems

1 Operation under the provisions of this section is limited to UWB field disturbance sensors mounted in terrestrial transportation vehicles. These devices shall operate only when the vehicle is operating, e.g. the engine is running. Operation shall occur only upon specific activation, such as upon starting the vehicle, changing gears, or engaging a turn signal.

2 The UWB bandwidth of a vehicular radar system operating under the provisions of this section shall be contained between 22 GHz and 29 GHz. In addition, the centre frequency, f_C, and the frequency at which the highest level emission occurs, f_M, must be greater than 24.075 GHz.

3 Following proper installation, vehicular radar systems shall attenuate any emissions within the 23.6-24.0 GHz band that appear 38º or greater above the horizontal plane by 25 dB below the limit specified in paragraph (4) of this section. For equipment authorized, manufactured or imported on or after 1 January, 2005, this level of attenuation shall be 25 dB for any emissions within the 23.6-24.0 GHz band that appear 30º or greater above the horizontal plane. For equipment authorized, manufactured or imported on or after 1 January, 2010, this level of attenuation shall be 30 dB for any emissions within the 23.6-24.0 GHz band that appear 30º or greater above the horizontal plane. For equipment authorized, manufactured or imported on or after 1 January, 2014, this level of attenuation shall be 35 dB for any emissions within the 23.6-24.0 GHz band that appear 30º or greater above the horizontal plane. This level of attenuation can be achieved through the antenna directivity, through a reduction in output power or any other means.

4 The general emissions limits applicable to all UWB devices with emissions at or below 960 MHz are as follows:

Emissions (quasi-peak-detected) below 960 MHz

Frequency (MHz)	Field strength (μV/m)	Measurement distance (m)
0.009-0.490	2 400/*F*(kHz)	300
0.490-1.705	2 400/*F*(kHz)	30
1.705-30.000	30	30
30.000-88.000	100	3
88.000-216.000	150	3
216.000-960.000	200	3

5 The radiated emissions above 960 MHz from a device operating under the provisions of this section shall not exceed the following average limits when measured using a resolution bandwidth of 1 MHz:

Frequency (MHz)	e.i.r.p. (dBm)
960-1 610	–75.3
1 610-22 000	–61.3
22 000-9 000	–41.3
29 000-31 000	–51.3
Above 31 000	–61.3

6 In addition to the radiated emission limits specified in the table above, UWB transmitters operating under the provisions of this section shall not exceed the following average limits when measured using a resolution bandwidth of no less than 1 kHz:

Frequency (MHz)	e.i.r.p. (dBm)
1 164-1 240	–85.3
1 559-1 610	–85.3

7 There is a limit on the peak level of the emissions contained within a 50 MHz bandwidth centered on the frequency at which the highest radiated emission occurs, f_M. The United States rules contain a procedure pursuant to which it is acceptable to employ a different resolution bandwidth, and a correspondingly different peak emission limit.

F *Technical requirements for indoor UWB systems*

1 Operation under the provisions of this section is limited to UWB transmitters employed solely for indoor operation.

a) Indoor UWB devices, by the nature of their design, must be capable of operation only indoors. The necessity to operate with a fixed indoor infrastructure, e.g., a transmitter that must be connected to the AC power lines, may be considered sufficient to demonstrate this.

b) The emissions from equipment operated under this section shall not be intentionally directed outside of the building in which the equipment is located, such as through a window or a doorway, to perform an outside function, such as the detection of persons about to enter a building.

c) The use of outdoor mounted antennas, e.g. antennas mounted on the outside of a building or on a telephone pole, or any other outdoors infrastructure is prohibited.

d) Field disturbance sensors installed inside of metal or underground storage tanks are considered to operate indoors provided the emissions are directed towards the ground.

e) A communications system shall transmit only when the intentional radiator is sending information to an associated receiver.

2 The UWB bandwidth of a UWB system operating under the provisions of this section must be contained between 3 100 MHz and 10 600 MHz.

3 The general emissions limits applicable to all UWB devices with emissions at or below 960 MHz are as follows:

Emissions (quasi-peak-detected) below 960 MHz

Frequency (MHz)	**Field strength (μV/m)**	**Measurement distance (m)**
0.009-0.490	2 400/*F*(kHz)	300
0.490-1.705	2 400/*F*(kHz)	30
1.705-30.000	30	30
30.000-88.000	100	3
88.000-216.000	150	3
216.000-960.000	200	3

4 The radiated emissions above 960 MHz from a device operating under the provisions of this section shall not exceed the following average limits when measured using a resolution bandwidth of 1 MHz:

Frequency (MHz)	**e.i.r.p. (dBm)**
960-1 610	–75.3
1 610-1 990	–53.3
1 990-3 100	–51.3
3 100-10 600	–41.3
Above 10 600	–51.3

5 In addition to the radiated emission limits specified in the table above, UWB transmitters operating under the provisions of this section shall not exceed the following average limits when measured using a resolution bandwidth of no less than 1 kHz:

Frequency (MHz)	e.i.r.p. (dBm)
1 164-1 240	–85.3
1 559-1 610	–85.3

6 There is a limit on the peak level of the emissions contained within a 50 MHz bandwidth centered on the frequency at which the highest radiated emission occurs, f_M. That limit is 0 dBm e.i.r.p. The United States rules contain a procedure pursuant to which it is acceptable to employ a different resolution bandwidth, and a correspondingly different peak emission limit.

7 UWB systems operating under the provisions of this section shall bear the following or similar statement in a conspicuous location on the device or in the instruction manual supplied with the device: "This equipment may only be operated indoors. Operation outdoors is a violation of United States Federal Law, per 47 USC 301, and could subject the operator to serious legal penalties."

G Technical requirements for hand held UWB systems

1 UWB devices operating under the provisions of this section must be hand-held, i.e., they are relatively small devices that are primarily hand held while being operated and do not employ a fixed infrastructure.

a) A UWB device operating under the provisions of this section shall transmit only when it is sending information to an associated receiver. The UWB intentional radiator shall cease transmission within 10 s unless it receives an acknowledgment from the associated receiver that its transmission is being received. An acknowledgment of reception must continue to be received by the UWB intentional radiator at least every 10 s or the UWB device must cease transmitting.

b) The use of antennas mounted on outdoor structures, e.g. antennas mounted on the outside of a building or on a telephone pole, or any fixed outdoors infrastructure is prohibited. Antennas may be mounted only on the hand-held UWB device.

c) UWB devices operating under the provisions of this section may operate indoors or outdoors.

2 The UWB bandwidth of a device operating under the provisions of this section must be contained between 3 100 MHz and 10 600 MHz.

3 The general emissions limits applicable to all UWB devices with emissions at or below 960 MHz are as follows:

Emissions (quasi-peak-detected) below 960 MHz

Frequency (MHz)	**Field strength (μV/m)**	**Measurement distance (m)**
0.009-0.490	2 400/*F*(kHz)	300
0.490-1.705	2 400/*F*(kHz)	30
1.705-30.000	30	30
30.000-88.000	100	3
88.000-216.000	150	3
216.000-960.000	200	3

4 The radiated emissions above 960 MHz from a device operating under the provisions of this section shall not exceed the following average limits when measured using a resolution bandwidth of 1 MHz:

Frequency (MHz)	**e.i.r.p. (dBm)**
960-1 610	–75.3
1 610-1 990	–63.3
1 990-3 100	–61.3
3 100-10 600	–41.3
Above 10 600	–61.3

5 In addition to the radiated emission limits specified in the Table above, UWB transmitters operating under the provisions of this section shall not exceed the following average limits when measured using a resolution bandwidth of no less than 1 kHz:

Frequency (MHz)	**e.i.r.p. (dBm)**
1 164-1 240	–85.3
1 559-1 610	–85.3

6 There is a limit on the peak level of the emissions contained within a 50 MHz bandwidth centered on the frequency at which the highest radiated emission occurs, f_M. That limit is 0 dBm e.i.r.p. The United States rules contain a procedure pursuant to which it is acceptable to employ a different resolution bandwidth, and a correspondingly different peak emission limit.

H Technical requirements applicable to all UWB devices

1 UWB devices may not be employed for the operation of toys. Operation onboard an aircraft, a ship or a satellite is prohibited.

2 Manufacturers and users are reminded of the provisions of rules specified for this purpose.

3 Emissions from digital circuitry used to enable the operation of the UWB transmitter shall comply with the limit of 500 microvolts per metre at 3 m if operating above 960 MHz, and if operating at or below 960 MHz, shall comply with the following limits.

Emissions (quasi-peak-detected) below 960 MHz

Frequency (MHz)	Field strength (μV/m)	Measurement distance (m)
0.009-0.490	2 400/*F*(kHz)	300
0.490-1.705	2 400/*F*(kHz)	30
1.705-30.000	30	30
30.000-88.000	100	3
88.000-216.000	150	3
216.000-960.000	200	3

The limits set out in this subpart apply, provided it can be clearly demonstrated that those emissions from the UWB device are due solely to emissions from digital circuitry contained within the transmitter and that the emissions are not intended to be radiated from the transmitter's antenna. Emissions from associated digital devices (e.g., emissions from digital circuitry used to control additional functions or capabilities other than the UWB transmission) are subject to specified limits.

4 Within the tables set out above, the tighter emission limit applies at the band edges. Radiated emission levels at and below 960 MHz are based on measurements employing a CISPR quasi-peak detector. Radiated emission levels above 960 MHz are based on RMS average measurements over a 1 MHz resolution bandwidth. The RMS average measurement is based on the use of a spectrum analyzer with a resolution bandwidth of 1 MHz, an RMS detector, and a 1 ms or less averaging time. If pulse gating is employed where the transmitter is quiescent for intervals that are long compared to the nominal pulse repetition interval, measurements shall be made with the pulse train gated on.

5 The frequency at which the highest radiated emission occurs, f_M, must be contained within the UWB bandwidth.

6 Imaging systems may be employed only for the type of information exchange described in their specific definitions. The detection of tags or the transfer or data or voice information is not permitted under the standards for imaging systems.

7 When a peak measurement is required, it is acceptable to use a resolution bandwidth other than the 50 MHz specified in this subpart. This resolution bandwidth shall not be lower than 1 MHz or greater than 50 MHz, and the measurement shall be centered on the frequency at which the highest radiated emission occurs, f_M. If a resolution bandwidth other than 50 MHz is employed, the peak e.i.r.p. limit shall be 20 log (RBW/50) dBm where RBW is the resolution bandwidth in megahertz that is employed. This may be converted to a peak field strength level at 3 m using E(dBuV/m) = P(dBm e.i.r.p.) + 95.2. If RBW is greater than 3 MHz, the application for certification filed with the Commission must contain a detailed description of the test procedure, calibration of the test setup, and the instrumentation employed in the testing.

8 The highest frequency employed to determine the frequency range over which radiated measurements are made shall be based on the centre frequency, f_C, unless a higher frequency is generated within the UWB device. For measuring emission levels, the spectrum shall be investigated from the lowest frequency generated in the UWB transmitter, without going below 9 kHz, up to the frequency range shown in these rules or up to f_C + 3/(pulse width (s)),

whichever is higher. There is no requirement to measure emissions beyond 40 GHz provided f_C is less than 10 GHz; beyond 100 GHz if f_C is at or above 10 GHz and below 30 GHz; or beyond 200 GHz if f_C is at or above 30 GHz.

9 The prohibition against Class B (damped wave) emissions does not apply to UWB devices operating under this subpart.

10 Responsible parties are reminded of the other standards and requirements, such as a limit on emissions conducted onto the AC power lines.

I Coordination requirements

1 UWB imaging systems require coordination through the FCC before the equipment may be used. The operator shall comply with any constraints on equipment usage resulting from this coordination.

2 The users of UWB imaging devices shall supply operational areas to the FCC Office of Engineering and Technology, which shall coordinate this information with the Federal Government through the National Telecommunications and Information Administration. The information provided by the UWB operator shall include the name, address and other pertinent contact information of the user, the desired geographical area(s) of operation, and the FCC ID number and other nomenclature of the UWB device. If the imaging device is intended to be used for mobile applications, the geographical area(s) of operation may be the state(s) or county(ies) in which the equipment will be operated. The operator of an imaging system used for fixed operation shall supply a specific geographical location or the address at which the equipment will be operated. This material shall be submitted to Frequency Coordination Branch, OET, Federal Communications Commission, 445 12th Street, SW, Washington, D.C. 20554, Attn: UWB Coordination.

3 The manufacturers, or their authorized sales agents, must inform purchasers and users of their systems of the requirement to undertake detailed coordination of operational areas with the FCC prior to the equipment being operated.

4 Users of authorized, coordinated UWB systems may transfer them to other qualified users and to different locations upon coordination of change of ownership or location to the FCC and coordination with existing authorized operations.

5 The FCC/NTIA coordination report shall identify those geographical areas within which the operation of an imaging system requires additional coordination or within which the operation of an imaging system is prohibited. If additional coordination is required for operation within specific geographical areas, a local coordination contact will be provided. Except for operation within these designated areas, once the information requested on the UWB imaging system is submitted to the FCC no additional coordination with the FCC is required provided the reported areas of operation do not change. If the area of operation changes, updated information shall be submitted to the FCC following the procedure in paragraph 2) of this section.

6 The coordination of routine UWB operations shall not take longer than 15 business days from the receipt of the coordination request by NTIA. Special temporary operations may be handled with an expedited turn-around time when circumstances warrant. The operation of UWB systems in emergency situations involving the safety of life or property may occur without coordination provided a notification procedure.

2.2.5 Study of UWB impact on GPS-enabled phones

Operational scenarios were developed for each of the GPS applications listed in § 2.2.1. These scenarios represent input provided by participants from government and commercial interests in response to public meetings and solicitations. Link budget analyses were performed under the assumptions implied by each of the proposed GPS application-based operational scenarios. Where applicable, these link budget analyses were performed utilizing technical characteristics and practices consistent with those specified in Recommendation ITU-R M.1477.

The results of the link budget analyses yielded a single limiting operational scenario with respect to anticipated worst-case interactions between mobile UWB transmitters and mobile GPS receivers. It was deemed that the protection requirements associated with this GPS operational scenario are more than adequate to protect GPS usage in all other applications[56].

The limiting scenario identified from this process is predicated on an emerging technology with the potential for enabling the use of GPS receivers in indoor locations. This technology is evolving as one method for implementing E-911 services in wireless telephone handsets. For indoor applications, the already low GPS signal power at the surface of the earth is further reduced as a result of additional propagation path attenuation (i.e. signal reduction) associated with the signal passing through the building walls and/or ceiling.

The particular interference concern inherent to this scenario is with regards to general UWB communications applications, primarily due to a possible rapid proliferation of devices. A similar methodology was also applied to assess the impact from other authorized UWB applications under assumptions associated with this scenario. In each case, extenuating factors such as the likelihood of an interaction and the potential for device proliferation were also given consideration.

2.2.5.1 UWB transmitter-to-GPS receiver link budget analyses

This section presents the link budget analysis performed for the GPS-enabled E-911 indoor operational scenario. An explanation and rationalization is offered for each of the parameter assumptions included in the analysis.

Table 152 presents the parameters included in the link budget analysis performed to determine the protection necessary to the GPS component associated with the E-911 operational scenario. A discussion of each parameter follows.

TABLE 152

Link budget analysis for GPS-enabled E-911 indoor operation

Parameter	Value
GPS protection requirement relative to UWB transmissions (I/N = –3 dB)	–114.5 dBm/MHz
GPS antenna gain in direction of UWB source	0 dBi
Propagation path loss @ 2 m	42.4 dB
UWB uncertainty factor	–3.0 dB
E-911 protection requirement	–75.1 dBm/MHz

GPS protection requirement

The requirement for GPS protection from UWB radiated emissions was specified as an I/N of –3 dB. The thermal noise density of a typical GPS receiver is –111.5 dBm as expressed in a nominal receiver bandwidth of 1 MHz. Thus, an I/N requirement of –3 dB yields a required protection threshold of –114.5 dBm/MHz.

[56] FCC 02-48, *First Report and Order, In the matter of: Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems*, ET Docket 98-153, February, 2002, https://apps.fcc.gov/edocs_public/attachmatch/FCC-02-48A1.pdf.

GPS antenna gain in direction of UWB source

The antenna subsystem utilized in this type of GPS application is often implemented as a silicone patch. The antenna typically produces an upper hemispherical pattern, with the gain maximized in the direction of the satellites in space. Table 153 defines the model used to determine the GPS antenna gain in the direction of an assumed UWB source. Emissions from UWB transmitters were assumed incident in the side lobe (–10 to 10°) region of the GPS receive antenna in this scenario.

TABLE 153

GPS receive antenna model

Off-axis angle (degrees relative to horizon)	**GPS antenna gain (dBi)**
10 to 90	3
–10 to 10	0
–90 to –10	–4.5

Propagation path loss at 2 m

An unobstructed, 2 m propagation path was assumed between a UWB transmitter and a GPS-aided handset in the E-911 operational scenario. Free-space path loss was determined from:

$$L_p = 20 \log_{10} (F) + 20 \log_{10} (D) - 27.55$$

where:

L_p: free-space propagation path loss (dB)

F: frequency (MHz)

D: propagation path length (m)[57]

For a propagation path of 2 m and GPS L1 centre frequency of 1 575.42 MHz, the theoretical free-space loss is 42.4 dB.

UWB uncertainty factor

A 3 dB factor was included in the link budget to account for lingering uncertainties with respect to future UWB signal structures and eventual device densities.

Summary

The required protection criteria is determined by summing the values in the right-hand column of Table 152, resulting in an equivalent isotropic radiated power (e.i.r.p.) limit of –75.1 dBm/MHz as necessary to protect GPS receivers from a single UWB emitter under the assumptions associated with the E-911 operational scenario.

2.2.5.2 United States adopted UWB emissions limits in the GPS frequency bands

The results obtained from the E-911 link budget analysis were used to establish on r.m.s. average emissions limit in the GPS frequency bands for general UWB communications applications. Similar analyses were performed for each authorized UWB application. Table 154 provides the applicable UWB emissions limits in the GPS bands for each of the authorized UWB applications. Note that the

[57] NTIA Special Publication 01-45, "*Assessment of Compatibility Between Ultrawideband (UWB) Systems and Global Positioning System (GPS) Receivers*," 2001, (http://www.ntia.doc.gov/osmhome/reports.html).

link budget result was slightly adjusted (from –75.1 to –75.3 dBm/MHz) in the table of emissions limits. This was done to facilitate reference to the existing general emissions limits applicable to un0licensed devices, which when expressed as an e.i.r.p. within a 1 MHz reference bandwidth, is –41.3 dBm/MHz. Thus, the limit for emissions associated with general UWB communications applications represents a reduction of 34 dB relative to the general unlicensed emissions limit.

It should be noted that the GPS protection requirements apply to the entire region of spectrum encompassing the existing L1 signal and the future L2C and L5 signals (960-1 610 MHz). As a consequence, other systems operating in this frequency range are afforded a level of protection equivalent to that provided to GPS. Coincidently, the same level of protection extends to existing (GLONASS) and emerging (Galileo) radionavigation systems operating within the RNSS.

TABLE 154

UWB emissions limits applicable to the GPS frequency bands

Authorized UWB application		**UWB emissions limits in GPS frequency bands**	
		Average (r.m.s.) e.i.r.p. (dBm/MHz)	**Spectral line (r.m.s.) e.i.r.p. (dBm)**
Ground penetrating/wall imaging radar		–65.3	–75.3
Through-wall imaging	BW < 960 MHz	–65.3	–75.3
	BW > 960 MHz	–46.3	–56.3
Surveillance systems		–53.3	–63.3
Medical imaging		–65.3	–75.3
Indoor communications		–75.3	–85.3
Handheld (including outdoor) communications		–75.3	–85.3
Vehicular radar		–75.3	–85.3

In addition to the r.m.s. average emissions limit, a spectral line emissions limit was also adopted. The spectral line limit is intended to protect GPS receivers from potential interference interactions involving un-modulated UWB waveforms. This limit is specified as 10 dB below the average limit when measured with a resolution bandwidth no less than 1 kHz. The spectral line emissions limit is applicable to the 1 164-1 240 MHz (L5 and L2C) and the 1 559-1 610 MHz (L1) frequency bands.

The limits depicted in Table 154 are specific to the UWB emissions generated by a device employing the technology. Within the GPS frequency bands, the UWB radiated emissions limits are significantly lower than those limits applied to most other unintentional radiators, in particular, commercial microprocessors. Considering existing microprocessor clock speeds, it is anticipated that unintentional emissions generated by companion digital circuitry integrated within a UWB communications device may be present (via leakage from device casing) within the GPS frequency bands at higher levels than actual UWB emissions. Since off-the-shelf (OTS) microprocessor technology will be implemented in UWB devices to perform functions unrelated to the transmission of the waveform, unintentional emissions that comply with those emission limits applicable to the microprocessor, but which exceed the limits applicable to UWB emissions, might result in a UWB device failing a compliance test. Therefore, a provision was established within the UWB rules to permit the integral use of OTS microprocessors in UWB devices[58]. This provision allows for radiated emissions from digital circuitry integral to a UWB device to exceed the UWB emissions limit (up to the applicable limit) if it can be clearly demonstrated that these emissions are due solely to emissions from digital circuitry contained within the transmitter and that these emissions are not intended to be radiated by the transmitting antenna of the UWB device.

2.2.6 Global positioning system (GPS) of the global navigation satellite system (GNSS)

Radionavigation Satellite Service:

Application: Global Positioning System (GPS) of the Global Navigation Satellite System (GNSS)

The GNSS is a worldwide position and time determination system, which includes one or more satellite constellations, aircraft receivers, and system integrity monitoring, augmented as necessary to support the required navigational performance for the actual phase of aircraft operation. The satellite navigation systems in operation are the GPS of the United States and the global orbiting navigation satellite system (GLONASS) of the Russian Federation. Both systems were offered to ICAO as a means to support the evolutionary development of GNSS.

The GPS consists of 24 satellite positions with four satellite positions in each of six 55° inclined equally spaced orbital planes. Each satellite will transmit the same two frequencies for navigational signals. These navigational signals are modulated with a predetermined bit stream, containing coded ephemeris data and time, and having a sufficient bandwidth to produce the necessary navigation precision without recourse to two-way transmission or Doppler integration. The system will provide accurate position determination in three dimensions anywhere on or near the surface of the Earth.

Frequency band:

1 559-1 610 MHz

L1 carrier frequency 1 575.42 MHz

Protection requirements:

Total tolerable interference level at victim receiver's isotropic antenna port

Parameter	Value	Unit	Remarks
Receiver aggregate wideband interference threshold in acquisition mode at antenna port	–146.5	dB(W/MHz)	Receiver aggregate wideband interference threshold in acquisition mode as given in ICAO Annex 10 and Rec. ITU-R M.1477. This value is considered to be applicable for noise-like signals only. For this analysis the UWB signal is considered to be noise-like. This value is taken as the maximum value of UWB interference signal power that still allows the receiver to meet its performance requirements
Antenna gain towards interference source	0	dB	Victim receiver antenna gain towards the interfering UWB signal

[58] FCC 03-33, *Memorandum Opinion and Order and Further Notice of Proposed Rulemaking in the matter of: Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems*, ET Docket 98-153, February, 2003, https://apps.fcc.gov/edocs_public/attachmatch/FCC-03-33A1.pdf, p.76.

Parameter	Value	Unit	Remarks
Single-to-multiple interference factor	10	dB	If there is a potential for other than interference sources at the same time, an allowance should be made for the aggregate interference. Since UWB is not considered as a radio service a 10% allowance is made.
Aeronautical safety factor	6	dB	
Total tolerable UWB interference level at isotropic antenna port	–162.5	dB(W/MHz)	

Interference scenarios and methodology

UWB characteristics

Parameter	Value	Unit	Remarks
United States indoor emission limit	–75.3	dBm/MHz	1 575 MHz
United States outdoor emission limit	–75.3	dBm/MHz	1 575 MHz
Slope mask indoor emission limit	–76.9	dBm/MHz	1 575 MHz
Slope mask outdoor emission limit	–86.9	dBm/MHz	1 575 MHz
Activity factor	100	%	

Methodology for single UWB transmitter

The methodology as described in document Recommendation ITU-R SM.1757, § 2.2.1 has been used. The propagation loss between transmitting and receiving antennas has been derived from free-space propagation.

Methodology for multiple UWB transmitters

For the calculation of the cumulative interference power generated by multiple UWB devices the NTIA airborne aggregate model, as given in document Recommendation ITU-R SM.1757, § 2.3 has been used.

Results of theoretical compatibility studies

Single interfering UWB device analysis:

Tolerable UWB emission limit for different victim receiver heights

Tolerable UWB emission limit for a single device at 1 575 MHz, dBm/MHz				
Rx height 70 ft (21 m)	Rx height 100 ft (30 m)	Rx height 1 000 ft (305 m)	Rx height 10 000 ft (3 048 m)	Rx height 45 000 ft (13 716 m)
–69.7	–66.6	–46.5	**–26.5**	**–13.4**

Required separation distances for given UWB emission limits

UWB United States indoor emission limit	United States limit –75.3 dBm/MHz at 1 575 MHz
Required separation distance (m)	11

UWB United States outdoor emission limit	United States limit –75.3 dBm/MHz at 1 575 MHz
Required separation distance (m)	11

UWB slope indoor emission limit	Slope mask –76.9 dBm/MHz at 1 575 MHz
Required separation distance (m)	9.2

UWB slope outdoor emission limit	Slope mask –86.9 dBm/MHz at 1 575 MHz
Required separation distance (m)	2.9

Aggregate interference analysis:

Maximum tolerable UWB emitter density for given UWB single device emission limits and victim receiver heights

UWB single device emission limit	Tolerable UWB emitter density/km^2				
	Rx height 70 ft (21 m)	Rx height 100 ft (30 m)	Rx height 1 000 ft (305 m)	Rx height 10 000 ft (3 048 m)	Rx height 45 000 ft (13 716 m)
United States indoor at 1 575 MHz –75.3 dBm/MHz	190	190	240	300	370
United States outdoor at 1 575 MHz –75.3 dBm/MHz	190	190	240	300	370
Slope in-door at 1 575 MHz –76.9 dBm/MHz	280	280	340	440	530
Slope out-door at 1 575 MHz –86.9 dBm/MHz	2 800	2 800	3 400	4 400	5 300

Maximum UWB single device emission limit for given emitter density and victim receiver height

Emitter density (emitters/km^2)	**Tolerable UWB emission limit for a single device at 1 575 MHz, dBm/MHz**				
	Rx height 70 ft (21 m)	Rx height 100 ft (30 m)	Rx height 1 000 ft (305 m)	Rx height 10 000 ft (3 048 m)	Rx height 45 000 ft (13 716 m)
1	–52.4	–52.3	–51.5	–50.4	–49.6
10	–62.4	–62.3	–61.5	–60.4	–59.6
100	–72.4	–72.3	–71.5	–70.4	–69.6
1 000	–82.4	–82.3	–81.5	–80.4	–79.6
10 000	–92.4	–92.3	–91.5	–90.4	–89.6
100 000	–102.4	–102.3	–101.5	–100.4	–99.6
1 000 000	–112.4	–112.3	–111.5	–110.4	–109.6

Conclusions

UWB devices may have the potential to cause harmful interference to aeronautical safety services. The development of provisions regulating the spectrum access for UWB devices should therefore be built up on a sound technical basis. The simplified static model, as described in this Annex, should be used for the initial evaluation of the potential for interference to aeronautical safety services from emissions of UWB devices. The maximum value of UWB interference signal power that still allows the aeronautical receiver to meet its performance requirements need to be derived by measurements. Because different UWB waveforms may affect the operation of aeronautical receivers in different ways, it is important to standardize UWB emission characteristics. The most threatening UWB signal characteristic needs to be determined and use for laboratory testing of aeronautical receivers. It may also be necessary to conduct field-testing on operational aircraft.

Test procedures for measuring aeronautical receiver characteristics in the presence of emissions from UWB devices needs to be developed. Recommendation ITU-R SM.1140 may provide guidance in the development of test procedures for measuring aeronautical receiver characteristics to be used for determining the influence of emissions from UWB devices into aeronautical receivers.

2.3 Galileo

2.3.1 Introduction

The effect of UWB systems versus the RNSS Galileo system, is studied in this section. The objective is to theoretically determine the degradations caused by UWB systems to Galileo receivers.

Table 155 indicates the main kinds of UWB applications that are being studied.

TABLE 155

Main kinds of UWB applications

UWB application
Ground penetrating/wall imaging radar
Through wall imaging
Surveillance systems
Medical imaging
Indoor communications
Handheld communications

2.3.2 Galileo services

2.3.2.1 Safety-of-life applications

Galileo will provide a specific service for critical applications such as Aviation application from en route navigation operations up to Precision approaches.

This service will be used also for critical applications such as Rail and Maritime applications.

2.3.2.2 Commercial applications

Galileo will provide a commercial service facilitating the development of professional applications and offering enhanced performance compared with the basic service, particularly in terms of service guarantee.

2.3.2.3 Mass market applications

Galileo will provide an open, free basic service, mainly involving applications for the general public and services of general interest. This service is comparable to that provided by civil GPS SPS, which is free of cost for these applications, but with improved quality and reliability.

This service will be used for Emergency service E112, which will be developed in the future in Europe.

2.3.2.4 Governmental applications

Galileo will provide a public regulated service (PRS), encrypted and resistant to jamming and interference, reserved principally for the public authorities responsible for civil protection, national security and law enforcement which demand a high level of continuity. It will enable secured applications to be developed in the European Union, and could prove in particular to be an important tool in improving the instruments used by the European Union.

2.3.3 Galileo signal characteristics

The following provides a brief description of the future Galileo signals available for use in Galileo applications The following sections provide a brief description of the future Galileo signals available for use in Galileo applications. These characteristics have been used for the studies.

Some ITU Recommendations such as Recommendation ITU-R M.1477, include the technical characteristics and protection criteria for Galileo: this specific ITU-R Recommendation is the basis of the following compatibility analysis.

2.3.3.1 Galileo L1

The Galileo L1 signal is centred on a frequency of 1 575.42 MHz with a bandwidth of 32 MHz (1 575.42 ± 16 MHz). As such, the L1 signal is completely contained within the 1 559-1 610 MHz frequency band allocated on a co-primary basis to the ARNS and the RNSS.

The Galileo L1 signal provides an Open Service (OS), a PRS, which both include a navigation message. Moreover an integrity message for Safety Application Service (SAS) is included in the OS signal. The L1 carrier is modulated with a BOC(1,1) code to provide the OS. The L1 carrier is also modulated with a BOCcos(15;2,5) code, to provide the PRS.

The minimum signal level at the surface of the Earth is specified as –127 dBm.

2.3.3.2 Galileo E6

The Galileo E6 signal is transmitted on a centre frequency of 1 278 MHz with a bandwidth of 40 MHz (1 278.75 ± 20 MHz).

The Galileo E6 signal provides a Commercial Service (CS), a PRS, which both include a navigation message. The L1 carrier is modulated with a BPSK(5) code to provide the CS. The E6 carrier is also modulated with a BOC(10,5) code, to provide the PRS. The minimum signal level at the surface of the Earth is specified as –125 dBm.

2.3.3.3 Galileo E5

The Galileo E5a signal is centred on a frequency of 1 176 MHz with a registered bandwidth of 24 MHz (1 176.45 ± 12 MHz). The E5a signal is contained within the 1 164-1 215 MHz frequency band allocated on a co-primary basis to the ARNS and the RNSS.

The Galileo E5a signal provides an OS, a SAS, which includes a navigation message. The E5a carrier is modulated with a BPSK(10) code to provide both OS and SAS.

The Galileo E5b signal is centred on a frequency of 1 207 MHz with a registered bandwidth of 24 MHz (1 207.14 ± 12 MHz). The E5b signal is completely contained within the 1 164-1 300 MHz frequency band allocated to the RNSS.

The Galileo E5b signal provides a SAS, which includes a navigation message and an integrity message. The E5ab carrier is modulated with a BPSK(10) code to provide SAS.

The minimum signal level at the surface of the Earth is specified as –125 dBm.

TABLE 156

Galileo signal characteristics

Carrier channel	Frequency (MHz)	Transmitted bandwith (MHz)	Ranging code rate (Mchip/s)	Symbol rates (symbols/s)	Multiplex type	Signal type		Primary code length (chips)	Secondary code length (chips)
E5a-I	1 176.45	24.00	10.23	50	QPSK	BPSK(10)	Data	10230	20
E5a-Q			10.23	N/A		BPSK(10)	Pilot	10230	100
E5b-I	1 207.14	24.00	10.23	250	QPSK	BPSK(10)	Data	10230	4
E5b-Q			10.23	N/A		BPSK(10)	Pilot	10230	100
E6-A	1 278.75	40.00	5.115	N/A	CASM	BOC (10,5)	Data	Classified	Classified
E6-B			5.115	1 000		BPSK(5)	Data	5115	–
E6-C			5.115	N/A		BPSK(5)	Pilot	10230	50
L1-A	1 575.42	32.74	7.672	N/A	CASM	BOC (15;2,5)	Data	Classified	Classified
L1-B			1.023	250		BOC(1,1)	Data	4092	–
L1-C			1.023	N/A		BOC(1,1)	Pilot	4092	25

N/A: Not available.

2.3.4 Operational scenarios

Operational scenarios need to be developed for each of the Galileo services.

Link budget analyses have to be performed under the assumptions implied by each of the proposed Galileo application-based operational scenarios. Where applicable, these link budget analyses are performed utilizing technical characteristics and practices consistent with those specified in several ITU-R Recommendations and in particular in Recommendation ITU-R M.1477.

2.3.5 UWB transmitter-to-Galileo receiver link budget analyses

The following analyses have been made taking into account a single UWB emitter. Protection levels have been defined in 1 MHz band to take into account the noise-like-effect.

The protection in the 1 KHz band to take into account the CW-like effect and the impact of spectral lines is clearly assessed.

2.3.5.1 Galileo antenna gain in the direction of the UWB source

The antenna subsystem utilized in almost all mobile applications is often implemented as a silicone patch. The antenna typically produces an upper hemispherical pattern, with the gain maximized in the direction of the satellites in space. Table 156 defines the model used to determine the Galileo antenna gain in the direction of an assumed UWB source.

Emissions from UWB transmitters were assumed incident in the side-lobe (–10 to 10º) region of the Galileo receive antenna in this scenario. Therefore, the assumed antenna gain is 0 dBi.

For safety-of-life aeronautical applications, as a worst case analysis, the antenna gain in the direction of the interferer is 5 dBi.

TABLE 157

Galileo receive antenna model

Off-axis angle (degrees relative to horizon)	Galileo antenna gain (dBi)
10 to 90	3
–10 to 10	0
–90 to –10	–4.5

2.3.5.2 Propagation path loss

Free-space path loss is determined from an unobstructed propagation path:

$$L_p = 20 \log_{10}(F) + 20 \log_{10}(D) - 27.55$$

where:

Lp: free-space propagation path loss (dB)

F: frequency (MHz)

D: propagation path length (m).

Depending on the UWB type of applications, the following assumptions for the separation distance between an UWB device and a RNSS receiver have been taken.

TABLE 158

Separation distance scenario

UWB application	Separation distance (m)
Ground penetrating/wall imaging radar	6
Through wall imaging	6
Surveillance systems	25
Medical imaging	6
Indoor communications	2
Handheld communications	1

In the case of safety-of-life applications, the path loss is usually calculated with a separation distance of 30 m. This distance can be found in the corresponding literature.

2.3.6 Single UWB transmitter-to-Galileo receiver link budget analyses: noise-like effect only

The following analyses have been made taking into account a single UWB emitter. Protection levels have been defined in the 1 MHz band to take into account the noise-like effect.

2.3.6.1 Galileo protection requirement

The requirement for Galileo protection is –141.3 dBW in any 1 MHz, therefore, –111.3 dBm/MHz (Acquisition mode: receiver aggregate wideband interference threshold).

Concerning aeronautical applications named “Safety-of-life”, two additional parameters are specifically mentioned:

– An aeronautical safety margin of 5.6 dB is included as explained in Recommendation ITU-R M.1477.

– An *I*/*N* of –20 dB. This value actually represents an error performance degradation of 1% for all sources of interference. It has to be noted that this degradation has been proposed by Radiocommunication WP 8D in September 2004 and sent to Radiocommunication TG 1/8. However, it is proposed to use such an *I*/*N* value to the "Safety-of-life" applications only.

For non-"Safety-of-life" applications, there is no aeronautical safety margin, and the *I*/*N* equals –6 dB.

2.3.6.2 Safety-of-life application

TABLE 159

Protection requirement for safety-of-life service (separation distance of 30 m)

Galileo frequency band	**E5a**	**E5b**	**L1**	**Unit**
Galileo protection requirement	–111.3	–111.3	–111.3	dBm/MHz
Aeronautical margin	–5.6	–5.6	–5.6	dB
I/*N*	–20	–20	–20	dB
Galileo antenna gain	5	5	5	dBi
Propagation path loss	63.40	63.63	65.94	dB
Galileo protection requirement	–78.50	–78.27	–78.96	dBm/MHz

2.3.6.3 Non-safety-of-life applications

TABLE 160

Protection requirement for a protection distance of 25 m

Galileo frequency band	**E5a**	**E5b**	**L1**	**Unit**
Galileo protection requirement	–111.3	–111.3	–111.3	dBm/MHz
I/*N*	–6	–6	–6	dB
Galileo antenna gain	0	0	0	dBi
Propagation path loss	61.82	62.04	64.36	dB
Galileo protection requirement	–55.48	–55.26	–52.94	dBm/MHz

TABLE 161

Protection requirement for a protection distance of 6 m

Galileo frequency band	**E5a**	**E5b**	**L1**	**Unit**
Galileo protection requirement	–111.3	–111.3	–111.3	dBm/MHz
Aeronautical margin	0	0	0	dB
I/*N*	–6	–6	–6	dB
Galileo antenna gain	0	0	0	dBi
Propagation path loss	49.42	49.65	51.96	dB
Galileo protection requirement	–67.88	–67.65	–65.34	dBm/MHz

TABLE 162

Protection requirement for a protection distance of 2 m

Galileo frequency band	**E5a**	**E5b**	**L1**	**Unit**
Galileo protection requirement	–111.3	–111.3	–111.3	dBm/MHz
Aeronautical margin	0	0	0	dB
I/*N*	–6	–6	–6	dB
Galileo antenna gain	0	0	0	dBi
Propagation path loss	39.88	40.11	42.42	dB
Galileo protection requirement	–77.42	–77.19	–74.88	dBm/MHz

TABLE 163

Protection requirement for a protection distance of 1 m

Galileo frequency band	**E5a**	**E5b**	**L1**	**Unit**
Galileo protection requirement	–111.3	–111.3	–111.3	dBm/MHz
Aeronautical margin	0	0	0	dB
I/*N*	–6	–6	–6	dB
Galileo antenna gain	0	0	0	dBi
Propagation path loss	33.86	34.09	36.40	dB
Galileo protection requirement	–83.44	–83.21	–80.90	dBm/MHz

2.3.6.4 Conclusion for noise like effect study

For the protection of the Galileo stations from UWB emissions having noise like spectra, safety-of-life and non-safety-of-life services have been considered in different scenarios. The worst-case limit is obtained for the Galileo non-safety-of-life applications with a maximum e.i.r.p. limit of –83.50 dBm/MHz, assuming a 1 m protection distance.

For safety-of-life, a maximum e.i.r.p. limit of –79 dBm/MHz is obtained, assuming a 30 m protection distance.

2.3.7 Study on noise-like and CW-like effects on Galileo

The purpose of this study is to investigate the effect of UWB systems upon RNSS, and in particular the Galileo system. The objective is to determine the degradations caused by UWB systems to Galileo receiver. The UWB signals that will be specifically under consideration are those that have spectral lines.

For UWB radar signals, the pulses are sent regularly in time with rate referred to as PRF, which results in a PSD composed of equally spaced spectral lines. The spacing between two spectral lines is equal to PRF.

Communication signals can have PPM, PAM or combined PPM/PAM formats. For the PPM, the modulation is achieved by shifting (or dithering) the pulse in time according to the symbol value. For the PAM, the symbol value directly modulates pulse amplitude. The pulses can be sent equally spaced in time or can follow a so-called "time hopping codes" which gives a pseudo-random shift around the periodic position.

2.3.7.1 UWB signal modelling

The first UWB transmission systems so-called "Impulse radio" were using very short pulses to transmit information resulting a very wide bandwidth (> 1 GHz) compared to conventional ones. It is worth noting that the bandwidth for this kind of signal is modulation and data rate independent since it depends only on the pulse width.

Various kinds of impulse-like signals can be found whether they are used for radar purposes (through-wall radar, imaging radar, anti-collision radar) or for communication ones.

For radar signals, the pulses are sent regularly in time with rate referred to as PRF, which results in a PSD composed of equally spaced spectral lines. The spacing between two spectral lines is equal to PRF.

Communication signals can have PPM, PAM or combined PPM/PAM formats. For the PPM, the modulation is achieved by shifting (or dithering) the pulse in time according to the symbol value. For the PAM, the symbol value directly modulates pulse amplitude. The pulses can be sent equally spaced in time or can follow a so-called "time hopping codes" which gives a pseudo-random shift around the periodic position.

The UWB modulation depend on the following parameters:

T_f: pulse period

PRF = $1/T_f$: pulse repetition frequency

$w(t)$: pulse filter.

The general expression of the UWB signal is at following:

$$x(t) = \sum_k s(k)\, w(t - kT_f + c(k)T_c - a(k)\Delta)$$

where $s(k)$ are:

iid symbols of unit variance in the PAM case: $s(k) \in \{-1,1\}$

$s(k) = 1$ in the no modulated case (no PAM).

T_c is the THC period and $c(k)$ is:

a periodic code with integer value in the THC case: $0 \le c(k) \le N_c$

$c(k) = 0$ in the no THC case.

Δ is the PPM period and $a(k)$ is:

iid symbols such that: $a(k) \in \{0,1\}$

$a(k) = 0$ in the no PPM case.

The different cases of UWB modulation can be summarize in Table 164.

TABLE 164

UWB modulation cases

	No PAM	**PAM**	**PPM**
Without THC	$x(t)=\sum_k (wt-kT_f)$	$x(t)=\sum_k s(k)\, w(t-kT_f)$	$x(t)=\sum_k w(t-kT_f-a(k)\Delta)$
With THC	$x(t)=\sum_k w(t-kT_f+c(k)T_c)$	$x(t)=\sum_k s(k)\, w(t-kT_f+c(k)T_c)$	$x(t)=\sum_k w(t-kT_f+c(k)T_c-a(k)\Delta)$

2.3.7.2 Signal model for Galileo

2.3.7.2.1 Introduction: overall view of Galileo signals

The Galileo system consists in four types of channels E5a, E5b L1 and E6.

Each channel carries two types of signal: pilot and data.

The pilot signal spectrum consists of a sequence of lines, which are typical for a given periodic signal. The spacing between the lines depends on the code length multiplied by the chip duration.

The power spectral-density of a base-band signal with QPSK modulation having spreading code rate f_c is given by [Holmes, 1982]:

$$G_s(f)=\frac{1}{f_c}\left[\frac{\sin(\frac{\pi f}{f_c})}{\frac{\pi f}{f_c}}\right]^2$$

The normalized power spectral-density of a base-band signal with BOC modulation having sub-carrier frequency f_s and spreading code rate f_c is given by [Betz, 2000]:

$$G_s(f)=f_c\left[\frac{\sin(\frac{\pi f}{2f_s})\sin(\frac{\pi f}{f_c})}{\pi f\cos(\frac{\pi f}{2f_s})}\right]^2$$

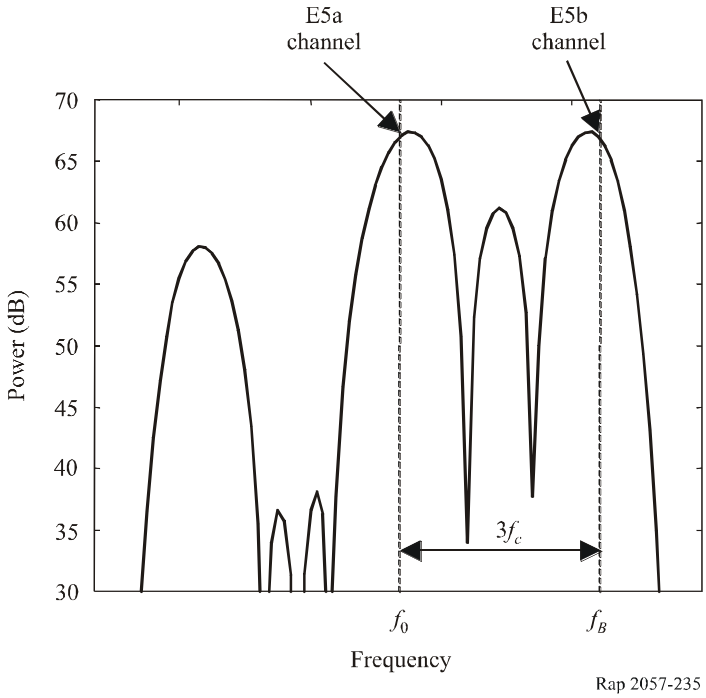
In the case of a BOC (m,n), f_s = m × 1.023 MHz and f_c = n × 1.023 MHz.

In the case of the pilot channels the power spectral-densities given by the preceding equations are discreet, with $f=k\frac{f_c}{L}$, where L is the period of spreading code and k is integer.

The GALILEO waveform of the E5 channel is an AltBOC(10,15) of spreading code f_c = 10.23 MHz. The sub-channels E5a and E5b of bandwidth $2f_c$ are respectively at the carried frequencies f_0 = 1 176.45 MHz and f_B =1 207.14 MHz such that: $f_B - f_0 = 3\ f_c$. Each sub-channels E5a and E5b are spreading with two periodic codes (data and pilot) of period T = 1 ms. The spectrum of the waveform of the E5 channel is shown in Fig. 235.

FIGURE 235

Waveform of the E5 channel



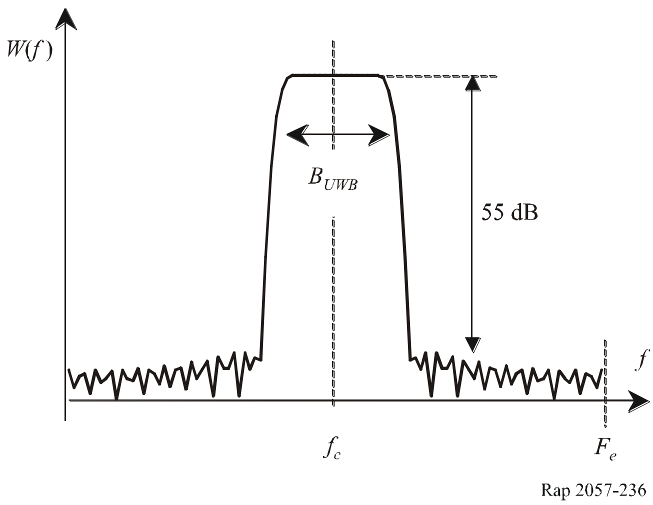
The signal E5a will be used for the following simulations that will determine the impact of UWB signals having spectral lines on such RNSS signal.

2.3.7.2.2 Signal generation

The UWB signals are generate at the sampling period 2F_e with B_{UWB} bandwidth at 2 dB. The Fourier transformation of the filter $w(t)$is shown in Fig. 236:

FIGURE 236

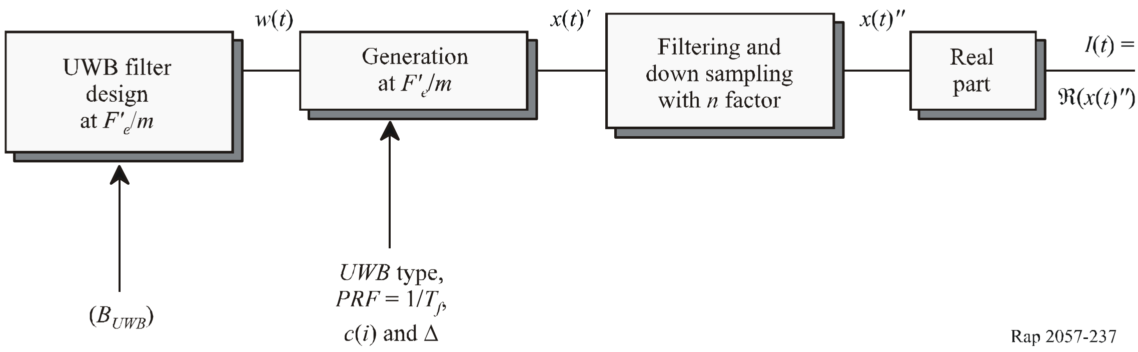
Fourier transform of the UWB filter



The signal is generate at $2F'_e = 2mF_e/n$ such that m, n and $T_f F'_e$ are integers. The frequency f_c is the IF of the Front-End of GALILEO. The generate signal is real. The different steps are summarized in Fig. 237.

FIGURE 237

UWB signal generation



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Where $\Re(z)$ is the real part of z. The signals $w(t)$ are $x(t)'$ at the sampling period F'_e/m and $x(t)''$ at the sampling period F_e.

2.3.7.2.3 Signal power

In order to study the effect of UWB device on GALILEO receiver it is necessary to use some interference criterions. These criterions depend on the power of the different signals. In that way the autocorrelation function of $x(t)$ is:

$$R_x(\tau) = E[x(t-\tau/2)x(t+\tau/2)^*]$$

where z^* is the conjugate of z and $E[]$ is the mathematical mean. The PSD of $x(t)$ is then defined by:

$$\gamma_x(f) = \int R_x(\tau)\exp(-j2\pi f\tau)\,d\tau$$

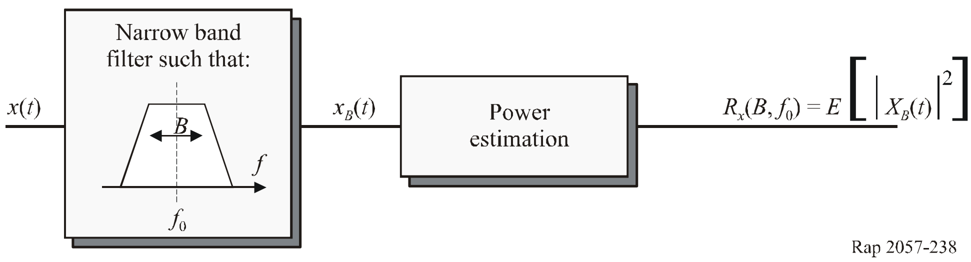
More precisely, the interference criterions depend on signal PSD in a narrow bandwidth such that:

$$R_x(B, f_0) = \int_{f_0-B/2}^{f_0+B/2} \gamma_x(f)\,df$$

Where $Rx\,(B, f_0)$ is the power of $x(t)$ within B and around f_0. This narrow-band power can be estimated according the scheme of Fig. 238.

FIGURE 238

Power measurement in a narrow-band filter



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In the simulation the narrow-band filters are FIR with 120 coefficients when $B < F_e/100$ and 600 coefficients when $B < F_e/100$.

Figure 239 give examples of UWB PSD when $B_{UWB} = 0.8F_e$ and $T_f F_e = 16$. The PSD (R_x (B, f)) is estimate within $B < F_e/256$ and a hamming filter of 256 coefficients. In PPM case $\Delta = 2/F_e$ and with THC $\Delta = 2/F_e$ Without THC $T_c = 1/F_e$ and $c_k = [1245]$ No PAM.

FIGURE 239

UWB PSD – No PAM without THC

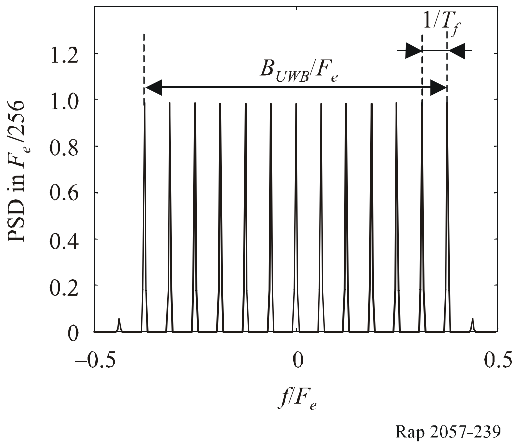

FIGURE 240

UWB PSD – PAM without THC

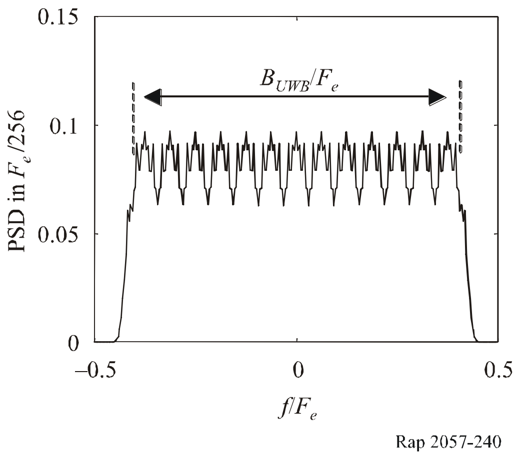

FIGURE 241

UWB PSD – PPM without THC: Δ = 2/F_e

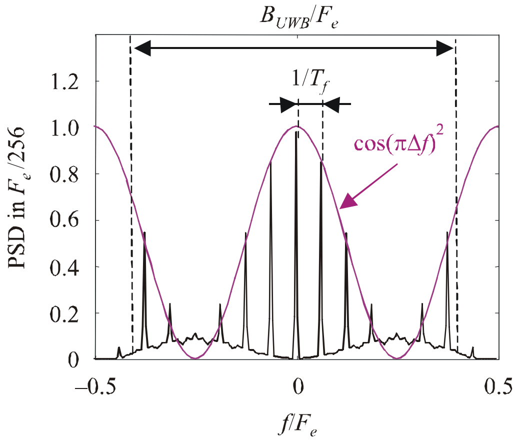

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FIGURE 242

UWB PSD – No PAM with THC: T_c = 1/F_e, c_k = [1245]

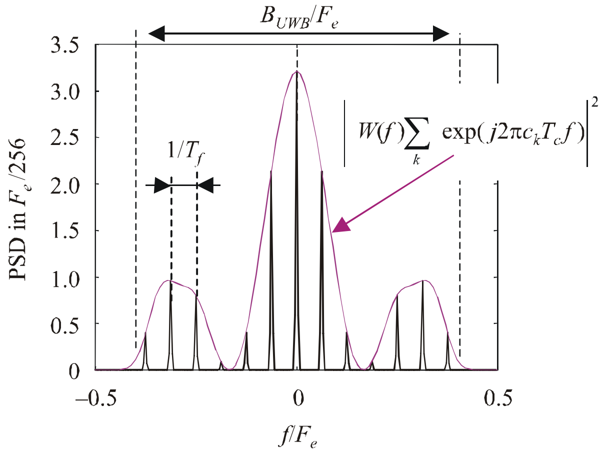

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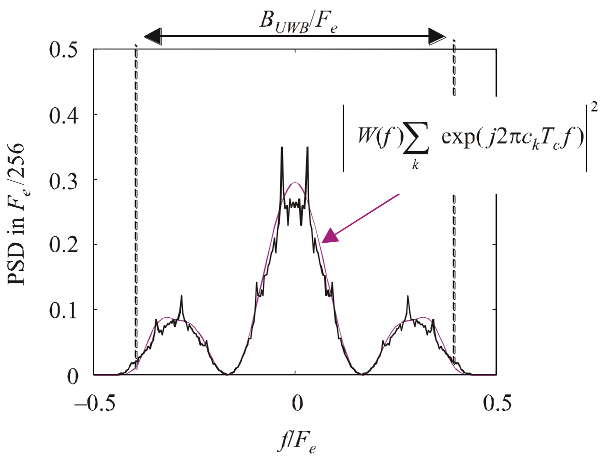
FIGURE 243

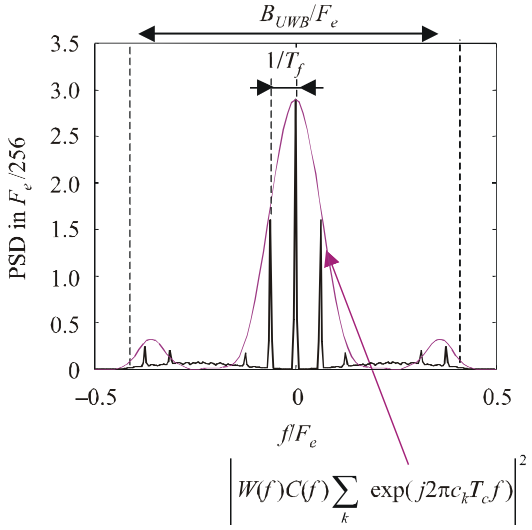
UWB PSD – PAM with THC: T_c = 1/F_e, c_k = [1245]



Rap 2057-243

FIGURE 244

UWB PSD – PPM with THC: $C(f) = \cos(\pi\Delta f)$, $\Delta = 2/F_e$, $T_c = 1/F_e$, c_k = [1245]



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The power R_x (B, f_0) of $x(t)$ within F_e and around f_0 can be rewritten using the following estimation for the signal $x(t)$ during a duration of K/F_e:

$$\hat{\gamma}_x = \lim_{K\to+\infty} \frac{1}{K}\sum_{k=1}^{K} \left|x(k/F_e)\right|^2 = R_x(F_e, f_0) \quad (88)$$

2.3.7.2.4 BWCF parameter

The level of the UWB signals is generally defined in dBm/MHz (B_{ref} = 1 MHz). As the bandwidth B of the signals as UWB are different from 1 MHz, it is necessary to define the bandwidth corrector factor (BWCF) parameter that connect the powers of the signal within B and MHz. More precisely the power of $x(t)$ in dBm/MHz is defined in a general way:

$$E_x = 10 \log_{10}(R_x(1 \text{ MHz}, f_0) \times F_e) \quad (89)$$

Where:

f_0: carried frequency of $x(t)$

F_e: (MHz).

E_x can be seen as a normalized power. The linear BWCF that connect the powers of the signal within B and a reference bandwidth B_{ref} is:

$$\rho_x(B, B_{ref}) = \frac{R_x(B, f_0)/B}{R_x(B_{ref}, f_0)/B_{ref}} \quad (90)$$

Noting that R_X (B, f_0) = R_X (B_{UWB}, f_0) when $B > B_{UWB}$, then ρ_x (B, B_{ref}) = ρ_x (B_{UWB}, B_{ref}) (B_{UWB}/B) when $B > B_{UWB}$, the factor ρ_x is in white-noise and CW-like cases:

Noise-like case for $B < B_{UWB}$: $\rho_x(B, B_{ref}) = 1$ (91)

Noise-like case for $B > B_{UWB}$: $\rho_x(B, B_{ref}) = B_{UWB} / B$

CW-like case: $\rho_x(B, B_{ref}) = B_{ref} / B$ (92)

The parameter $\rho_x(B, B_{ref})$ can be seen as a criterion that evaluate the whiten level of a signal. Noting $BWCF_x(B, B_{ref}) = 10 \log_{10}(\rho_x(B, B_{ref}))$, the BWCF (dB), the relation between E_x (equation (88)) and γ_x (89) is:

$$E_x = 10 \log_{10}(\gamma_x) - BWCF_x(F_e, 1 \text{ MHz}) \tag{93}$$

Figure 245 shows the case with $x(t)$ being an UWB signal only with no THC and no PAM with $B_{UWB} = 50$ MHz and B_{ref} = 1 MHz.

FIGURE 245

Linear BWCF of UWB no PAM and THC: B_{ref} = 1 MHz B_{UWB} = 50 MHz

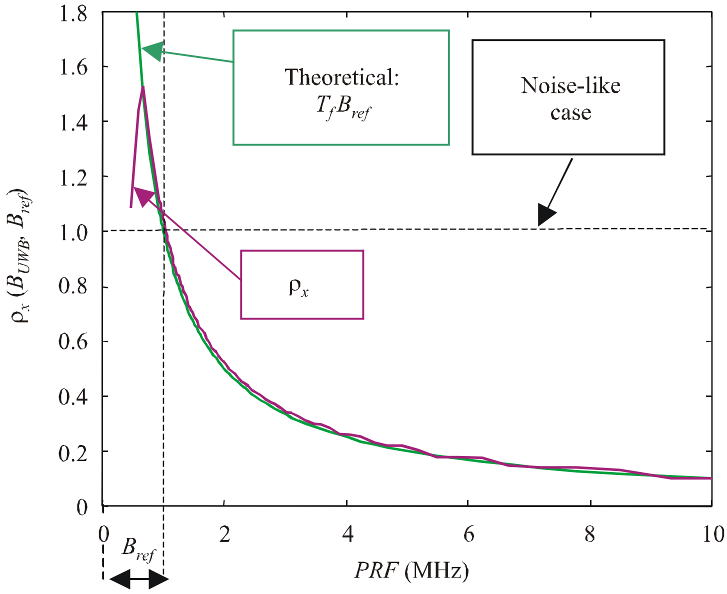

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Figure 245 shows that $\rho_x(B_{UWB}, B_{ref}) = T_f B_{ref}$ when $PRF > B_{ref}/2$ and $\rho_x(B_{UWB}, B_{ref}) \rightarrow 1$ when $PRF < B_{ref}/2$. When $PRF < B_{ref}/2$ the signal behave as a white-noise because the length of the filter $w(t) * h_{B_{ref}}(t)$ is more important than the pulse period T_f.

The estimation of the BWCF $\rho_x(B, B_{ref})$ of equation (6) need the estimation of $R_x(B_{ref}, f_0)$ in a narrow-band B_{ref} (typically 1 MHz). This estimation is done accordingly to the scheme of Fig. 238. The signal $x_{B_{ref}}(t)$ at the output of the narrow-band filter can written as:

$$x_{B_{ref}}(t) = h_{B_{ref}}(t) * x(t)$$

where: (94)

$$R_x(B_{ref}, f_0) = E\left[\left|x_{B_{ref}}(t)\right|^2\right]$$

where $h_{B_{ref}}(t)$ is the impulse response of the narrow-band filter and "*" is the convolution product. Using the expression of $x(t)$ for an UWB in no PAM and THC case (see Table 164), the signal $x_{B_{ref}}(t)$ can be rewritten as:

$$x_{B_{ref}}(t) = \sum_k w_{B_{ref}}(t - k\ T_f)$$

where: (95)

$$w_{B_{ref}}(t) = h_{B_{ref}}(t) * w(t)$$

The filter $w_{B_{ref}}(t)$ as the same bandwidth B_{ref} of the filter $h_{B_{ref}}(t)$. Thus, the time duration of the filter $w_{B_{ref}}(t)$ is approximately equal to $T_B \approx 1/B_{ref}$. When $T_B > T_f$ the signal $x_{B_{ref}}(t)$ can be rewritten as:

$$T_B > T_f\text{:}\ x_{B_{ref}}(t) = \sum_k w_{B_{ref},T_f}(t - kT_f)$$

where:

$$w_{B_{ref},T_f}(t) = \sum_{i=-L}^{L} w_{B_{ref}}(t - iT_f)\Pi_{T_f}(t) \qquad (96)$$

$\Pi_{T_f}(t) = 1$ when $|t| < T_f$ and $\Pi_{T_f}(t) = 0$ otherwise

$$T_B \le T_f : x_{B_{ref}}(t) = \sum_k w_{B_{ref},T_f}(t - kT_f) \text{ where } w_{B_{ref},T_f}(t) = w_{B_{ref}}(t) \qquad (97)$$

where $T_B = Int((2L+1)T_f)$ and:

$$w_{B_{ref},T_f}(t) = 0 \text{ when } |t| > T_f \qquad (98)$$

Finally it is noticed that the filter $w_{B_{ref},T_f}(t)$ is distorted when $T_B > T_f$ (or $B_{ref} < PRF$) because $w_{B_{ref},T_f}(t) \ne w_{B_{ref}}(t)$. Finally $R_x(B_{ref}, f_0)$ is:

$$T_B > T_f : R_x(B_{ref},\ f_0) = \frac{1}{T_f}\sum_k \left|W_{B_{ref}\ ,T_f}(k / T_f)\right|^2$$

(99)

$$T_B > T_f : R_x(B_{ref},\ f_0) = \frac{1}{T_f}\sum_k \left|W(k / T_f)\right|^2$$

where:

$W_{B_{ref},T_f}(f)$ and $W(f)$ are respectively the Fourier transform of $w_{B_{ref},T_f}(t)$ and $w_{B_{ref}}(t)$.

In order to confirm this previous result Fig. 246 represents the BWCF when B_{ref} = 2 MHz.

FIGURE 246

Linear BWCF of UWB no PAM and no THC: B_{ref} = 2 MHz B_{UWB} = 50 MHz

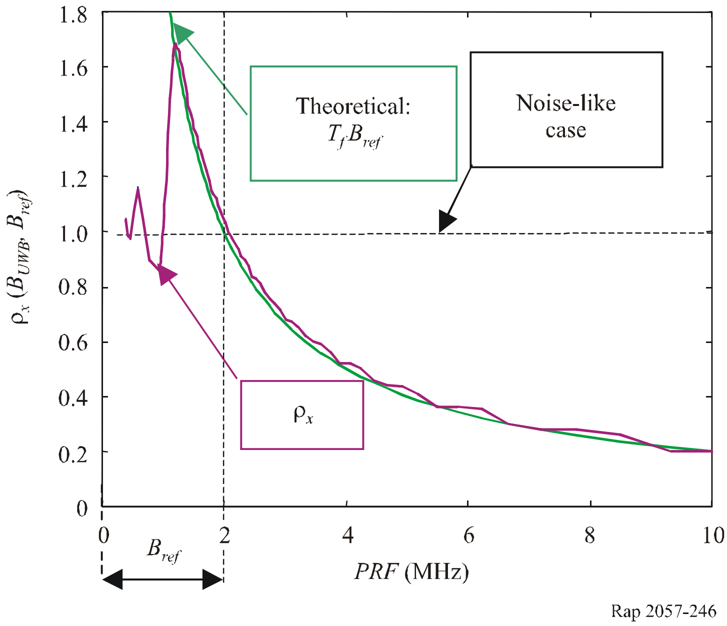


Figure 246 shows that for very low PRF the BWCF is equal to 1 as in white-noise like case. In the same context the behavior of the BWCF parameter for high PRF is at following:

FIGURE 247

Linear BWCF of UWB no PAM and THC: B_{ref} = 2 MHz B_{UWB} = 50 MHz (high PRF)

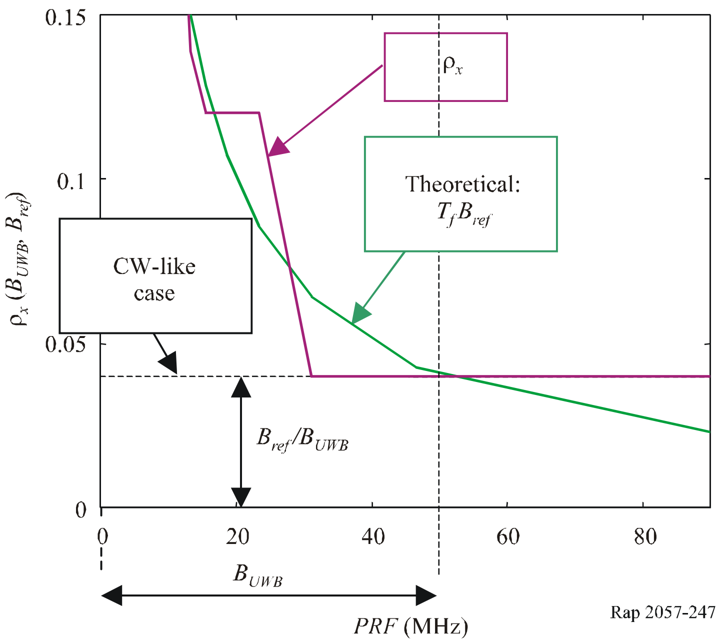


Figure 247 shows that when $PRF > B_{UWB}/2$ the signal is in CW case because $\rho_x(B_{UWB}, B_{ref}) = B_{ref}/B_{UWB}$. In summary in no PAM and no THC case:

Noise-like case $PRF < B_{ref}/2$: $\rho_x(B_{UWB}, B_{ref}) \rightarrow 1$

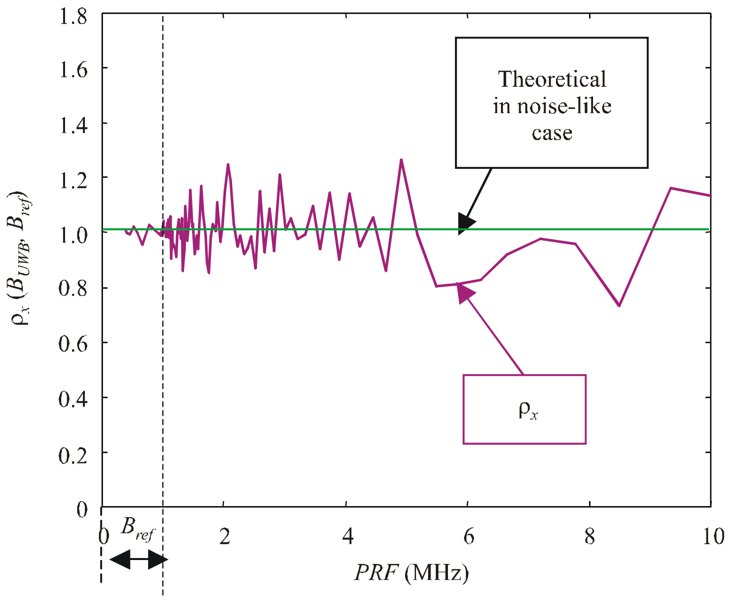
Pulse-like case $B_{ref}/2 < PRF < B_{UWB}/2$: $\rho_x(B_{UWB}, B_{ref}) = T_f B_{ref}$

CW-like case $PRF > B_{UWB}/2$: $\rho_x(B_{UWB}, B_{ref}) = B_{ref}/B_{UWB}$

Figure 248 shows the case of an UWB signal with PAM and no THC with B_{UWB} = 50 MHz and B_{ref} = 1 MHz.

FIGURE 248

Linear BWCF of UWB PAM and no THC: B_{ref} = 1 MHz B_{UWB} = 50 MHz



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As predicted in the case of a PAM UWB the signal behaves as a white noise where the BWCF is equal to 1.

2.3.7.2.5 Spectral line attenuation

In the case of UWB with spectral-line, the power attenuation of one spectral measured in a filter of 1 kHz is an important parameter. As the signal power is in dBm/MHz this parameter has the following expression (dB):

$$I\_ICW = BWCF_x(1 \text{ MHz}, 1 \text{ kHz}) + 30 \tag{100}$$

In the case of No PAM UWB and no THC (see Fig. 249) the theoretical value (I_ICW_th) depend on the number of spectral-lines within 1 MHz and:

$$I\_ICW\_th = -10 \log_{10}(Int(PRF)) \tag{101}$$

where PRF is in MHz and $Int(x)$ is the integer part of x. Figure 249 shows the case of an UWB signal with no THC and no PAM with B_{UWB} = 50 MHz.

FIGURE 249

I_ICW of an UWB no PAM and no THC: B_{UWB} = 50 MHz

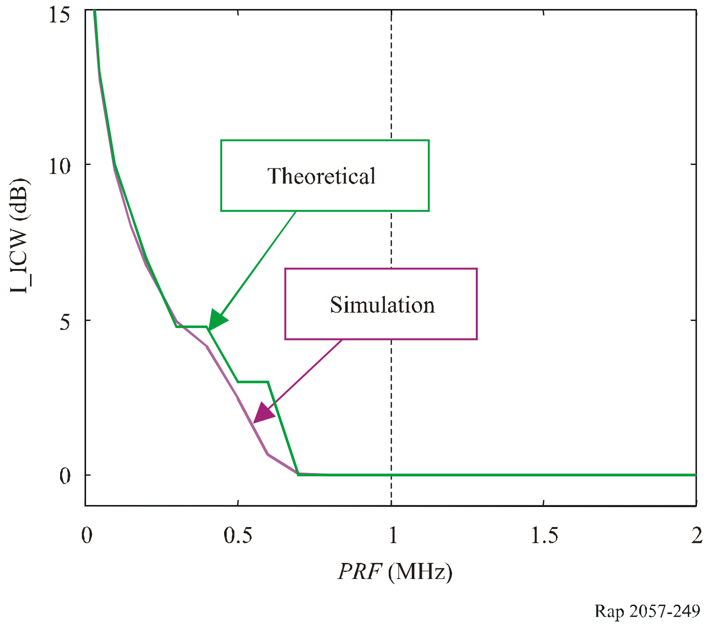


Figure 249 shows that the simulated and theoretical curves are very closed.

2.3.7.2.6 Peak power and peak attenuation

The peak power is associated to the power of the UWB filter $w(t)$ of (1) within 50 MHz. The peak power as the following expression (dB):

$$P_{Peak} = 10 \log_{10}(R_w(50 \text{ MHz}, f_0) \times F_e / 50) \tag{102}$$

In the particular case of a UWB of bandwidth B_{UWB} > 50 MHz this peak power (dB):

$$P_{Peak0} = 10 \log_{10}(R_w(B_{UWB}, f_0) \times F_e / B_{UWB}) \tag{103}$$

When the relation between P_{Peak} and $P_{Peak\,0}$ is:

$$P_{Peak} = P_{Peak0} + 10 \log_{10}(B_{UWB} / 50) \tag{104}$$

The previous case where B_{UWB} < 50 MHz is not representative of the reality. In this note the peak attenuation is of interest such that:

$$AP_{Peak} = E_x - P_{Peak} \tag{105}$$

where E_x is the power of the UWB signal within 1 MHz defined in equation (88). Noting that in the theoretical case, the relation between R_w (B_{UWB}, f_0) and R_x (B_{UWB}, f_0) is for UWB signal:

$$\frac{R_w(B_{UWB}, f_0)}{R_x(B_{UWB}, f_0)} = T_f F_e \tag{106}$$

and that:

$$R_x(B_{UWB}, f_0) = \gamma_x \text{ with } E_x = 10 \log_{10}(\gamma_x) - BWCF_x(F_e, 1 \text{ MHz}) \tag{107}$$

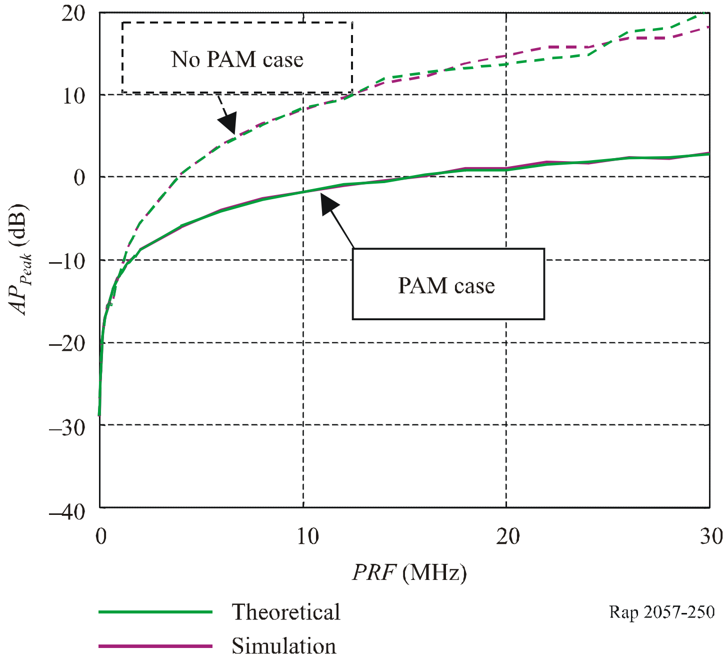
Where γ_x is defined in equation (88).The theoretical value of AP_{Peak} is according to equations (102), (105), (106):

$$\begin{aligned} AP_{Peak} &= -10\ \log_{10}(T_f F_e) - BWCF_x(F_e, 1\text{ MHz}) - 10\ \log_{10}(F_e / B_{UWB}) \\ &= -10\ \log_{10}(T_f F_e) - BWCF_x(B_{UWB}, 1\text{ MHz}) \end{aligned} \tag{108}$$

when B_{UWB} > 50 MHz. Figure 250 shows the case of an UWB signal with no THC with B_{UWB} = 50 MHz.

FIGURE 250

***AP_{Peak}* of an UWB no PAM and no THC: *B_{UWB}* = 50 MHz**



The difference between the PAM and no-PAM case depend on the bandwidth corrector factor $BWCF_x$ (F_e, 1 MHz). In addition it is noted that the theoretical and simulated curves are very close.

2.3.7.2.7 Summary of theoretical results and conclusion

The theoretical *BWCF*, *I_ICW* and AP_{Peak} of the previous sections have been established for UWB without THC in the PAM an no-PAM cases. The reference bandwidth is B_{ref} = 1 MHz. Noting F_e as the sampling frequency of the GALILEO receiver and supposing that the bandwidth of the UWB verify $F_e < B_{UWB}$ and the apparent bandwidth of UWB seen by the receiver is F_e. Using these different assumptions these theoretical results are summarized in Table 165.

TABLE 165

Theoretical *BWCF*, *I_ICW* and AP_{Peak} (UWB without THC)

	No PAM		PAM
BWCF	$PRF < B_{ref}/2$:	$BWCF = 0$	0 dB
	$B_{ref}/2 < PRF < F_e/2$:	$BWCF = 10 \log_{10} (B_{ref}/PRF)$	
	$PRF > F_e/2$:	$BWCF = 10 \log_{10} (B_{ref}/F_e)$	
I_ICW	$-10 \log_{10} (Int(PRF))$		None
AP_{Peak}	$-10 \log_{10} (F_e/PRF) - BWCF$		$-10 \log_{10} (F_e/PRF)$

The sampling frequency F_e can be seen as the bandwidth of the receiver. *Int*(*PRF*) is the integer part of *PRF*.

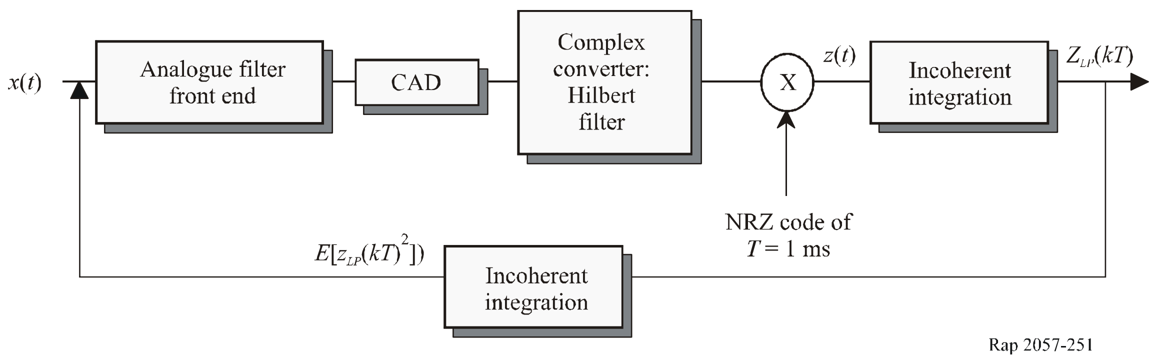
2.3.7.3 Galileo receiver simulator

2.3.7.3.1 General description

The GALILEO receiver corresponds to the E5a channel. However for all channels the signal processing depend on the steps illustrated on Fig. 251.

FIGURE 251

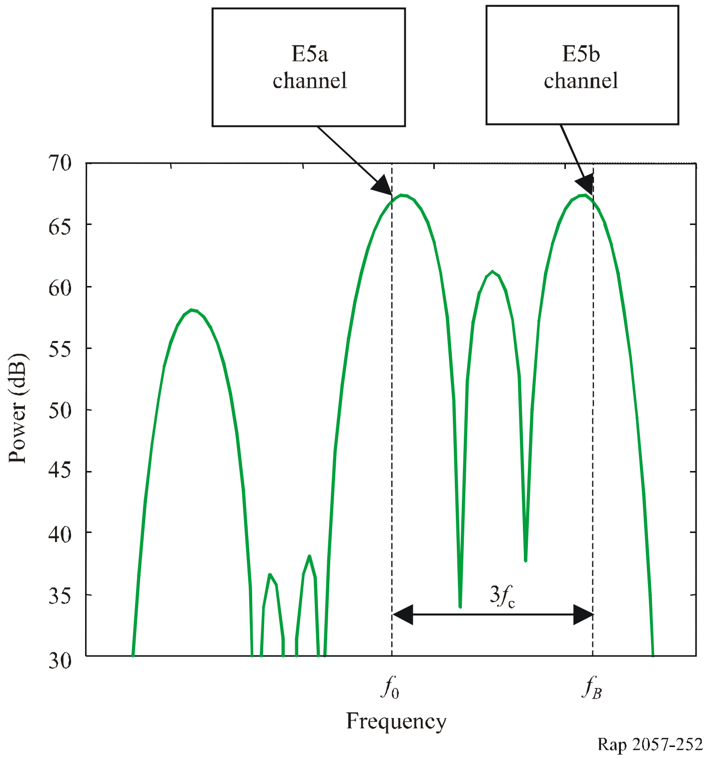
GALILEO receiver



The GALILEO waveform of the E5 channel is an AltBOC(10,15) of spreading code f_c = 10.23 MHz. The sub-channels E5a and E5b of bandwidth $2f_c$ are respectively at the carried frequencies f_0 =1 176.45 MHz and f_B = 1 207.14 MHz such that: $f_B - f_0 = 3f_c$. Each sub-channels E5a and E5b are spreading with two periodic codes (data and pilot) of period T = 1 ms. The spectrum of the waveform of the E5 channel is then Fig. 252:

FIGURE 252

Waveform of the E5 channel



2.3.7.3.2 GALILEO front-end

The purpose of the GALILEO front-end is to:

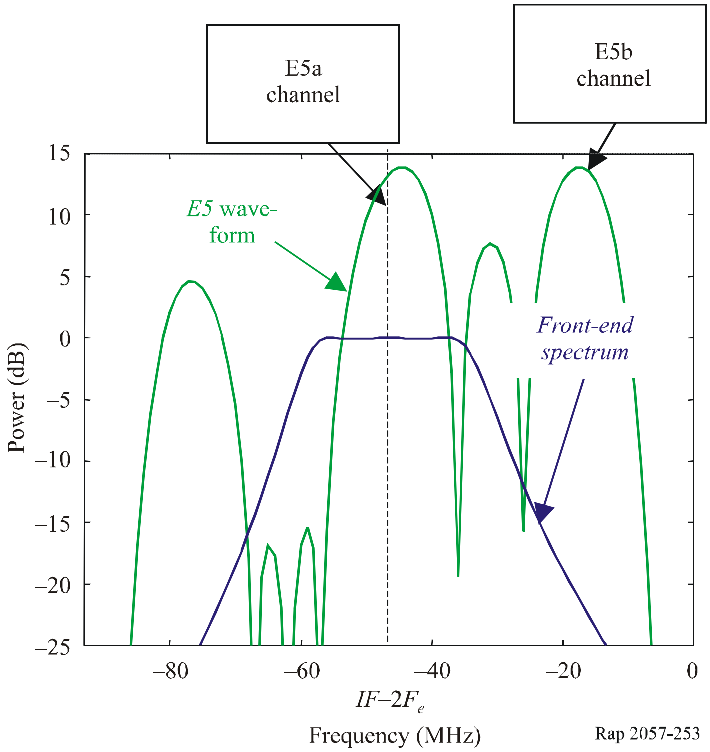
– Transpose the E5a channel to an IF (Intermediate Frequency).

– Filtering the E5a channel of bandwidth $2f_c$ = 20.46 MHz in order to attenuate the E5b sub-channel and approximate the sub-channel E5a as a NRZ waveform.

In order to respect these previous purposes, the simulation is done with a front-end filter of bandwidth B = 27 MHz and IF = 140 MHz. This spectrum of the front-end filter is the following after the CAD of sampling frequency $2F_c$ = 186.66 MHz.

FIGURE 253

Spectrum of the front-end filter



The front-end filter is done through the use of an ARMA. At the output of the front-end the GALILEO waveform has the following spectrum:

FIGURE 254

Waveform of the E5 channel at the output of the front-end

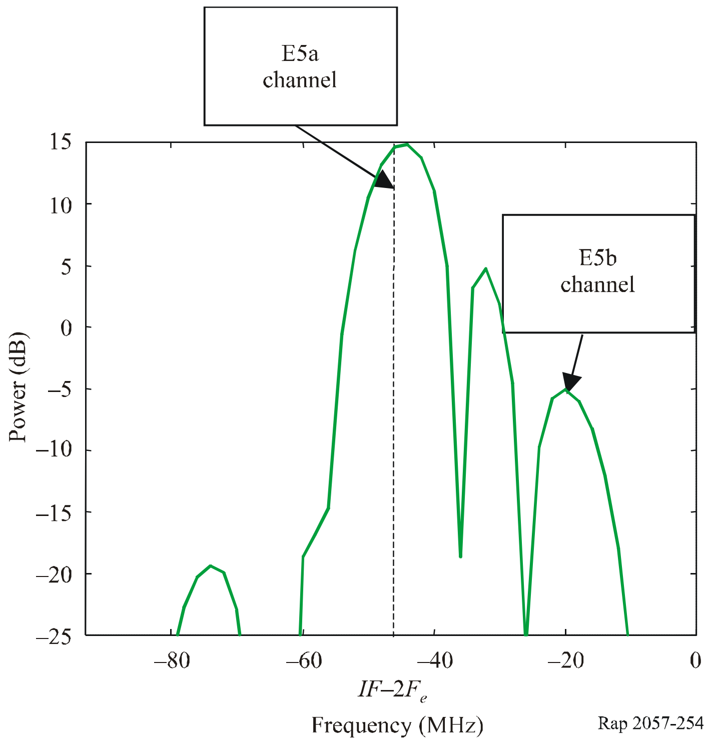


Figure 255 shows that the attenuation of the E5b channel is 20 dB.

2.3.7.3.3 Digital and complex converter (Hilbert filtering)

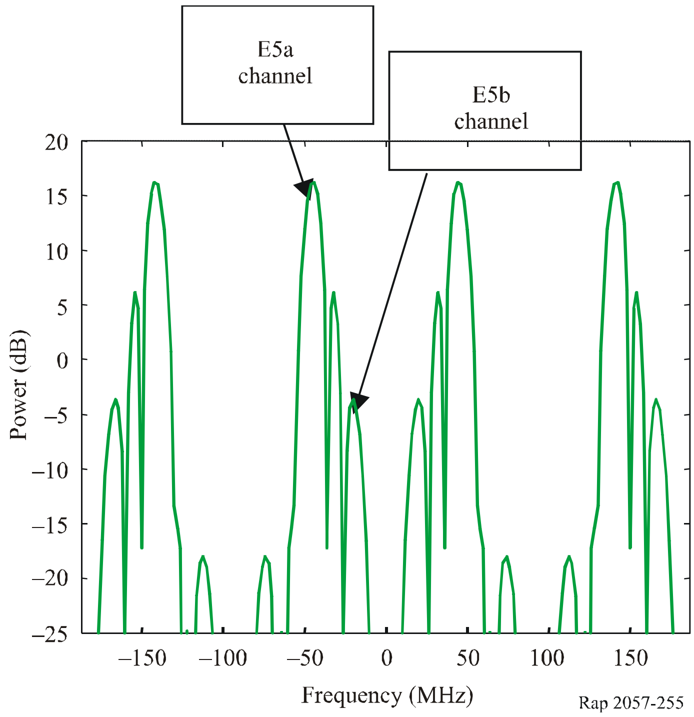
The signal after the front-end filter is real and analogue. In the converter analogue digital (CAD) the signal is firstly sample at $2F_e$ = 186.66 MHz and secondly over sample at $4F_e$ = 373.33 MHz such that:

$$x_{4F_e}(2k) = x_{2F_e}(k) \text{ and } x_{4F_e}(2k+1) = 0 \qquad (109)$$

Where $x_F(k)$ is the kth sample of the signal $x(t)$ at the sampling frequency F. The spectrum of the digital signal at $4F_e$ is the Fig. 255:

FIGURE 255

Waveform of the E5a channel at the output of CAD at $4F_e$ = 373.33 MHz



In Fig. 255 the spectrum of the E5a channel is duplicated when $f > 0$ because the signal is real and when $f < -93.33$ MHz because of the over sampling of the signal. The purpose of the Hilbert filtering is then to:

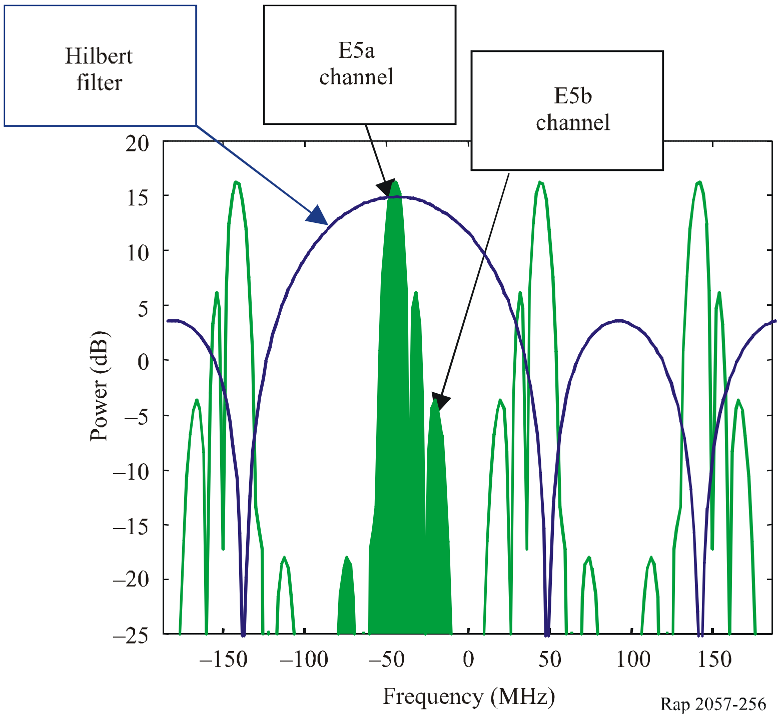
– Extract the signal between the frequencies $f > -93.33$ MHz and $f < 0$ MHz.

– Transpose the E5a channel at the null frequency.

In that the way the Hilbert filter is chosen as an integrator (FIR filter with 4 coefficients equal to 1). This Hilbert filter is transpose at $FI\text{-}2F_e$ and has the following spectrum:

FIGURE 256

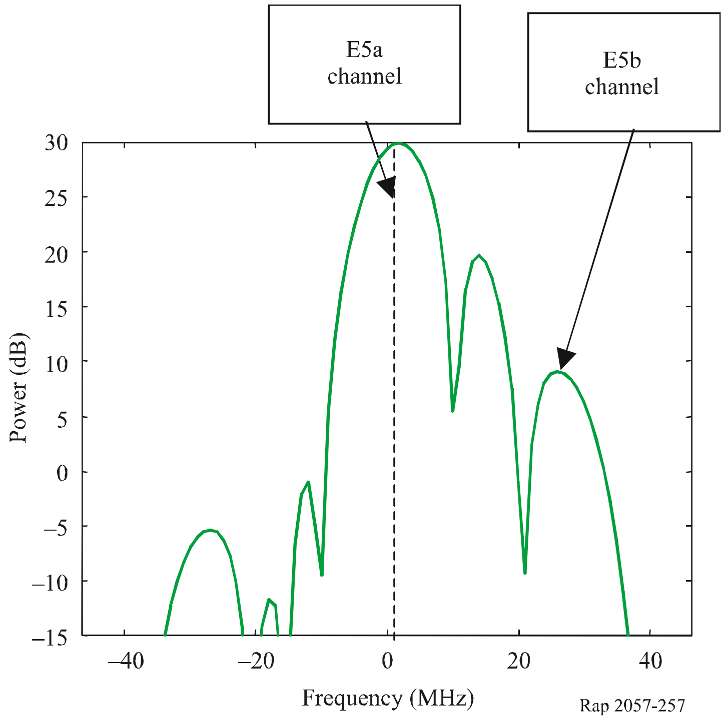
Hilbert filter



After the Hilbert filter the signal is transpose at the null frequency and re-sampled at the frequency F_e. Finally the E5a waveform is the Fig. 257:

FIGURE 257

Waveform of the E5a channel at the output of Hilbert filtering

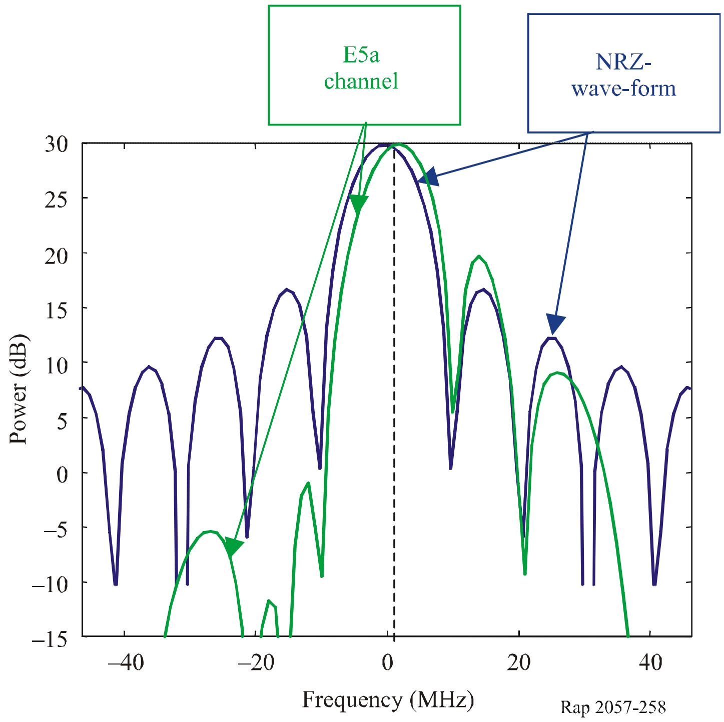


2.3.7.3.4 Correlator with the spreading code

The spreading code is a NRZ waveform with binary rate of f_c = 10.23 MHz. In order to design a good GALILEO receiver, the main-spectrum-lobe of this NRZ code must look like to the main-lobe of the E5a channel. The correlator generates at the output, the signal $z(t)$ of Fig. 251. Figure 258 compares the main-lobe of each waveforms.

FIGURE 258

Main-lobe of the E5a channel and a NRZ waveform



As the main lobe of the E5a channel and NRZ waveform are closed, the E5a channel can be approximated as a QPSK NRZ waveform. The QPSK code is composed with 2 BPSK codes (data and pilot). In the simulation the correlation is done with the pilot code in NRZ-BPSK waveform. In order to improve the GALILEO receiver in detection and tracking, the receiver used the periodicity of the code. Indeed, at the *k*th period the detector estimate after a coherent integration the following signal:

$$z_{LP}(k\,T) = \frac{1}{T}\int_{(k-1)T}^{kT} z(t)\mathrm{d}t \qquad (110)$$

Where $T = 1$ ms. The signal z_{LP} $(k\ T)$ can be seen as the output of a narrow-band filter of bandwidth 1 kHz and input $z(t)$. The GALILEO receiver can then build a detector with an incoherent integration of the signal z_{LP} $(k\ T)$ such that:

$$P = \frac{1}{K}\sum_{k=1}^{K}\left|z_{LP}(k\,T)\right|^2 \qquad (111)$$

The power P is then compare to a threshold to decide the presence of the GALILEO signal. The sensibility of the detector depend on the duration $k\ T$.

2.3.7.4 Interference model at the GALILEO receiver

2.3.7.4.1 Definitions

The signal $x(t)$ at the input of GALILEO receiver can be decomposed on the three following signals:

– $c(t)$: signal of GALILEO

– $I(t)$: interference signal

– $n(t)$: white noise due to system temperature.

The expression of $x(t)$ at input of receiver is:

$$x(t) = c(t) + I(t) + n(t) \tag{112}$$

And the signal $z(t)$ at the output of the correlator is:

$$z(t) = c(t)'' + I(t)'' + n(t)'' \tag{113}$$

Where $c(t)''$ $c(t)''$, $I(t)''$, $n(t)''$ are respectively the GALILEO, Interference and noise signal at the output of the code correlator. The power of the signals $c(t)$, $I(t)$, $n(t)$ at the input of receiver are respectively:

$$\gamma_c = R_c(F_e, f_0),\ \gamma_I = R_I(F_e, f_0) \text{ and } \gamma_n = R_n(F_e, f_0) \tag{114}$$

Where f_0 is the carried frequency of the E5a channel. The power of the same signal at the output of receiver are:

$$\gamma''_c = R_{c''}(F_e, f''_0),\ \gamma''_I = R_{I''}(F_e, f''_0) \text{ and } \gamma''_n = R_{n''}(F_e, f''_0) \tag{115}$$

Where f''_0 = 0 MHz at the output of correlator. The powers of equations (113), (114) are estimated on the spreading code duration: T = 1 ms.

2.3.7.4.2 Interference degradation of the GALILEO receiver

The signal to noise ratio at the output of receiver is:

$$\frac{\gamma''_c}{\gamma''_I + \gamma''_n} = \left(\frac{\gamma''_c}{\gamma''_n}\right) / \left(1 + \left(\frac{\gamma''_I}{\gamma''_n}\right)\right) \tag{116}$$

Thus, the degradation in dB due to the interference $I(t)$ at the output of the receiver is:

$$\Delta I_{out} = 10\ \log_{10}\left(1 + \left(\frac{\gamma''_I}{\gamma''_n}\right)\right) \tag{117}$$

In this context, D as the maximum GALILEO receiver degradation is defined such that:

$$\Delta I_{out} < D \tag{118}$$

Noting, the receiver factor as:

$$\beta_I = \left(\frac{\gamma''_I}{\gamma_I}\right) / \left(\frac{\gamma''_n}{\gamma_n}\right) \tag{119}$$

According to (116), (117), (118), the relation between γ_I / γ_n and D is:

$$\frac{\gamma_I}{\gamma_n} < \frac{10^{D/10} - 1}{\beta_I} \tag{120}$$

The expression (119) shows that the maximum interference noise ratio depend on both the degradation D and the receiver factor β_I. Thus, it is estimated the parameter β_I by simulation. This parameter depend on the receiver characteristics and also on the interference waveform.

TABLE 166

Receiver factor estimated by simulations (UWB without THC)

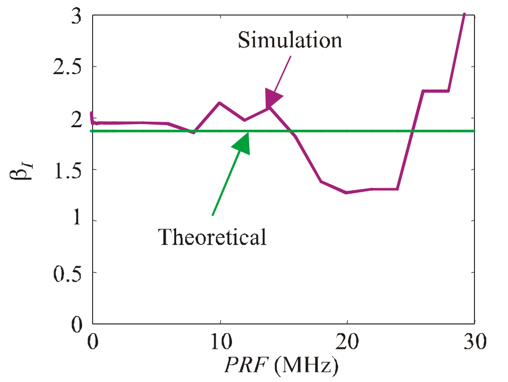
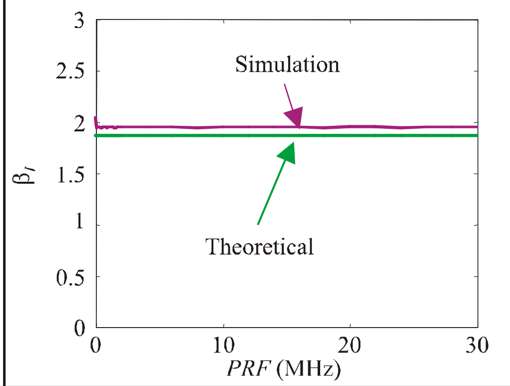
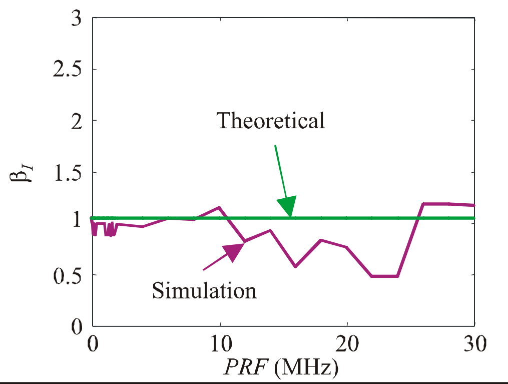
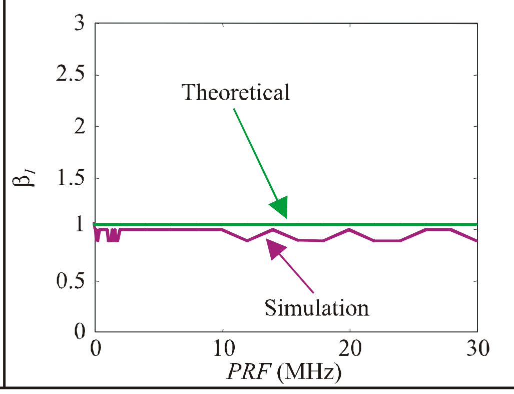
	No PAM	PAM
$min\ (B_{UWB}, F_e)$ = $F_e/2$		
$min\ (B_{UWB}, F_e)$ = F_e		

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Table 166 shows that β_I can be approximated by:

$$\beta_I \approx \frac{F_e}{min\left(B_{UWB}, F_e\right)} \tag{121}$$

This approximation is available in the PAM case and in the no-PAM case when $PRF < B_R/2$ (B_R = 27 MHz: the front-end filter bandwidth). When $PRF < B_R/2$ in no-PAM case, there is less than two spectral-lines in the front-end bandwidth and the signal behaves as a CW.

Proof of equation (120): Noting that the bandwidths of $I(t)''$ and $n(t)''$ are equals to B_R, the ratio γ''_I / γ''_n verify $\gamma''_I / \gamma''_n = \rho$ (ρ is the interference noise ratio). As the bandwidth of $I(t)$ is min(B_{UWB}, F_e), the ratio γ''_I / γ_I verify $\gamma''_I / \gamma_I = B_R / min\ (B_{UWB}, F_e)$ and in the same way as the bandwidth of $n(t)$ is F_e then $\gamma''_n / \gamma_n = B_R / F_e$. Finally the receiver factor β_I is $\beta_I = (\gamma''_I / \gamma_I) / (\gamma''_n / \gamma_n) = F_e / min(B_{UWB}, F_e)$.

2.3.7.4.3 Limit of detection

When the noise power ($\gamma_I + \gamma_n$) cannot be neglected in front of the GALILEO signal power (γ_c), the receiver cannot detected the associated signal $c(t)$. Indeed, the signal z_{LP} (k T) at the output the coherent integration can be decomposed as follows:

$$z_{LP}(kT) = C_{LP}(k\ T) + N_{LP}(k\ T) \tag{122}$$

Where $C_{LP}(k\,T)$ and $N_{LP}(k\,T)$ are respectively the signal and noise component of $Z_{LP}(k\,T)$ such that:

$$C_{LP}(k\,T) = \frac{1}{T}\int_{(k-1)T}^{k\,T} c(t)''\mathrm{d}t \quad N_{LP}(k\,T)\frac{1}{T}\int_{(k-1)T}^{k\,T} I(t)'' + n(t)''\mathrm{d}t \tag{123}$$

In this context it is possible to build a detector of the GALILEO signal knowing the statistic of the noise component N_{LP} $(k\,T)$ such that:

$$\begin{aligned}&\text{Signal Hypothesis: } z_{LP}\ (k\,T) > \eta\\ &\text{Noise Hypothesis : } z_{LP}\ (k\,T) < \eta\end{aligned} \tag{124}$$

Where the threshold η is chosen according to a required detection probability P_{det} and the standard deviation of N_{LP} $(k\,T)$ in Gaussian Hypothesis. In this condition (ISSL) establishes that the signal noise ratio in limit of detection is:

$$(C/N_0)(\text{dB.Hertz}) = 10\ \log_{10}\left(2\,\frac{\alpha(P_{det})}{\tau}\left(\sqrt{B_{LP}\tau} + \alpha(P_{det})\right)\right) \tag{125}$$

Where B_{LP} = 1 kHz is the bandwidth of the coherent integrator of the GALILEO receiver and:

$$P_{det} = \int_{-\infty}^{\alpha(P_{det})} \frac{1}{\sqrt{2\pi}}\exp\left(-\frac{x^2}{2}\right)\mathrm{d}x \tag{126}$$

As the time integration is equal to τ = T = 1 ms, Table 167 represents the S/N for different values of P_{det}.

TABLE 167

(C/N_0) limit of detection

P_{det}	C/N_0
99%	41.9 dB.Hz
95%	39.9 dB.Hz
90%	37.67 dB.Hz

These results have led ITU-R to specify a required C/N_0 to 41.2 dB.Hz (see Recommendation ITU-R M.1477). This value is associated to a probability detection close to 99%.

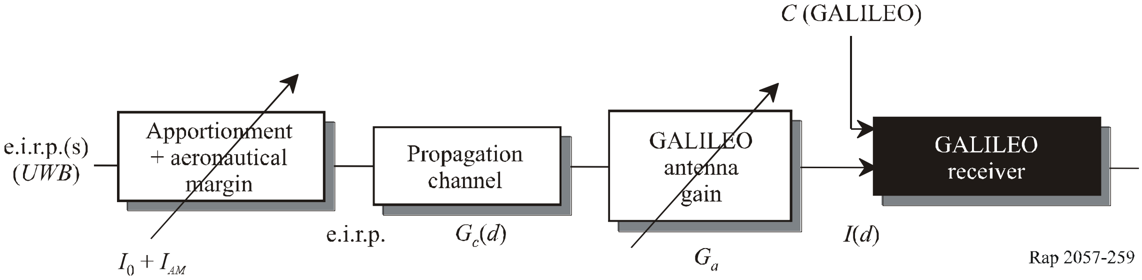
2.3.7.5 Interference assessment

2.3.7.5.1 Problem formulation

Figure 259 shows the important parameters to specify the maximum e.i.r.p. ($e.i.r.p._{max}$) of the UWB interferences.

FIGURE 259

Budget-link parameters



The GALILEO protection requirement is the parameter e.i.r.p. For each application there are the two following adjustable gains:

– I_{AM}: aeronautical margin (dB)

– I_0: apportionment factor (dB).

The input e.i.r.p. (dBm/MHz) is then amplified to e.i.r.p. such that:

$$\text{e.i.r.p.}' = \text{e.i.r.p.} - I_0 - I_{AM} \qquad (127)$$

In the single UWB case the attenuation $G_c\,(d, \Phi)$ due to the propagation between the UWB system and the GALILEO receiver is for a separated distance d:

$$\text{Single case: } G_c(d) = 20\ \log_{10}(d) + G_f \ \text{ where } G_f = 20\ \log_{10}(4\pi f_0 / 300) \qquad (128)$$

Where f_0 in MHz is the carried frequency of the receiver. In the aggregate UWBs case (Integral method), the attenuation $G_c(d)$ due to the propagation between the UWBs system and the GALILEO receiver is:

$$\text{Aggregate case: } \begin{aligned} G_c(d) &= -10\ \log_{10}\left(\ln\left(\frac{R_1}{d}\right)\right) - 10\ \log_{10}(\rho\eta) - 8 + G_f \\ &= -10\ \log_{10}\left(\ln\left(\frac{R_1}{d}\right)\right) + G_{Agg} \end{aligned} \qquad (129)$$

where:

$G_{Agg} = -10\ \log_{10}\,(\rho\eta) - 8 + G_f$

ρ: average density of transmitters/m^2

η: activity factor

d: minimum radius of the observed zone

R_1: maximum radius of the observed zone.

More precisely the repartition of UWBs is uniform between the circles of radius d and R_1. The UWB power **I**(d) (dBm/MHz) at the input of receiver is then:

$$\text{I}(d) = \text{e.i.r.p.}' - G_c\,(d) + G_a \qquad (130)$$

The maximum admissible e.i.r.p. such that (e.i.r.p. < e.i.r.p.$_{max}$) is specifying by taking into account the following constraints:

– The distance of reference: d_0 (depends on the application)

– Receiver constraints: D, (C/N_0), C, T_K

– Spectrum constraints: P_{C2}, P_{C2}, P_{C3}.

The receiver constraints parameters: D, (C/N_0), C, T_K are:

– D: the maximum GALILEO degradation at the output of receiver

– (C/N_0): the signal noise ratio in limit of detection

– C: minimum received GALILEO signal power at the output of antenna dW. ITU-R recommends **C** = –157.3 dBW

– T_K: receiver system noise temperature. ITU-R recommends. T_K = 350 K.

The spectrum constraints parameters P_{C2}, P_{C2}, P_{C3} are:

– $\mathbf{C}_1$ (general limits): the power measured within 1 MHz bandwidth should not exceed the limit noted P_{C1} (dB/MHz)

– C_2: the power of the spectral lines should not exceed the limits – P_{C2} (dB) when measured in a filter of bandwidth no less than 1 kHz

– C_3: the peak power ($w(t)$) should not exceed the limits P_{C3} (dB/50 MHz) when measured in a filter of bandwidth 50 MHz.

2.3.7.5.2 Maximum interference power at input of receiver

2.3.7.5.2.1 Limit of detection case

This section gives the maximum permitted UWB power $I_{max,D}$ at the input of receivers, to detect the signal of GALILEO. $I_{max,D}$ can be deduce from the receivers constraints parameters. (C/N_0), C, T_K and must verify:

$$I(d) < I_{max,D} \tag{131}$$

$$\text{e.i.r.p.}_{max} - I_0 - I_{AM} - G_c(d) + G_a < I_{max,D}$$

The receiver system noise temperature T_K determines the power (dBm/MHz) of the receiver noise as following:

$$N_0 = -138.6 \text{ dBm/MHz} + 10 \log10(T_K) \tag{132}$$

Noting that (C/N_0) is in dB.Hz, C in dBW and N_{max} (Noise + interference) in dBm/MHz, the relation between these parameters is:

$$(C/N_0) = C - N_{max} \tag{133}$$

Where N_{max} is the maximum Noise + interference power (dBW/Hz). Noting that the ratio $C - N_{max}$ is:

$$C - N_{max} = 10 \ \log_{10}\left(\frac{\gamma_c}{R_n(1 \text{ Hz}, f_0) + R_{I_{max}} \ (1 \text{ Hz}, f_0)}\right) = (C/N_0) \tag{134}$$

Where γ_c and R_n (1 Hz, f_0) are defined in equation (113) and $R_{I_{max}}(1 \text{ Hz}, f_0)$ is the maximum interference power such that:

$$I_{max\ ,D} = 10 \ \log_{10}\left(R_{I_{max}} \ (1 \ \text{Hz}, f_0)\right) + 90 \tag{135}$$

where $I_{max}(d)$ is in dBm/MHz. Noting that:

$$C - N_0 = 10 \ \log_{10}\left(\frac{\gamma_c}{R_{I_{max}} \ (1 \ \text{Hz}, f_0)}\right) - 90 \tag{136}$$

where C and N_0 are respectively in dBW and dBm/MHz. The maximum interference power in dBm/MHz is according to equations (132), (134), (135):

$$I_{max,\,D} = 10\ \log_{10}\left(10^{(C-N_0-[C/N_0]+90)/10} - 1\right) + N_0 \qquad (137)$$

Table 168 gives $I_{max,D}$ for different values of (C/N_0) when T_K = 350 K, C = –157.3 dBW.

TABLE 168

$I_{max,D}$ for different values of C/N_0 when T_K = 350 K, C = –157.3 dBW

$I_{max,D}$	C/N_0
–110.3 dBm/MHz	41.2 dB.Hz
–111.43 dBm/MHz	41.9 dB.Hz
–108.47 dBm/MHz	39.9 dB.Hz
–105.7 dBm/MHz	37.67 dB.Hz

2.3.7.5.2.2 UWB with spectrum constraints

Associated to different spectrums constraints C_i ($1 \le i \le 3$), the maximum interference power I_{max} (d_i) is admitted for a maximum GALILEO receiver degradation D. Using (92), (119) and $BWCF_n$ (F_e, 1 MHz) = 0, the conditions on the powers of the interference and thermal noise is:

$$I - N_0 + BWCF_I\left(F_e, 1\ \text{MHz}\right) < \Delta\beta_I \qquad (138)$$

where:

$$I = 10\ \log_{10}(\gamma_I) - BWCF_I\ (F_e, 1\ \text{MHz})$$

$$N_0 = 10\ \log_{10}(\gamma_n) \qquad (139)$$

$$\Delta\beta_I = 10\log_{10}\left(\frac{10^{D/10}-1}{\beta_I}\right)$$

The parameter β_I is defined in (121). Finally, the maximum value of $I_{max}(d_i)$ is:

$$I_{max}(d_i) = N_0 - BWCF_I\ (F_e, 1\ \text{MHz}) + \Delta\beta_I \qquad (140)$$

2.3.7.5.3 Minimum distance of UWB(s)

The purpose of this section is to determine the minimum distance between UWB(s) and GALILEO receiver by jointly taking into account the spectrum and detection constraints. The power $I(d)$ at the input of GALILEO receiver must:

– allow the detection of the GALILEO signal: $I(d) < I_{max,D}$ (see equation (136)).

– Take into account the spectrums constraints: $I(d) < I_{max}$ (d_i) for $1 \le i \le 3$ (see equation (139)).

Each spectrum constraint gives a different value of the maximum e.i.r.p. (e.i.r.p.$_{max}$). The values of the maximum e.i.r.p. E_{max} (i) associated to the i-th constraint, are summarize in Table 169.

TABLE 169

Maximum e.i.r.p. $E_{max}(i)$ with respect to the constraints with a single UWB

I	C_i	$E_{max}(i)$
1	Power within 1 MHz	P_{C1}
2	Spectral lines power in 1 kHz	$P_{C1} – P_{C2}$ + I_ICW
3	Peak power	$P_{C3} + AP_{Peak}$

The relation between $E_{max}(i)$ (see Table 169) and $I_{max}(d_i)$ is according to equations (126), (129) and (139):

$$I_{max}(d_i) = E_{max}(i) - I_0 - I_{AM} - G_c(d_i) + G_a \tag{141}$$

According to equations (139), (140), the minimum distance d_i (P_{C1}) associated to the *i*-th constraint is:

$$G_c(d_i(P_{C1})) = -I_0 - I_{AM} + G_a - N_0 + E_{max}(i) + BWCF_I(F_e, 1\text{ MHz}) - \Delta\beta_I \tag{142}$$

It is noticed that d_i (P_{C1}) depends on the UWB parameters I_ICW, AP_{Peak}, $BWCF_I$ (F_e,1 MHz) and the receiver parameters β_I and *D*.

As the parameters I_ICW, AP_{Peak}, $BWCF_I$ (F_e, 1 MHz) and β_I depends on the *PRF* and the UWB waveform, the distance d_i depends also on the *PRF*. The purpose of this work is to determined the maximum e.i.r.p.$_{max}$ such that:

Spectrum constraints: $d_0 = \max_{PRF}(\min(d_i(PRF, P_{C1} = e.i.r.p._{max})))$ (143)

Detection constraint: $e.i.r.p._{max} - I_0 - I_{AM} - G_c(d_0) + G_a < I_{max,D}$ (144)

Where d_0 is the reference distance depending on the UWB application. As the function $d_{12}(PRF, P_{C1}) = \min_{1\le i\le 2}(d_i(PRF, P_{C1}))$ has only one maximum in ($PRF = PRF_{max}$, $P_{C1} = e.i.r.p._{12}$) and d_3 is an increasing function of *PRF* independent to P_{C1}, the maximum e.i.r.p. is according to equations (141), (142), (143).

If: ($PRF_0 \le PRF_{max}$) then:

$$e.i.r.p._{max} = \min\{\text{e.i.r.p.}_{12}, I_0 + I_{AM} + G_c(d_0) - G_a + I_{max,D}\}$$

If: ($PRF_0 > PRF_{max}$) then: (145)

$$e.i.r.p._{max} = \min\left\{\begin{array}{c} e.i.r.p._{12} + G_c(d_0) - G_c(d_{12}(PRF_0,\ e.i.r.p._{12})), \\ I_0 + I_{AM} + G_c(d_0) - G_a + I_{max,D} \end{array}\right\}$$

where:

$$d_3(PRF_0) = d_0 \text{ and } d_0 = \min_{1\le i\le 2}(d_i(PRF_{max},\ e.i.r.p._{12})) \tag{146}$$

2.3.7.5.3.1 Single UWB case

According to equations (127), (141), the minimum distance d_i (P_{C1}) associated to the i-th constraint is:

$$d_i(P_{C1}) = \rho_{max}(i, P_{C1}) d_{ref}$$
$$d_{ref} = \frac{300}{4\pi f_0} 10^{(-I_0 - I_{AM} + G_a - N_0)/20} \tag{147}$$
$$\rho_{max}(i, P_{C1}) = 10^{(E_{max}(i) + BWCF_I(F_e, 1 \text{ MHz}) - \Delta\beta_I)/20}$$

Where only the amplitude factor $\rho_{max}(i, P_{C1})$ depends on the i-th spectrum constraint. The distance d_{ref} depends on the UWB application. Noting that $\rho_{max}(i, P_{C1}) = 10^{P_{C1}/20} \tilde{\rho}_{max}(i)$ for $(1 \le i \le 2)$ where $\tilde{\rho}_{max}(i)$ is independent to P_{C1} according to equation (146), the maximum e.i.r.p. verifies equation (144) with:

$$e.i.r.p._{12} = -20 \log_{10}\left(\frac{d_{ref}}{d_0} \min_{1 \le i \le 2}\left(\tilde{\rho}_{max}(i, PRF_0)\right)\right) \text{ and } G_c(d) = 20 \log_{10}(d) + G_f \tag{148}$$

where:

$$\tilde{\rho}_{max}(i) = 10^{\left(\tilde{E}_{max}(i) + BWCF_I(F_e, 1 \text{ MHz}) - \Delta\beta_I\right)/20} \text{ and } d_3(PRF_0) = d_0 \tag{149}$$

TABLE 170

Normalized maximum e.i.r.p. $\tilde{E}_{max}(i)$ with respect to the constraints with a single UWB

I	C_i	$\tilde{E}_{max}(i) = \tilde{E}_{max}(i) - P_{C1}$
1	Power within 1 MHz	0
2	Spectral lines power in 1 kHz	$-P_{C2}$ + I_ICW

In the following simulations T_K = 350K, (C/N_0) = 41.2 dB.Hz, C =–157.3 dBW and P_{C3} = –50 (dBm/50 MHz).

Tables 171 and 172 give the e.i.r.p.$_{max}$ in hand-held communication (d_0 = 1 m, G_a = 0 dB I_0 = –6 dB, I_{AM} = 0 dB) for UWB without THC and P_{C3} = –50 (dBm/50 MHz).

TABLE 171

Hand-held communication application for no PAM and THC UWB (BUWB = 90 MHz)

D **(dB)**	$\boldsymbol{P_{C3}}$ **(dB)**	***e.i.r.p.***$_{max}$
0.50	0.00	–96.29 dBm/MHz
0.50	10.00	–95.16 dBm/MHz
0.50	20.00	–91.73 dBm/MHz
1.00	0.00	–93.03 dBm/MHz
1.00	10.00	–91.89 dBm/MHz
1.00	20.00	–88.46 dBm/MHz

TABLE 172

Hand-held communication application for PAM and no THC UWB (BUWB = 90 MHz)

D **(dB)**	***e.i.r.p.$_{max}$***
0.50	–95.36 dBm/MHz
1.00	–92.09 dBm/MHz
1.5	–90.07 dBm/MHz

Figure 260 gives the distance d_i (*PRF*, e.i.r.p.$_{max}$) as a function of the PRF when P_{C2} = 10 dB and D = 1 dB.

FIGURE 260

Minimal distances d_i(*PRF*, e.i.r.p.$_{max}$) when P_{C2} = 10 dB and D = 1 dB with (e.i.r.p.$_{max}$ = –91.9 dBm/MHz)

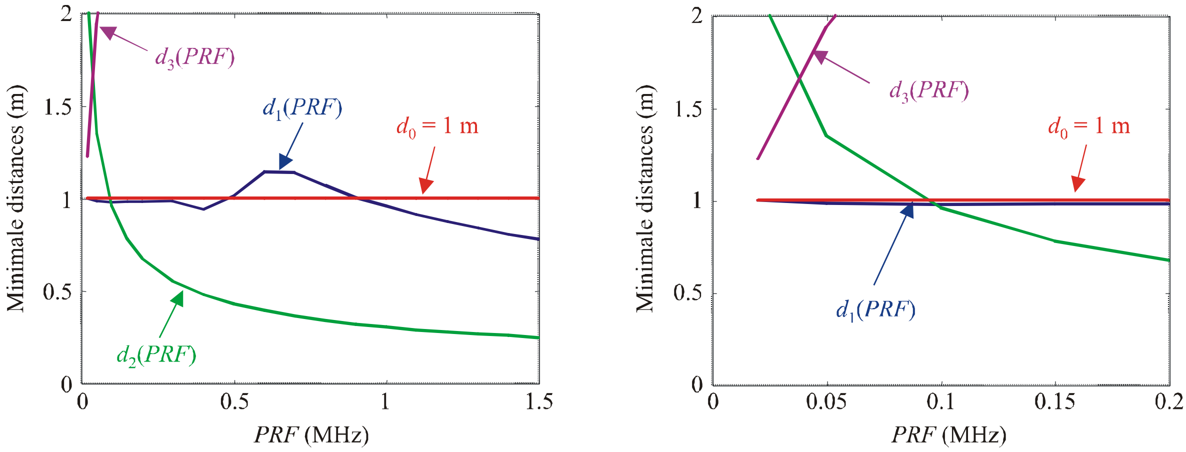


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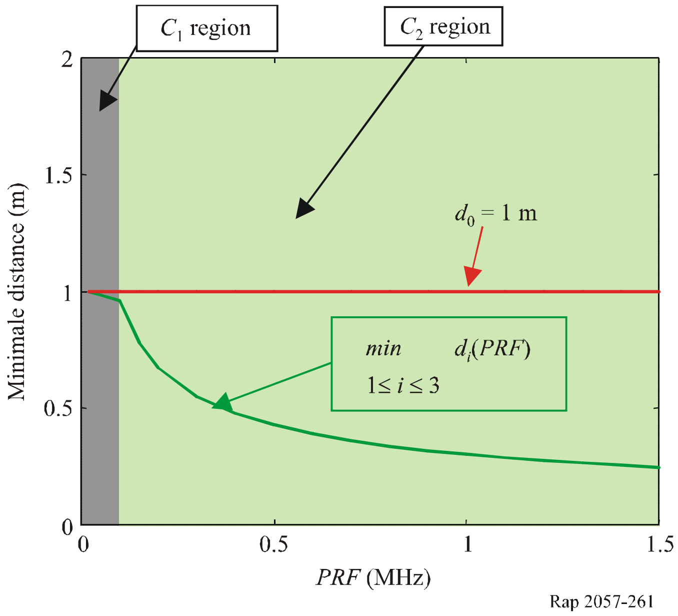
FIGURE 261

Minimal distance $\min_{1\le i\le 3} d_i$ (PRF, e.i.r.p.$_{max}$) when P_{C2} = 10 dB and D = 1 dB with (e.i.r.p.$_{max}$ = –91.9 dBm/MHz)



Figures 260 and 261 show that $\min_{1\le i\le 3} d_i(PRF,\ e.i.r.p._{max}) = d_1(PRF,\ e.i.r.p._{max})$ when PRF < 0.1 MHz and $\min_{1\le i\le 3} d_i(PRF,\ e.i.r.p._{max}) = d_2(PRF,\ e.i.r.p._{max})$ when $PRF \geq$ 0.1 MHz. Thus when PRF < 0.1 MHz the signal is in C_1 region and when $PRF \geq$ 0.1 MHz the signal is in C_2 region. In addition, Fig. 261 shows that the minimum distance is under d_0 = 1 m for all PRF due to constraints of the calculation of the e.i.r.p.$_{max}$ in equations (142), (143).

Tables 173 and 174 give the e.i.r.p.$_{max}$ in *Safety-of-life services* (d_0 = 30 m, G_a = 5 dB I_0 = –20 dB, I_{AM} = –5.6 dB) for UWB without THC and P_{C3} = –50 (dBm/50 MHz).

TABLE 173

Safety-of-life services application for no PAM and THC UWB (BUWB = 90 MHz)

D **(dB)**	P_{C2} **(dB)**	***e.i.r.p.$_{max}$***
0.50	0.00	–91.35 dBm/MHz
0.50	10.00	–90.21 dBm/MHz
0.50	20.00	–86.79 dBm/MHz
1.00	0.00	–86.81 dBm/MHz
1.00	10.00	–86.81 dBm/MHz
1.00	20.00	–79.54 dBm/MHz

TABLE 174

Safety-of-life services application for PAM and no THC UWB (BUWB = 90 MHz)

D **(dB)**	***e.i.r.p.*$_{max}$**
0.50	–90.42 dBm/MHz
1.00	–86.81 dBm/MHz
1.5	–84.79 dBm/MHz

In the hand-held communication context (d_0 = 1 m, G_a = 0 dB I_0 = –6 dB, I_{AM} = 0 dB) with no PAM and THC UWB, Figs. 262-265 gives the *e.i.r.p.*$_{max}$ with respect to (D, P_{C2}, I_0, d_0) when P_{C3} = –50 (dBm/50 MHz).

FIGURE 262

***e.i.r.p.*$_{max}$ with respect to *D* when P_{C2} = 10 dB , I_0 = –6 dB, d_0 = 1 m in hand-held communication**

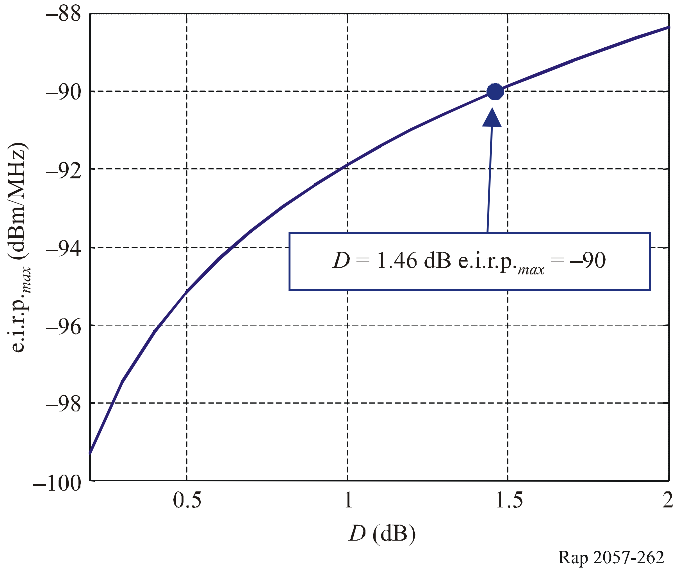
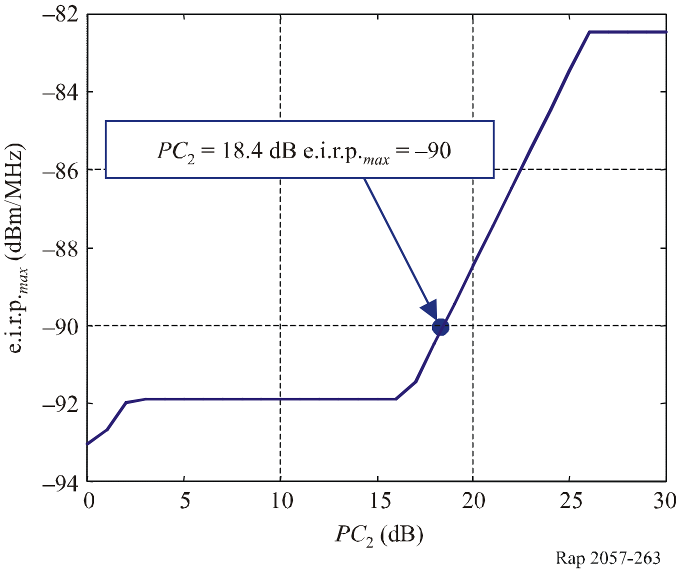


FIGURE 263

***e.i.r.p.$_{max}$* with respect to *P_{C2}* when *D* = 1 dB , *I_0* = –6 dB, *d_0* = 1 m in hand-held communication**



Rap 2057-263

FIGURE 264

***e.i.r.p.$_{max}$* with respect to *I_0* when *P_{C2}* = 10 dB , *D* = 1 dB, *d_0* = 1 m in hand-held communication**

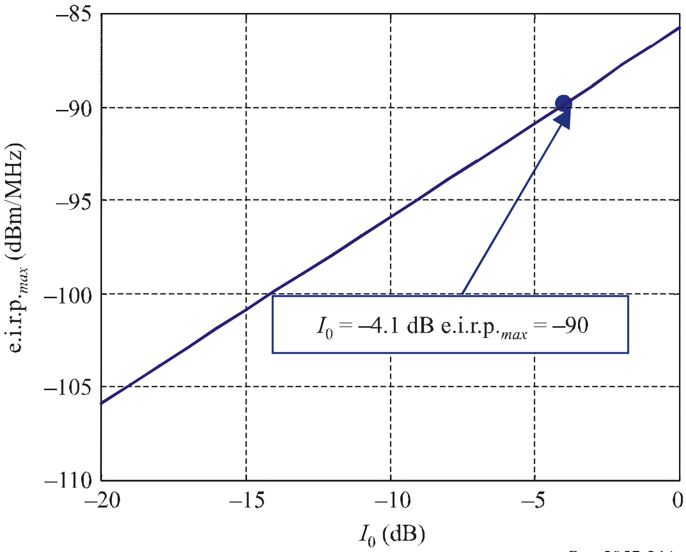


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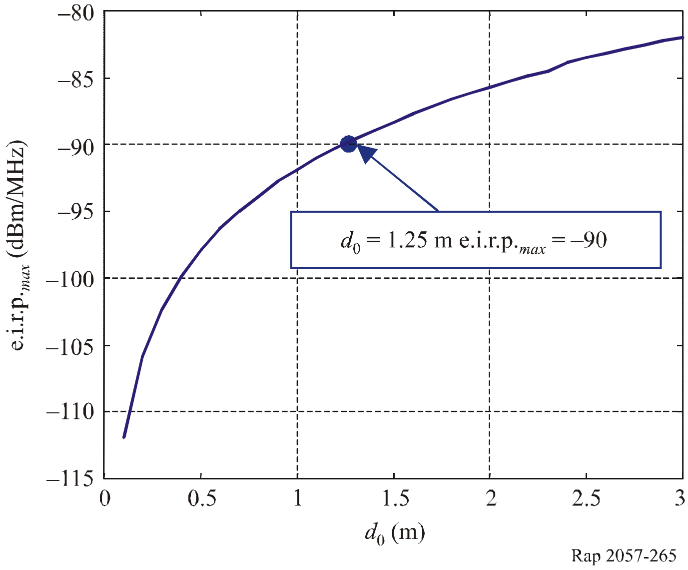
FIGURE 265

e.i.r.p.$_{max}$ **with respect to** ***d_0*** **when** ***D*** **= 1 dB ,** ***I_0*** **= –6 dB,** ***P_{C2}*** **= 50 dB in hand-held communication**



Concerning the impact of a single UWB device, the conclusion is that the e.i.r.p. should not exceed –90 dBm/MHz along with an 18 dB attenuation on each peak within 1 kHz, which means that the e.i.r.p. should not exceed –108 dBm/kHz for spectral lines. The degradation of the receiver equals 1 dB.

2.3.7.5.3.2 Aggregate UWBs case

In this context $R_1 = \Delta R_1 + d$. According to equations (128), (131), the minimum distance $d_i\,(P_{C1})$ associated to the i-th constraint is:

$$d_i(P_{C1}) = \frac{\Delta R_1}{\exp\left(\dfrac{1}{\rho_{max}(i, P_{C1})d_{ref}}\right) - 1}$$

$$d_{ref} = 10^{\left(-I_0 - I_{AM} + G_a - N_0 - G_{Agg}\right)/10} \qquad (150)$$

$$\rho_{max}(i, P_{C1}) = 10^{\left(E_{max}(i) + BWCF_I\left(F_e, 1\ \text{MHz}\right) - \Delta\beta_I\right)/10}$$

Where only the amplitude factor $\rho_{max}\,(i, P_{C1})$ depends on the i-th spectrum constraint. The coefficient d_{ref} depends on the UWB application. Noting that $\rho_{max}\,(i, P_{C1}) = 10^{P_{C1}/10}\tilde{\rho}_{max}(i)$ for $(1 \le i \le 2)$ where $\tilde{\rho}_{max}(i)$ is independent to P_{C1} according to (149), the maximum e.i.r.p. verifies equation (144) with:

$$e.i.r.p._{12} = -10\ \log_{10}\left(d_{ref}\ \ln\left(1 + \frac{\Delta R_1}{d_0}\right)\min_{1 \le i \le 2}\left(\tilde{\rho}_{max}\left(i, PRF_0\right)\right)\right)$$

$$G_c(d) = -10\ \log_{10}\left(\ln\left(1 + \frac{\Delta R_1}{d}\right)\right) + G_{Agg} \qquad (151)$$

where:

$$\tilde{\rho}_{max}(i) = 10^{\left(\tilde{E}_{max}(i) + BWCF_I(F_e,\ 1\ \text{MHz}) - \Delta\beta_I\right)/10} \text{ and } d_3(PRF_0) = d_0 \qquad (152)$$

In the following simulations T_K = 350 K, (C/N_0) = 41.2 dB.Hz, C = –157.3 dBW.

Table 175 gives the e.i.r.p.$_{max}$ in hand-held communication (d_0 = 1 m, G_a = 0 dB I_0 = –6 dB, I_{AM} = 0 dB, D = 1 dB) for aggregate UWBs (ρ = 0.1 (1/m^2), ΔR_1 = 50 m) without THC. The activity factor is a variable parameter.

TABLE 175

Hand-held communication application for no PAM and THC UWBs (BUWB = 90 MHz, ρ = 0.1 (1/m^2), ΔR_1 = 50 m D = 1 dB, P_{c2} = 18 dB)

H	*e.i.r.p.$_{max}$*
0.1	–85 dBm/MHz
0.2	–87 dBm/MHz
0.3	–89 dBm/MHz
0.4	–91 dBm/MHz
0.5	–92 dBm/MHz

This table clearly shows that using hypothesis from typical scenario deployment concerning the activity factor and the UWB density, the aggregate case does not add any additional constraint on the UWB devices compared to the single case.

2.3.7.6 Conclusion for Galileo

The e.i.r.p. of a single UWB device should not exceed –90 dBm/MHz along with an 18 dB attenuation on each peak within 1 kHz, which means that the e.i.r.p. should not exceed –108 dBm/kHz for spectral lines.

2.3.7.7 References

BETZ J. W. [19-22 Sept. 2000] Design and performance of code tracking for the GPS M Code Signal. Proc. ION GPS 2000, Salt Lake City, UT.

FCC [2002] Revision of Part 15 of the Commission’s Rules Regarding UWB Transmission System. Federal Communications Commission, ET Docket 98-153, FCC 02-48, adopted February 14, 2002.

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HEI-al – HEIN G. W. *et al.* [2003] Galileo Frequency and Signal Design, GPS World 2003.

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2.4 GLONASS

2.4.1 Introduction

The GLONASS system is designed to solve radionavigation problems of different users. Radiation from mission oriented spaceborne transmitters is used as a source of signals employed for navigation solutions. On that basis the GLONASS receivers have been, from the outset, developed to operate using signals of low PSD. Therefore radiation produced by UWB systems of different applications could cause harmful interference to operation of the GLONASS receivers.

The below section discusses effects of UWB signals on the GLONASS receivers under different interference scenarios to define operation features of UWB systems to ensure compatibility.

2.4.2 Employment of the GLONASS system

The GLONASS Global Navigation Satellite System is designed to provide position-fixing, motion velocity and time measurements for maritime, aeronautical, terrestrial and other users.

The GLONASS system ensures operation of super important applications such as aeronautical navigation of aircraft on-route flight, approach and landing.

2.4.3 Characteristics of signals in the GLONASS system

BPSK signals of four types are used in the GLONASS system. They are 16M4G7X, 4M01G7X, 1M02G7X, 10M2G7X. Table 176 shows characteristics of those signals.

PSD of any such signal is defined by the following analytical expression:

$$S(f) = \frac{1}{f_c}\left(\sin\left(\frac{\pi \cdot f}{f_c}\right) \Big/ \left(\frac{\pi \cdot f}{f_c}\right)\right)^2 \tag{153}$$

where:

f: frequency at which PSD is estimated

f_c = 0.511 · n – signal chipping rate (MHz).

TABLE 176

GLONASS signal characteristics

Signal	Frequency (MHz)	Bandwidth (MHz)	Code rate (Mchip/s)	Symbol rate (Symbol/s)	Signal type	
16M4G7X	1 201.5	16.4	8.191	200	BPSK(16)	data
4M10G7X		4.1	2.047	200	BPSK(8)	data
10M2G7X	1 246.00	10.2	5.11	50	BPSK(10)	data
1M02G7X		1.02	0.511	50	BPSK(1)	data
10M2G7X	1 602.00	10.2	5.11	50	BPSK(10)	data
1M02G7X		1.02	0.511	50	BPSK(1)	data

2.4.4 Scenarios of interference effect on the GLONASS RNSS receivers

The level of UWB signals effect on operation of GLONASS navigation receivers is defined by e.i.r.p. of an UWB device and a distance between that UWB device and a navigation receiver antenna. Minimum distance between an UWB system and a navigation receiver depends on application mission of appropriate assets.

This Report considers navigation receivers of two main types:

– an airborne GLONASS navigation receiver designed for aircraft navigation (an airborne receiver);

– a low-cost commercial general-purpose GLONASS receiver.

Two scenarios of interference effect are analysed in relation to operation of the airborne navigation receivers. They are:

Scenario 1: A single UWB device causing interference to a navigation receiver at the stage of aircraft landing (Fig. 266).

Scenario 2: Multiple UWB devices causing interference to a navigation receiver installed in an aircraft approaching a runway (Fig. 267).

Aircraft altitude is 30 m (subject to RTCA No. 297-96/SC 159-710 (formerly DO-194)).

FIGURE 266

Scenario 1

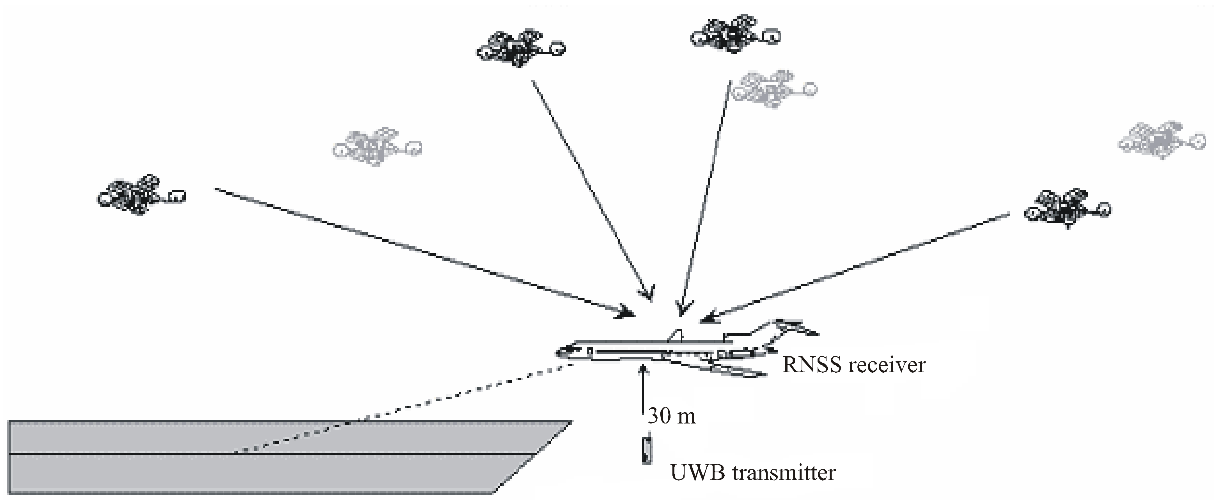

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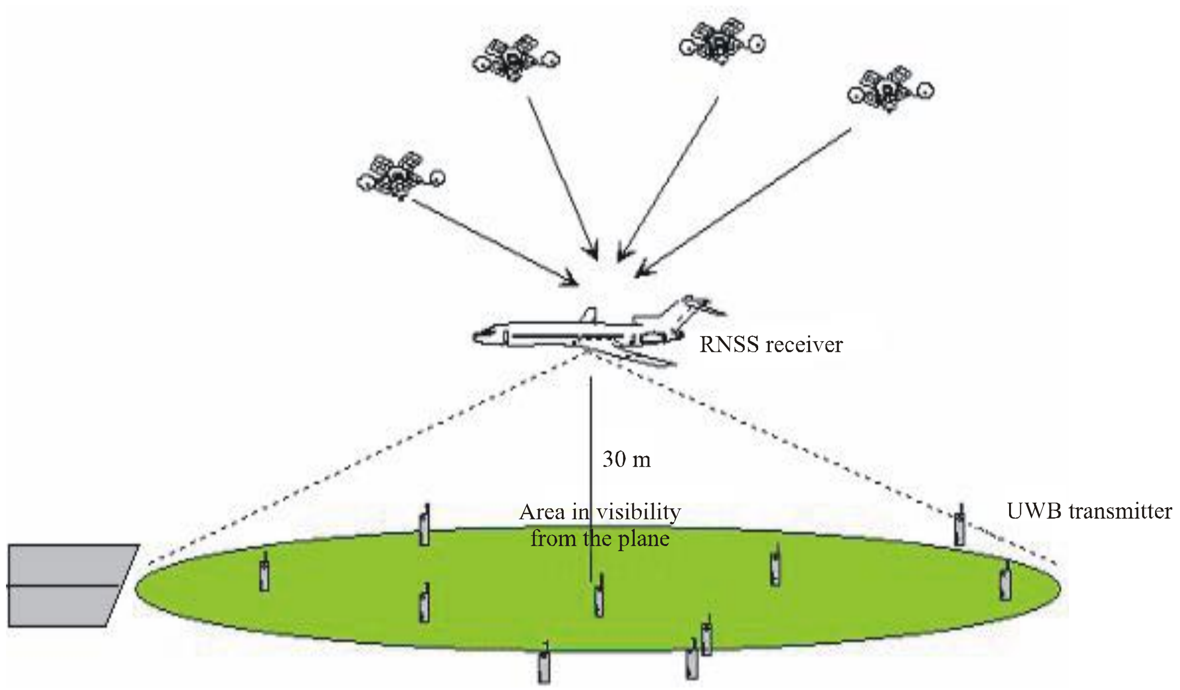
FIGURE 267

Scenario 2



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Scenarios of interference to a commercial (low-cost) GLONASS receiver from a single UWB device were analysed for different applications of that device. Seven different scenarios were defined. Table 177 shows protection distances for different scenarios in relation to different types of UWB device applications.

TABLE 177

Protection distances for different applications of UWB devices

Types of UWB devices	Protection distance (m)
Ground penetrating radar (GPR) systems	6
Through-wall imaging radars	6
Safety-of-life systems	25
Medical applications	6
Indoor communications	2
Hand-held computer intercommunications	1
Automotive radars	2

Moreover two additional cases of interference effect on navigation receivers were analysed for each of the above scenarios:

– The first case assumes that interference of constant spectral density affects a navigation receiver front end in the receiver operational frequency band (wide-band interference).

– The second case assumes that a navigation receiver is affected by a periodic pulse sequence therefore a single or several spectral lines of a transmitted signal affect the receiver front end (a narrow-band interference).

2.4.5 Protection criteria for the GLONASS system

Irrespective to different forms of operational signals, selection of protection criteria should be based on a nature of interference affecting a RNSS receiver front end and it should not be a function of operational signal waveform or pulse repetition rate. Therefore it is assumed that limits on power spectral density may be used as protection criteria.

In case of a wide-band interference at a receiver front end its effect on the receiver is identical to increasing its noise temperature by several degrees. Therefore it may be assumed that limitation of receiver noise temperature could be used as a protection criterion.

The ITU has not yet defined a criterion of a fixed increase in noise temperature. That criterion has been proposed by analogy with protection of other services such as the fixed service. This section assumes that occurrence of interference at an airborne GLONASS receiver input would be equivalent to increasing its noise temperature by 1%. Since a nominal value of GLONASS receiver noise temperature is 400°k then interference could increase it by at least 4°k. Such an increase in the noise temperature is identical to interference of –162 dBW/MHz at a GLONAAS navigation receiver front end.

To protect an airborne GLONASS receiver from a narrow-band interference its power spectral density shall not exceed –177 dBW/kHz.

Criteria of a commercial GLONASS receiver protection from wide-band interference are defined by the requirement that I/N at that receiver front end shall not exceed –6 dB to be identical to increasing the receiver noise temperature by 25%. Such increasing in noise temperature is similar to interference of –148 dBW/kHz in power spectral density at the receiver front end.

Power spectral density at the front end of a commercial GLONASS receiver shall not exceed –163 dBW/kHz to provide its protection from narrow-band interference.

2.4.6 Analysis of UWB systems interfering with a GLONASS receiver

2.4.6.1 GLONASS receiver antenna gain

Estimation of airborne receiver protection requirements assumed its antenna gain of 5 dB.

Antenna gain of 3 dB was assumed for a commercial receiver in the direction to an interfering source.

2.4.6.2 UWB signal propagation loss

Estimation of UWB signal loss for propagation between a transmitting source and a GLONASS receiver antenna used a free-space propagation model. Based on that model, losses in a radio link could be calculated using the equation (154):

$$L_p = 20\log(4\pi fD/c) \tag{154}$$

where:

- L_p: propagation loss (dB)
- f: central frequency of the GLONASS receiver operational band
- D: protection distance from a navigation receiver to an UWB device (m)
- c = $3 \cdot 10^8$ m/s, – velocity of light.

2.4.6.3 Estimation of acceptable e.i.r.p. from an UWB device for a single UWB signal

Objective of this analysis consists in defining an acceptable e.i.r.p. for signals transmitted from different UWB devices. The level of that e.i.r.p. is a function of GLONASS receiver antenna gain, signal frequency, distance from an UWB device to a GLONASS receiver and an acceptable power spectral density at the navigation receiver front end. For a specified set of the above parameters the e.i.r.p. from an UWB device is defined by the equation (155):

$$e.i.r.p._{UWB} = P_{rec} - G_{Arec} + L_p - A_{marg} \tag{155}$$

where:

- $e.i.r.p._{UWB}$: e.i.r.p. of an UWB device (dBm/MHz)
- P_{rec}: maximum acceptable power spectral density of interference at a receiver front end (dBm/MHz)
- G_{Arec}: navigation receiver antenna gain in the direction of an UWB device (dB)
- A_{marg}: an additional margin of 5.6 dB for a safety-of-life system (referred to an airborne receiver).

2.4.6.4 Estimation of acceptable e.i.r.p. of an UWB device for aggregate UWB interference

Such analysis is required to define an acceptable e.i.r.p. from an UWB device for aggregate interference to a navigation receiver from multiple UWB devices operating at the Earth surface. The case is common for an airborne GLONASS receiver. It is obvious that e.i.r.p. of UWB devices would be a function of aircraft altitude, density of UWB devices located along the aircraft route and operation intensity of those devices. Estimation of power produced by multiple UWB devices at a navigation receiver front end used a model developed by NTIA such as:

$$P_{rec} = \frac{e.i.r.p._{UWB}\lambda^2 G_{Arec}\,\rho R_e}{16\pi(R_e + h)} \cdot \ln\left(\frac{2(R_e + h)H + h^2}{h^2}\right) \tag{156}$$

where:

- P_{rec}: maximum acceptable power spectral density of interference at a receiver front end (dBm/MHz)
- $e.i.r.p._{UWB}$: e.i.r.p. of an UWB device (dBm/MHz)
- $\lambda = c/f$: operational wave length (m)
- G_{Arec}: navigation receiver antenna gain in the direction of an UWB device (dB)
- ρ: averaged location density for UWB devices (devices/m^2)
- h: navigation receiver antenna altitude above the Earth surface (m)
- R: distance from navigation receiver antenna projection on the Earth surface to a radio horizon (m)
- R_e: effective Earth radius (m)
- $H =$ R_e (1-cos(R/R_e).

Transformation of the above expression yields the following equation for a maximum acceptable e.i.r.p. from a single UWB device. It would be as:

$$e.i.r.p._{UWB}^{agg} = P_{rec} - G_{Arec} + 10\ \log\left[\frac{16\pi f^2}{c^2\rho}\right] + 10\ \log\left[\frac{R_e + h}{R_e \ln\left(\frac{2(R_e + h)H + h^2}{h^2}\right)}\right] - A_{marg} \tag{157}$$

where:

- $e.i.r.p._{UWB}$: e.i.r.p. of an UWB device (dBm/MHz)
- P_{rec}: maximum acceptable power spectral density of interference at a receiver front end (dBm/MHz)
- G_{Arec}: navigation receiver antenna gain in the direction of an UWB device (dB)
- h: navigation receiver antenna altitude above the Earth surface (m)
- ρ: averaged location density for UWB devices (devices/m^2)
- R: distance from navigation receiver antenna projection on the Earth surface to a radio horizon (m)
- R_e: effective Earth radius (m)
- $H =$ R_e (1-cos(R/R_e)
- A_{marg}: an additional margin of 5.6 dB for a safety-of-life system (referred to an airborne receiver).

2.4.7 Protection requirements of airborne GLONASS receivers

2.4.7.1 Requirements of protecting the airborne GLONASS receivers from wide-band interference caused by a single UWB device

Wide-band interference power spectral density at an airborne GLONASS navigation receiver shall not exceed –132 dBm/MHz. Using the equation for a maximum acceptable e.i.r.p. from an UWB device (see § 2.4.6.4) could provide obtaining the maximum acceptable e.i.r.p. emitted from a single UWB device. The e.i.r.p. values are shown in Table 178.

TABLE 178

Maximum e.i.r.p. from an UWB device with a single-source wide-band interference

Signal	Frequency (MHz)	Transmission band (MHz)	e.i.r.p.$_{UWB}$ (dBm/MHz)
16M4G7X	1 201.5	16.4	–79.0
4M10G7X		4.1	
10M2G7X	1 246.00	10.2	–78.7
1M02G7X		1.02	
10M2G7X	1 602.00	10.2	–76.5
1M02G7X		1.02	
Protection distance	30 m		I/N = –20 dB
Antenna gain	5 dB		

The estimation assumed that navigation receiver antenna gain would be G_{Arec} = 5 dB in the direction of an interference source with an additional margin for system safety being A_{marg} = –5.6 dB.Analysis of the estimation results shown in Table 179 suggests that a limit of –79 dBm/MHz imposed on an UWB device e.i.r.p. may be used as protection requirements of airborne GLONASS navigation receivers.

Data shown in Table 178 were obtained for an airborne navigation receiver for which interference caused by an UWB device shall meet the criterion of I/N = –20 dB.

2.4.7.2 Requirements of protecting the airborne GLONASS receivers from wide-band interference caused by multiple UWB devices

The protection criteria for a discussed case is a function of UWB devices density (ρ)/m^2. Therefore two different scenarios of aggregate interference effect on a GLONASS navigation receiver from multiple UWB devices were analysed including one for a suburban case of ρ = 10^{-3} device/m^2 and the other one for an urban case of ρ = 10^{-2} device/m^2. It was assumed that the aircraft undertakes manoeuvres in a standard atmosphere with a refraction factor of 4/3. Definition of protection requirements of such navigation receivers used the NTIA model which assumes the effective Earth radius of 8 493 km and a distance to radio horizon of 22.1 km. Table 179 shows the estimation results for a navigation receiver affected with wide-band interference.

TABLE 179

Maximum e.i.r.p. of an UWB device under aggregate wide-band interference

<table>
<tr><th rowspan="2">Signal</th><th rowspan="2">Frequency (MHz)</th><th rowspan="2">Transmission band (MHz)</th><th>ρ = 10^{-3} dev./m^2</th><th>ρ = 10^{-2} dev./m^2</th></tr>
<tr><th>e.i.r.p.$_{UWB}$ (dBm/MHz)</th><th>e.i.r.p.$_{UWB}$ (dBm/MHz)</th></tr>
<tr><td>16M4G7X</td><td rowspan="2">1 201.5</td><td>16.4</td><td rowspan="2">–64.7</td><td rowspan="2">–84.7</td></tr>
<tr><td>4M10G7X</td><td>4.1</td></tr>
<tr><td>10M2G7X</td><td rowspan="2">1 246.00</td><td>10.2</td><td rowspan="2">–64.4</td><td rowspan="2">–84.4</td></tr>
<tr><td>1M02G7X</td><td>1.02</td></tr>
<tr><td>10M2G7X</td><td rowspan="2">1 602.00</td><td>10.2</td><td rowspan="2">–64.2</td><td rowspan="2">–82.2</td></tr>
<tr><td>1M02G7X</td><td>1.02</td></tr>
<tr><td colspan="2">Protection distance</td><td>30 m</td><td>I/N = –20 dB</td><td></td></tr>
<tr><td colspan="2">Antenna gain</td><td>5 dB</td><td></td><td></td></tr>
</table>

Analysis of the obtained results shows that the model proposed by NTIA for aggregate interference caused by multiple UWB devices would provide for realistic estimates of maximum e.i.r.p. from UWB devices but only for an urban case, because the e.i.r.p. limits for UWB devices obtained under a suburban scenario are less stringent compared with those obtained for a single-source interference.

Analysis of results presented in Table 180 shows that maximum e.i.r.p. of –84.7 dBm/MHz from an UWB device may be used as a protection requirement of an airborne GLONASS navigation receiver for an urban case. The said value is 5.7 dB less than the requirements for a single-source interference.

2.4.7.3 Requirements of protecting the GLONASS receivers from narrow-band interference caused by a single UWB device

Power spectral density of narrow-band interference at the front end of an airborne GLONASS navigation receiver shall not exceed –147 dBm/kHz. Using the equation for a maximum acceptable e.i.r.p. from an UWB device (see § 2.4.6.4) could provide obtaining the maximum acceptable e.i.r.p. emitted from a single UWB device. The e.i.r.p. values are shown in Table 180.

The estimation assumed that airborne navigation receiver antenna gain would be 5 dB with an additional margin for system safety being –5.6 dB. Analysis of the estimation results shown in Table 180 suggests that a maximum acceptable e.i.r.p. of –94 dBm/kHz may be used as protection requirements of airborne GLONASS navigation receivers.

TABLE 180

Maximum e.i.r.p. from an UWB device for a single-source CW-like interference

Signal	Frequency (MHz)	Transmission band (MHz)	$e.i.r.p._{UWB}$, (dBm/kHz)
16M4G7X	1 201.5	16.4	–94.0
4M10G7X		4.1	
10M2G7X	1 246.00	10.2	–93.7
1M02G7X		1.02	
10M2G7X	1 602.00	10.2	–91.5
1M02G7X		1.02	
Protection distance	30 m		*I*/*N* = –20 dB
Antenna gain	5 dB		

Data shown in Table 180 were obtained for an airborne navigation receiver for which interference caused by an UWB device shall meet the criterion of *I*/*N* = –20 dB.

2.4.7.4 Requirements of protecting the airborne GLONASS receivers from narrow-band interference caused by multiple UWB devices

The estimation was based on the parameters shown in § 2.4.7.3. Table 181 presents the estimates for interference power spectral density equal to –147 dBm/kHz.

TABLE 181

Maximum e.i.r.p. of an UWB device under aggregate CW-like interference

Signal	Frequency (MHz)	Transmission band (MHz)	$\rho = 10^{-3}$ dev./m^2	$\rho = 10^{-2}$ dev./m^2
			$e.i.r.p._{UWB}$ (dBm/kHz)	$e.i.r.p._{UWB}$ (dBm/kHz)
16M4G7X	1 201.5	16.4	–79.7	–99.7
4M10G7X		4.1		
10M2G7X	1 246.00	10.2	–79.4	–99.4
1M02G7X		1.02		
10M2G7X	1 602.0	10.2	–77.2	–97.2
1M02G7X		1.02		
Protection distance	30 m		*I*/*N* = –20 dB	
Antenna gain	5 dB			

Analysis of the results presented in Tables 180 and 181 shows that if location density for UWB devices is equal to 10^{-2} dev./m^2 then the limits on e.i.r.p. from an UWB device would be more stringent by 5.7 dB as compared with those for single-source interference.

Maximum e.i.r.p. of –99.7 dBm/kHz from an UWB device may be used as protection requirements of an aeronautical navigation receiver installed in an aircraft when it is at stages of take-off or landing.

2.4.8 Requirements of protecting the commercial GLONASS receivers from interference caused by a single UWB device

2.4.8.1 Requirements of protecting the commercial GLONASS receivers from wide-band interference

Interference-to-noise ratio for a commercial GLONAS receiver shall not exceed *I*/*N* = –6 dB. Appropriate maximum interference power spectral density would be –118 dBm/MHz. Using the above data for estimating the protection requirements of the commercial GLONASS receivers yields the results shown in Table 182.

TABLE 182

Maximum e.i.r.p. of an UWB device

UWB applications	Protection distance (m)	Signal	Frequency (MHz)	$e.i.r.p._{UWB}$ (dBm/MHz)
Ground penetrating radar systems. In-wall imaging radars	6	16M4G7X	1 201.5	–71.4
		4M10G7X		
		10M2G7X	1 246.00	–71.1
		1M02G7X		
		10M2G7X	1 602.00	–68.9
		1M02G7X		
Safety-of-life systems	25	16M4G7X	1 201.5	–59.0
		4M10G7X		
		10M2G7X	1 246.00	–58.7
		1M02G7X		
		10M2G7X	1 602.00	–56.5
		1M02G7X		
Medical applications	6	16M4G7X	1 201.5	–71.4
		4M10G7X		
		10M2G7X	1 246.00	–71.1
		1M02G7X		
		10M2G7X	1 602.00	–68.9
		1M02G7X		
Indoor communications	2	16M4G7X	1 201.5	–81.0
		4M10G7X		
		10M2G7X	1 246.00	–80.7
		1M02G7X		
		10M2G7X	1 602.00	–78.4
		1M02G7X		

TABLE 182 (*end*)

UWB applications	Protection distance (m)	Signal	Frequency (MHz)	*e.i.r.p.UWB* (dBm/MHz)
Communication between hand-held computers	1	16M4G7X	1 201.5	–87.0
		4M10G7X		
		10M2G7X	1 246.00	–86.7
		1M02G7X		
		10M2G7X	1 602.00	–84.5
		1M02G7X		
Automotive applications	2	16M4G7X	1 201.5	–73.0
		4M10G7X		
		10M2G7X	1 246.00	–72.7
		1M02G7X		
		10M2G7X	1 602.00	–70.5
		1M02G7X		
Antenna gain	3 dB	I/N = –6 dB		

The estimations assumed that commercial navigation receiver antenna gain was 3 dB with no system safety margin (A_{marg} = 0 dB). Analysis of data in Table 181 shows that the UWB device e.i.r.p. obtained for protection distance of 1 m and equal to –87.0 dBm/MHz may be used as protection requirements of commercial GLONASS navigation receivers.

2.4.8.2 Requirements of protecting the commercial GLONASS receivers from narrow-band interference

Interference-to-noise ratio for commercial GLONAS receivers shall not exceed I/N = –6 dB. Corresponding maximum interference power spectral density would be –133 dBm/kHz. Using the above data for estimating the protection requirements of the commercial GLONASS receivers yields the results shown in Table 183.

TABLE 183

Maximum e.i.r.p. of an UWB device

UWB applications	Protection distance (m)	Signal	Frequency (MHz)	*e.i.r.p.UWB* (dBm/kHz)
Ground penetrating radar systems. In-wall imaging radars	6	16M4G7X	1 201.5	–86.4
		4M10G7X		
		10M2G7X	1 246.00	–86.1
		1M02G7X		
		10M2G7X	1 602.00	–83.9
		1M02G7X		

TABLE 183 (*end*)

UWB applications	Protection distance (m)	Signal	Frequency (MHz)	*e.i.r.p.*$_{UWB}$ (dBm/kHz)
Safety-of-life systems	25	16M4G7X	1 201.5	–74.0
		4M10G7X		
		10M2G7X	1 246.00	–73.7
		1M02G7X		
		10M2G7X	1 602.00	–71.5
		1M02G7X		
Medical applications	6	16M4G7X	1 201.5	–86.4
		4M10G7X		
		10M2G7X	1 246.00	–86.1
		1M02G7X		
		10M2G7X	1 602.00	–83.9
		1M02G7X		
Indoor communications	2	16M4G7X	1 201.5	–95.9
		4M10G7X		
		10M2G7X	1 246.00	–95.6
		1M02G7X		
		10M2G7X	1 602.00	–93.4
		1M02G7X		
Communication between hand-held computers	1	16M4G7X	1 201.5	–102.0
		4M10G7X		
		10M2G7X	1 246.00	–101.7
		1M02G7X		
		10M2G7X	1 602.00	–99.5
		1M02G7X		
Automotive applications	2	16M4G7X	1 201.5	–95.9
		4M10G7X		
		10M2G7X	1 246.00	–95.6
		1M02G7X		
		10M2G7X	1 602.00	–93.4
		1M02G7X		
Antenna gain	3 dB	I/N = –6 dB		

The estimations assumed that commercial navigation receiver antenna gain was 3 dB with no system safety margin (A_{marg} = 0 dB). Analysis of data in Table 183 shows that the UWB device e.i.r.p. obtained for protection distance of 1 m and equal to –102.0 dBm/kHz may be used as protection requirements of commercial GLONASS navigation receivers.

2.4.9 Conclusions

Analysis of the obtained results shows that the acceptable e.i.r.p. from UWB devices should be of –79 dBm/MHz to provide protection of airborne GLONASS navigation receivers in case of a single-source wide-band interference. The acceptable e.i.r.p. from UWB devices should be of –94 dBm/MHz in case of single-source narrow-band interference.

Employment of the NTIA model to consider aggregate interfering effect of multiple UWB devices distributed over a certain area provides for obtaining realistic results only for an urban scenario of operating the UWB devices. Estimates based on that model for UWB devices operating in suburban areas are significantly less stringent as compared with those for a single-source UWB signal.

Consideration of aggregate effect from interfering devices on GLONASS navigation receivers would result in 5.7 dB increase in requirements for maximum e.i.r.p. from UWB devices. In that case an acceptable e.i.r.p. from UWB devices would be of –84.7 dBm/MHz to provide protection of airborne GLONASS navigation receivers under aggregate wide-band interference. The acceptable e.i.r.p. from UWB devices would be –99.7 dBm/kHz for aggregate narrow-band interference affecting an airborne navigation receiver.

Protection of commercial GLONASS navigation receivers requires that the acceptable e.i.r.p. from UWB devices shall not exceed –87.0 dBm/MHz for a single-source wide-band interference and –102.0 dBm/kHz for narrow-band interference.

Annex 5

Studies related to the impact of devices using ultra-wideband technology on systems operating within the broadcasting service and the broadcasting-satellite service

1 Impact of UWB systems on terrestrial broadcasting

1.1 Assessment of the impact of UWB systems on the T-DAB system

1.1.1 Summary

This Section presents the results of the study which has been carried out, by using the minimum coupling loss MCL methodology, to assess the impact of UWB systems on the T-DAB system operating in the VHF/UHF bands (174-230 MHz/1 452-1 492 MHz).

A large number of interference scenarios have been considered (indoor, outdoor and indoor to outdoor). For each of the considered scenarios, the protection distance, d_{min}, from the T-DAB receiver to the UWB transmitter, has been calculated by using alternatively, as UWB radiated power density level, the United States UWB emission limits and the UWB slope emission masks proposed for UWB applications in the band 3.1-10.6 GHz. The calculated distances have been compared with two threshold values 0.3 m and 1 m, which are respectively the protection distances required to ensure a high protection to the T-DAB system in indoor and outdoor environments, for mobile and portable reception.

The free-space propagation model has been used for indoor and outdoor interference scenarios, while the propagation model defined in Recommendation ITU-R P.1411 has been used for outdoor interference scenarios. The *C*/*I* values of T-DAB receiver have been assumed to be equal to its *C*/*N*. The activity factor of the interfering UWB devices has not been taken into consideration, because, for a given *C*/*I* value, d_{min} can only be calculated or measured when the interfering transmitter is operating. The aggregate interference effect has only been considered in the case of outdoor interference scenarios.

Finally, the obtained results have been analysed to estimate the interference potential from the UWB systems to the T-DAB system.

1.1.2 Introduction

UWB systems are based on pulse modulation techniques, which have recently gained importance in civil applications, thanks to current technology permitting to transmit and receive very narrow width pulses (*PW* = 10 ps to 10 ns). The modulations used by UWB systems are PAM, OOK, bi-phase or PPM, the later being the most popular. Generally, the resulting UWB signal has a relatively low psd that might means a low probability of interference with other radio services. Actually, the impact of a UWB system on a given radio service depends on the overall characteristics of the concerned UWB system: transmitter power (average and peak), modulation technique used, PW, PRF, density of UWB equipment, etc.

The following sections presents the results of the study carried out by TDF to assess the impact of UWB systems on the T-DAB system operating in the VHF/UHF bands (174-230 MHz/1 452-1 492 MHz). Firstly, the relevant characteristics of the concerned systems have been determined. Then the protection distance (minimum separation distance) from the T-DAB receiver to the UWB transmitter has been calculated by applying respectively the United States UWB emission limits in force and the UWB slope emission masks proposed for UWB applications in the band 3.1-10.6 GHz (see § 1.1.5). Finally, the obtained results have been analysed to estimate the interference potential from the UWB systems to the T-DAB system.

1.1.3 System characteristics and propagation models

This Section deals with the system characteristics and the propagation models used in this study. The relevant characteristics of the concerned systems are defined either in national or in international Recommendations and agreements. As for the propagation models used, they are defined in ITU-R P-Series Recommendations.

1.1.3.1 Recommendations, agreements and documents used to determine the characteristics of the concerned systems

The following Recommendations and agreement have been used to determine the characteristics of the DVB-T system:

– Recommendation ITU-R BT.1368.

– Recommendation ITU-R BT.419.

– WIESBADEN 1995 Special arrangement [1].

FCC 02-45 and the UWB slope emission masks given in § 1.1.5 have been used to determine the UWB radiated power density levels below 3.1 GHz.

The following Recommendations have been used to define the propagation conditions:

– Recommendation ITU-R P.525.

– Recommendation ITU-R P.1411.

1.1.3.2 T-DAB system

1.1.3.2.1 System characteristics

TABLE 184

T-DAB system characteristics

General characteristics	
Modulations	QPSK
Code rates	1/3, 2/5, 1/2, 3/5, 3/4
Access Technique	FDM/OFDM
Frequency bands	47-68 MHz (Band I)(1) 87.5-108 MHz (Band II) (1) 170-230 MHz (Band III) 1 452-1 492 MHz (Band L)
Channel width	1 536 MHz
Receiver characteristics	
Sensitivity (Gaussian channel) QPSK	 –91 dBm
Antenna characteristics	
Fixed antenna reception (outdoor reception) Height Coaxial cable loss Diagram Gain Polarization *Mobile and Portable antenna reception (indoor/outdoor reception)* Height Coaxial cable loss Diagram Gain Polarization	 10 m 2 dB (Band III), 3 dB (Band IV), 5 dB (Band V) Omnidirectional (no directivity discrimination) 0 dBi (Band VHF), 2.15 dBi (Band UHF) Vertical (no vertical/horizontal discrimination) 1.5 m 0 dB Omnidirectional (no directivity discrimination) 0 dBi (Band VHF), 2,15 dBi (Band UHF) Vertical (no vertical/horizontal discrimination)
C/N for most popular modulation schemas with related coding rates (Ricean channel)	
T-DAB (QPSK, 1/2)	15 dB

(1) Not considered in this study

Table 184 shows the relevant characteristics of the T-DAB system with related coding rates. These characteristics have been used to simulate the behaviour of the victim T-DAB receiver in the presence of UWB emissions.

Note that, the choice of other T-DAB modulation schemas will not influence the results of this study (see § 1.1.3.2.2).

1.1.3.2.2 T-DAB carrier-to-interference ratio (*C*/*I*) in the presence of an interfering UWB emission

Table 185 shows the comparison of the *C*/*I* values, which have been measured in the presence of an interfering UWB emission, and the practical *C*/*N* value of T-DAB. We can see that the *C*/*I* values are in the range of the practical *C*/*N* value of T-DAB. Consequently, in this study which deals with portable and mobile T-DAB reception, in the presence of an interfering UWB emission, the *C*/*I* values of T-DAB have been assumed to be equal to its *C*/*N* values in the case of a transmission through a Ricean or a Rayleigh channel (see Table 186). Given that $C/I = C/N$, we can write $I = N$. Expressed in power ratio ($10 \log_{10}(I/N)$), this equality becomes $I/N = 0$ dB, which is the protection criterion used in this study.

TABLE 185

Comparison of the measured *C*/*I* and the practical *C*/*N* values of T-DAB

T-DAB modulation schema with related code rate	$(C/I)_{T\text{-}DAB/UWB}$ (Gaussian channel)	$(C/N)_{T\text{-}DAB}$
QPSK	9.5, 10.7 and 12.4 dB according to PRF rates 1 MHz, 5 MHz and 10 MHz (see Table 187)	8.4 dB (Gaussian channel) and 15 dB (Rayleigh channel)

TABLE 186

Used $(C/I)_{T\text{-}DAB/UWB}$ values (for Ricean and Rayleigh channels)	
T-DAB (QPSK) UWB	15 dB

1.1.3.3 UWB equipment characteristics

Table 187 shows the basic characteristics of the UWB equipment used for *C*/*I* measurements. We should recall that in this study, the relevant characteristics of UWB equipment are its emission limits, which are given in § 1.1.5.

TABLE 187

UWB equipment characteristics

Modulations	PPM
Pulse width (PW)	≈ 500 ps
Pulse peak amplitude	8.5 V/50 Ω
Pulse train	Time dithered (randomized pulse train)
PRBS used for dithering	Unknown
Pulse repetition frequency (PRF)	1 MHz, 5 MHz and 10 MHz
f_{max_level}	≈ 1.38 GHz
Bandwidth (−15 dB below f_{max_level})	≈ 3.8 GHz
Antenna height	≥ 1.5 m (depending on how and where the equipment is used)

1.1.3.4 Protection distance

The protection distance (or minimum separation distance) is the distance necessary between the interfering transmitter and the victim receiver to protect the latter from the harmful emissions. This distance is usually calculated by using the MCL (minimum coupling loss) and an appropriate propagation model. The term d_{min} refers to the protection distance.

1.1.3.5 Minimum coupling loss

The MCL, which is in fact simply the transmission loss, A_{pro}, can easily be derived from the link budget between the interfering transmitter and the victim receiver:

$$MCL = e.i.r.p._i\,(\text{dBW}) + G_{iso\_v}\,(\text{dB}) - A_{cable\_v}\,(\text{dB}) - P_{sens\_v}\,(\text{dBW}) + (C/I)_v \qquad (158)$$

$$= ERP_i\,(\text{dBW}) + G_{dip\_v}\,(\text{dB}) + 4.3 - A_{cable\_v}\,(\text{dB}) - P_{sens\_v}\,(\text{dBW}) + (C/I)_v$$

where:

e.i.r.p.: effective isotropic radiated power

ERP: effective radiated power

G_{iso}: isotropic antenna gain

G_{dip}: dipole antenna gain

P_{sens}: receiver sensitivity

$()_i$: stands for the interfering transmitter

$()_v$: stands for to the victim receiver.

The *MCL* is then converted into d_{min} by using an appropriate propagation model.

1.1.3.6 Propagation models

Two propagation models have been used in this study. These models are:

– The free-space propagation model defined in Recommendation ITU-R P.525, which has been used for indoor and outdoor assessment.

– The propagation model defined in Recommendation ITU-R P.1411, which has been used for outdoor assessment.

1.1.3.6.1 Free-space propagation model

The free space propagation model is often used in LoS situations thanks to its simplicity and reliability. d_{min} can be calculated in two different ways by using this propagation model:

– by the field strength equation given for a standard reference antenna (isotrope antenna):

$$E_t \text{ (V/m)} = \frac{\sqrt{30 \ \text{e.i.r.p.}_t}}{d} \qquad \text{V/m}$$

$$d \text{ (m)} = \log^{-1}((e.i.r.p._t \text{ (dBW)} - E_t \text{ (dBµV/m)} + 134.77)/20)$$

where:

$e.i.r.p._t$: $\frac{G^t_{iso} P_t}{A^t_{cable}}$

E: field strength at distance, d (V/m)

G_{iso}: isotropic antenna gain (dB)

A_{cable}: antenna cable attenuation (dB)

d: distance (m)

$()_t$: stands for the transmitter

d_{min}: is calculated as follows:

$$d_{min} \text{ (m)} = \log^{-1}((\text{e.i.r.p.}_i \text{ (dBW)} - E_{max\_i} \text{ (dBµV/m)} + 134.77)/20) \quad (159)$$
$$= \log^{-1}((\text{ERP}_i \text{ (dBW)} - E_{max\_i} \text{ (dBµV/m)} + 136.92)/20)$$

where:

E_{max}: maximum permissible interference field strength

$()_i$ stands for the interfering transmitter

– by the free space basic transmission loss equation:

$$A_0 = 20 \log\left(\frac{4\pi d}{\lambda}\right)$$

$$d \text{ (m)} = \log^{-1} ((A_0 \text{ (dB)} - 20 \log f \text{ (Hz)} + 147.6)/20)$$

where:

d: distance (m)

λ: wavelength (m)

d_{min}: is calculated as follows:

$$d_{min} \text{ (m)} = \log^{-1}((MCL \text{ (dB)} - 20 \log f \text{ (Hz)} + 147.6)/20) \quad (160)$$

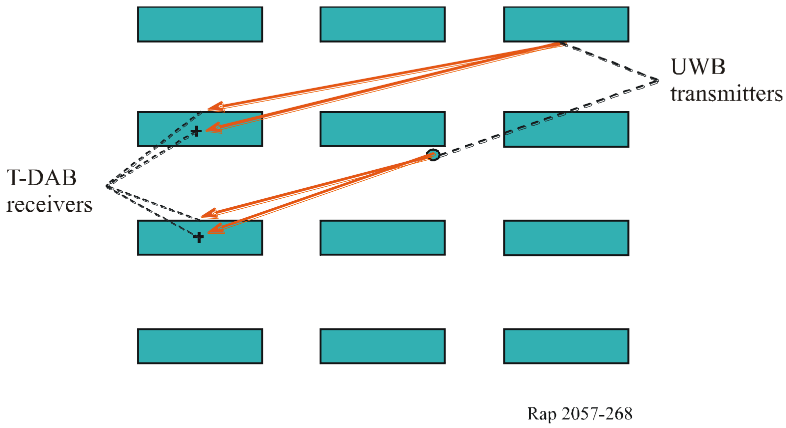
Note that in the present case where the MCL, defined by equation (1), is substituted for A_0, the equations (159) and (160) become identical.

1.1.3.6.2 Recommendation ITU-R P.1411-1 propagation model

Recommendation ITU-R P.1411 provides information and methods for the assessment of the propagation characteristics of short-range outdoor radio systems operating between 300 MHz and 100 GHz. It defines categories for short propagation paths, and proposes methods for estimating path loss and delay spread over these paths.

FIGURE 268

LoS situations within street canyons



In this study, regarding the foreseen applications of UWB systems in the field of communications and measurements, only the LoS situations within street canyons have been considered (see Fig. 268).

According to Recommendation ITU-R P.1411, in the UHF frequency range, the basic transmission loss can be characterized by two slopes and a single breakpoint.

An approximate lower bound (LB) is given by:

$$L_{LoS,l} = L_{bp} + \begin{cases} 20 \log_{10}\left(\dfrac{d}{R_{bp}}\right) & \text{for} \quad d \le R_{bp} \\ 40 \log_{10}\left(\dfrac{d}{R_{bp}}\right) & \text{for} \quad d > R_{bp} \end{cases} \tag{161}$$

where R_{bp} is the breakpoint distance and is given by:

$$R_{bp} \approx \frac{4 h_b h_m}{\lambda} \tag{162}$$

An approximate upper bound (UB) is given by:

$$L_{LoS,u} = L_{bp} + 20 + \begin{cases} 25 \log_{10}\left(\dfrac{d}{R_{bp}}\right) & \text{for} \quad d \le R_{bp} \\ 40 \log_{10}\left(\dfrac{d}{R_{bp}}\right) & \text{for} \quad d > R_{bp} \end{cases} \tag{163}$$

L_{bp} is a value for the basic transmission loss at the break point, defined as:

$$L_{bp} = \left| 20 \log_{10}\left(\frac{\lambda^2}{8 \pi h_b h_m}\right)\right| \tag{164}$$

d_{min} is simply calculated by substituting the MCL for L_{LoS} in equations (161) and (163). The conditions $d \leq R_{bp}$ and $d > R_{bp}$ can also be expressed in terms of the MCL:

– for LB, $d \leq R_{bp} = MCL \leq L_{bp}$ and $d > R_{bp} = MCL > L_{bp}$,

– for UB, $d \leq R_{bp} = MCL \leq H_{bp}$ and $d > R_{bp} = MCL > H_{bp}$, where $H_{bp} = L_{bp} + 20$.

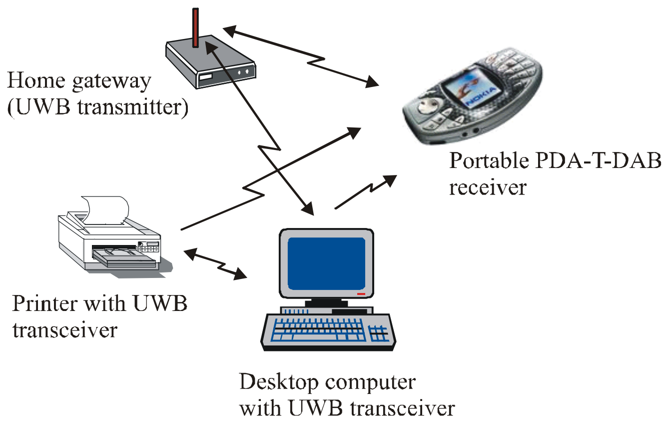
1.1.4 Considered scenarios

1.1.4.1 Both the victim T-DAB receiver end the interfering UWB transmitter are operating in indoor environment

In this scenario, the interfering UWB transmitter could be very close (few metres) to the victim T-DAB receiver. Therefore, the victim receiver and the interfering transmitter have been assumed to be in LoS. This assumption justifies the use of the free space propagation model. d_{min} required to ensure high level protection to T-DAB receiver in indoor environment, d_{min}^{in}, has reasonably been fixed to 0.3 m. This assumption takes into consideration the use of portable PDA-T-DAB receivers beside the domestic UWB transceivers (see Fig. 269)

FIGURE 269

T-DAB/UWB indoor interference scenario



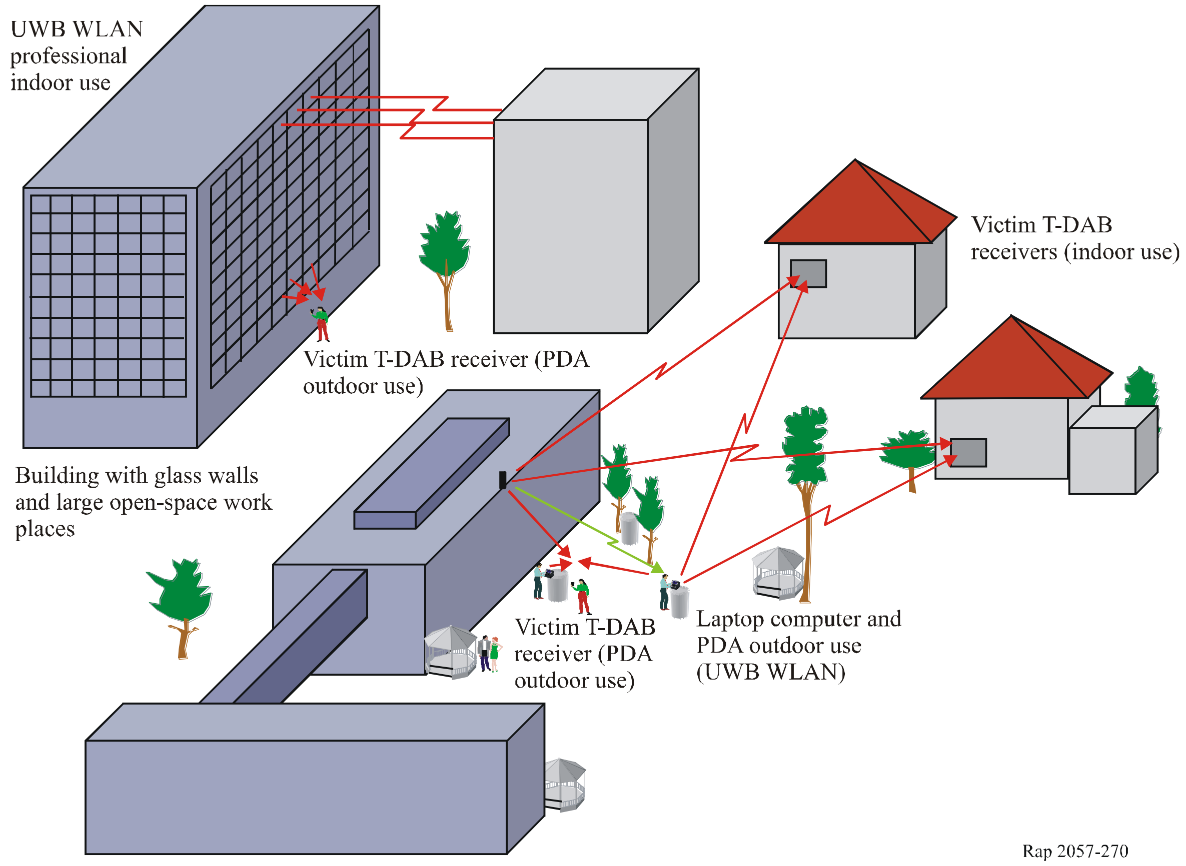
Because of the wide rage of indoor UWB applications foreseen, there is a strong likelihood that the T-DAB receiver is threatened by more than one UWB transmitter (see Fig. 269). Nevertheless, in domestic indoor environments, the dominant interferer would probably be the strongest one. Consequently, no aggregate effect has been assumed in the T-DAB/UWB indoor interference scenario. For the UWB system omnidirectional antenna with 0 dBi gain has been assumed (antenna height = 1.5 m).

1.1.4.2 The victim T-DAB receiver is situated at outdoor environment whereas the interfering UWB transmitter is operating in indoor/outdoor environment

In this scenario, the interfering UWB transmitter could be located in indoor or outdoor environments. It has been assumed that the victim receiver and the interfering transmitter are always in LoS (see Fig. 270). Depending on the nearby environment of interfering transmitter and victim receiver, the propagation conditions can be defined by the free space propagation or by Recommendation ITU-R P.1411 propagation model described in § 1.1.3.6.2. In this study both models have been used for the assessment.

FIGURE 270

Outdoor T-DAB/UWB interference scenarios



As in the indoor interference scenario, the victim T-DAB receiver could be threatened by more than one UWB transmitter. This time the multiple interference is due to the professional use of UWB WLAN/PLAN, for example in buildings having glass walls and large open-space work places (with negligible indoor to outdoor loss), which would potentially generate high aggregate interference to T-DAB receivers operating nearby. Consequently, unlike to the home indoor interfering scenario, both the single and multiple interference have been considered. d_{min} required to ensure a high protection to T-DAB receiver in outdoor environment, d_{min}^{out}, has reasonably been fixed to 1 m. This assumption takes into consideration the pedestrian use of portable PDA-T-DAB receivers (see Fig. 269). For the UWB system omnidirectional antenna with 0 dBi gain has been assumed (antenna height = 1.5 m).

In this study, distinction has been made between "indoor to outdoor" (T-DAB in outdoor and UWB in indoor) and "outdoor to outdoor" interference scenarios.

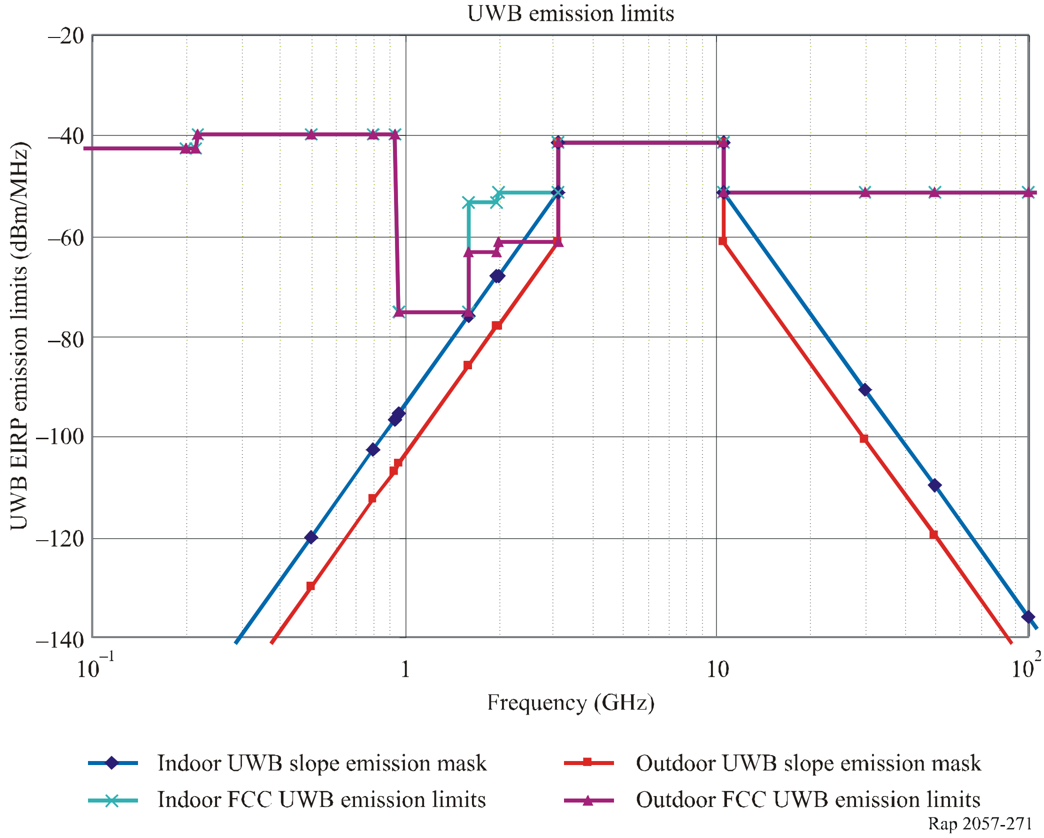
For the multiple interference case, assuming that all UWB equipment affecting a victim receiver are transmitting independent bursts and non-of them are dominant, a simple power aggregation low has been used: 10 log$N$, where N is the number of UWB interference.

1.1.5 UWB emission limits

The UWB radiated power densities used to calculate the MCL has been derived from the UWB emission limits given in Fig. 271.

FIGURE 271

The United States emission limits and the slope emission masks



These limits are known as:

– the United States emission limits for indoor and outdoor communication and measurement systems. These limits are in force in the United States since 22 April 2002. In the VHF/UHF bands, the indoor and outdoor United States limits are identical and defined in Section 15.209 of Part 15 of the Federal Communications Commission's rules;

– the slope emission masks for indoor and outdoor systems. These masks are proposed to ensure the protection of the services operating below 3.1 GHz and above 10.6 GHz. They meet the United States' requirement in the frequency range 3.1-10.6 GHz.

The numerical values of the United States emission limits and the slope emission masks are given in Annex 7.

1.1.6 T-DAB/UWB interference scenario results

This section presents the results of d_{min} calculations, between the victim T-DAB receiver and the interfering UWB transmitter. These results are based on the scenarios described in § 1.1.4. For the shake of clarity, they are presented in a graphical form.

1.1.6.1 T-DAB/UWB indoor and outdoor interference scenarios

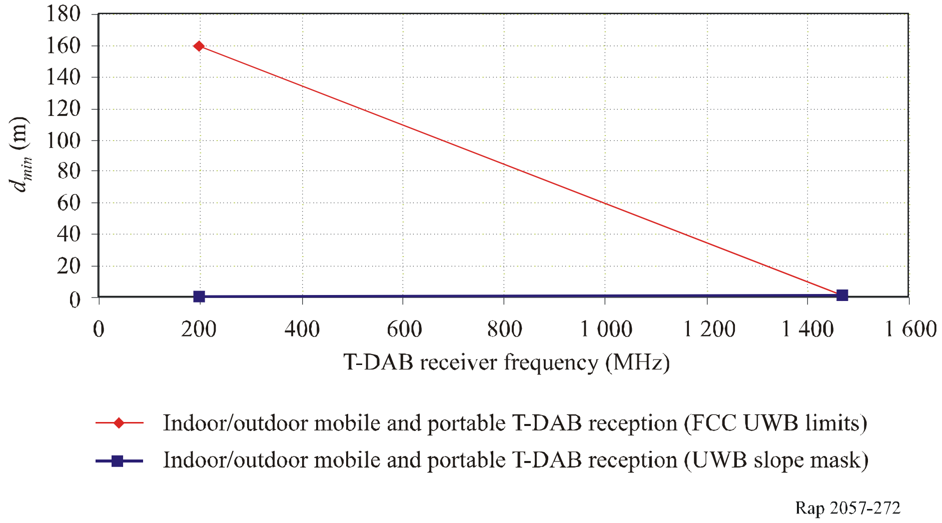
1.1.6.1.1 Mobile and portable T-DAB reception in indoor/outdoor environment – Free space propagation

In a T-DAB service area the minimum field strength to be protected at the receiver antenna is the same for both indoor and outdoor scenarios. Moreover, the antenna gain and the sensitivity of the receivers used for indoor reception are identical to the antenna gain and the sensitivity of the receivers used for outdoor reception. Consequently, in free space propagation single UWB interference case, indoor and outdoor impact scenarios are addressed as a single scenario.

A) *Single UWB interference case*

FIGURE 272

Indoor/outdoor T-DAB/UWB single interference scenario – Mobile and portable T-DAB reception



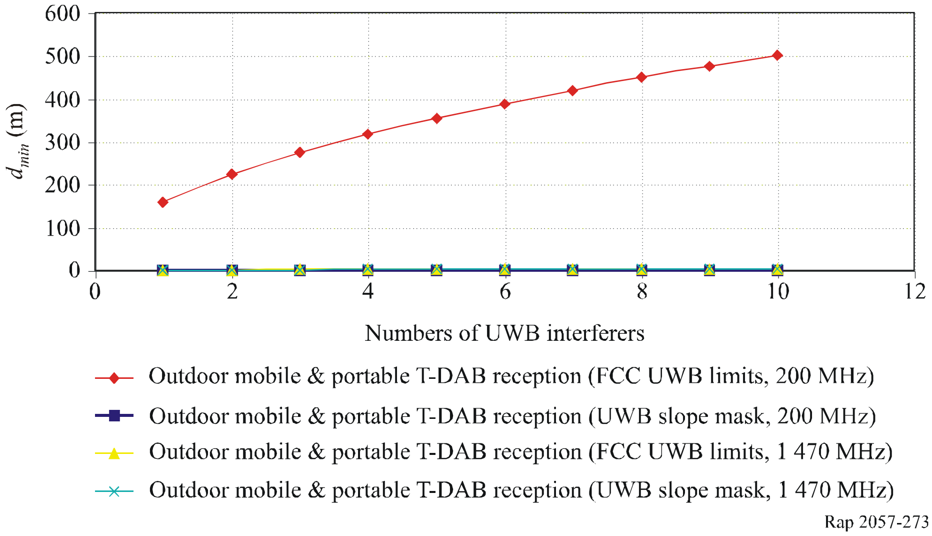
d_{min} has been calculated according to the scenario described in § 1.1.4.2. Firstly, the MCL has been calculated by using equation (158), then d_{min} has been calculated by using equation (160), which represents the free space propagation. The obtained results related to the United States emission limits and the slope emission masks are shown in Fig. 272. The results are presented in Table 186.

B) *Aggregate UWB interference case*

The aggregate UWB interference effect on d_{min} has been investigated by using a simple power aggregation low: 10 log$N$, where N is the number of interference. The obtained results are shown in Fig. 273. The results are presented in Table 188.

FIGURE 273

**Outdoor T-DAB/UWB aggregate interference scenario –
Mobile and portable T-DAB reception**



Summary of the results

TABLE 188

T-DAB/UWB impact assessment – mobile and portable T-DAB reception in indoor/outdoor environment – Free space propagation

Indoor/outdoor single interference scenario (see Annex 2)			
Calculation based on:	**Calculated d_{min} (m)**	d^{in}_{min} / d^{out}_{min} **(m)**	**Impact**
United States limits	159 (200 MHz)	0.3/1	Yes (d_{min} >> d^{out}_{min})
	0.9 (1 470 MHz)	0.3/1	Yes (d_{min} > d^{out}_{min})
Slope mask	0-0.17	0.3/1	No (d_{min} << d^{out}_{min})
Outdoor aggregate interference scenario (see Attachment 3)			
Calculation based on:	**Calculated d_{min} (m)**	d^{out}_{min} **(m)**	**Impact**
United States limits	159-520 (200 MHz)	1	Yes (d_{min} >> d^{out}_{min})
	0.9-2.83 (1 470 MHz)	1	Yes (d_{min} > d^{out}_{min})
Slope mask	0.17-0.55	1	No (d_{min} << d^{out}_{min})

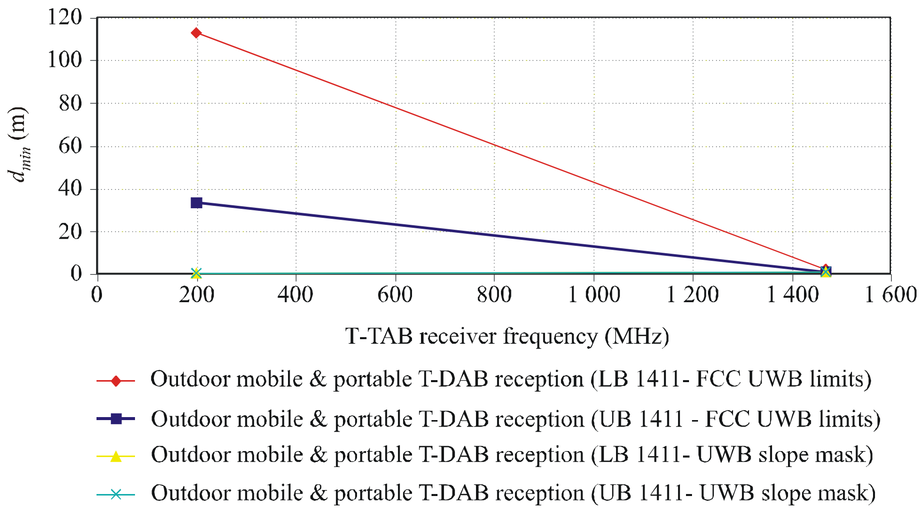
1.1.6.1.2 Mobile and portable T-DAB reception in outdoor environment – LoS situation within street canyons

A) *Single UWB interference case*

d_{min} has been calculated according to the scenario described in § 1.1.4.2. Firstly, the MCL has been calculated by using equation (158), then d_{min} has been calculated by using equations (161) and (163), which represent the Recommendation ITU-R P.1411 propagation model for LoS situation within street canyons. The obtained results related to the United States emission limits and the slope emission masks are shown in Fig. 274. The results are presented in Table 189.

FIGURE 274

Outdoor T-DAB/UWB single interference scenario –
Mobile and portable T-DAB reception



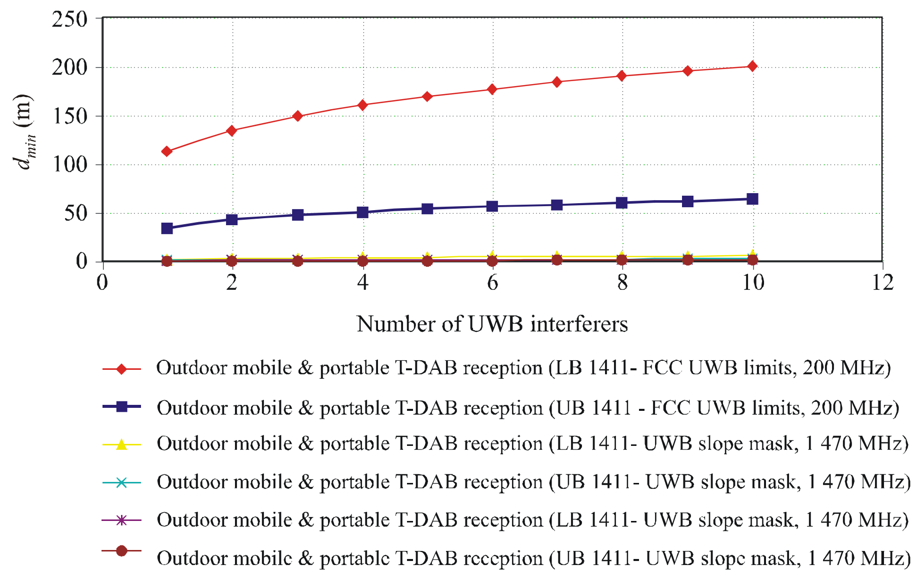
Rap 2057-274

B) *Aggregate UWB interference case*

The aggregate UWB interference effect on d_{min} has been investigated by using a simple power aggregation low: 10 log*N*, where *N* is the number of interference. The obtained results are shown in Fig. 275. These results are presented in Table 189.

FIGURE 275

Outdoor T-DAB/UWB aggregate interference scenario –
Mobile and portable T-DAB reception



Rap 2057-275

Summary of the results

TABLE 189

T-DAB/UWB impact assessment – Mobile and portable T-DAB reception in outdoor environment – LoS situation within street canyons

Single interference scenario (see Annex 4)			
Calculation based on:	**Calculated d_{min} (m)**	d_{min}^{out} **(m)**	**Impact**
United States limits 200 MHz	LB = 112.71 UB = 33.26	1	Yes (d_{min} >> d_{min}^{out})
1 470 MHz	LB = 1.79 UB = 0.79	1 1	Yes (d_{min} > d_{min}^{out}) No (d_{min} < d_{min}^{out})
Slope mask	LB = 0.24-0.35 UB = 0.11-0.21	1	No (d_{min} << d_{min}^{out})
Aggregate interference scenario (see Annex 5)			
Calculation based on:	**Calculated d_{min} (m)**	d_{min}^{out} **(m)**	**Impact**
United States limits 200 MHz	LB = 112.71-200.43 UB = 33.26-63.38	1	Yes (d_{min} >> d_{min}^{out})
1 470 MHz	LB = 1.79-5.66 UB = 0.79-1.98	1 1	Yes (d_{min} > d_{min}^{out}) No (d_{min} < d_{min}^{out}) up to 2 interferers
Slope mask	LB = 0.24-1.10 UB = 0.11-0.53	1 1	No (d_{min} << d_{min}^{out}) up to 8 interferers No (d_{min} << d_{min}^{out})

1.1.6.2 T-DAB in outdoor/UWB in indoor interference scenarios

1.1.6.2.1 Mobile and portable T-DAB reception in outdoor environment – Free space propagation

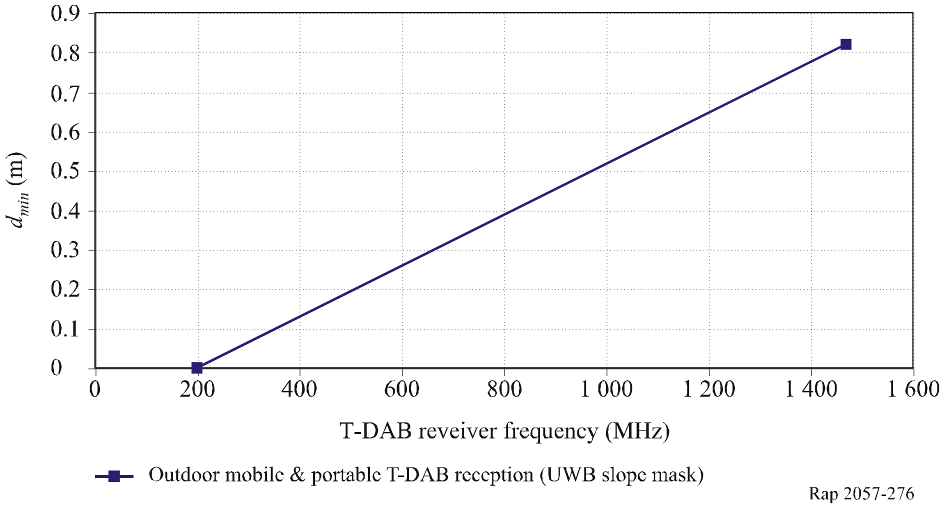
A) *Single UWB interference case*

This section presents the results of d_{min} calculations, between the victim T-DAB receiver in outdoor environment and the interfering UWB transmitter in Indoor environment. These results are based on the scenarios described in § 1.1.4, for the UWB slope mask only. In the VHF/UHF bands, the indoor and outdoor United States limits are identical (see § 1.1.5). Consequently, if the d_{min} calculations were made according to this scenario, by using the United States UWB limits, the results would be identical to those obtained in § 1.1.6.2.

d_{min} has been calculated according to the scenario described in § 1.1.4.2. Firstly, the MCL has been calculated by using equation (158) then d_{min} has been calculated by using equations (161) and (163), which represent the Recommendation ITU-R P.1411 propagation model for LoS situation within street canyons. The obtained results related to the United States emission limits and the slope emission masks are shown in Fig. 276. The results are presented in Table 190.

FIGURE 276

**T-DAB in outdoor/UWB in indoor single interference scenario –
Mobile and portable T-DAB reception**

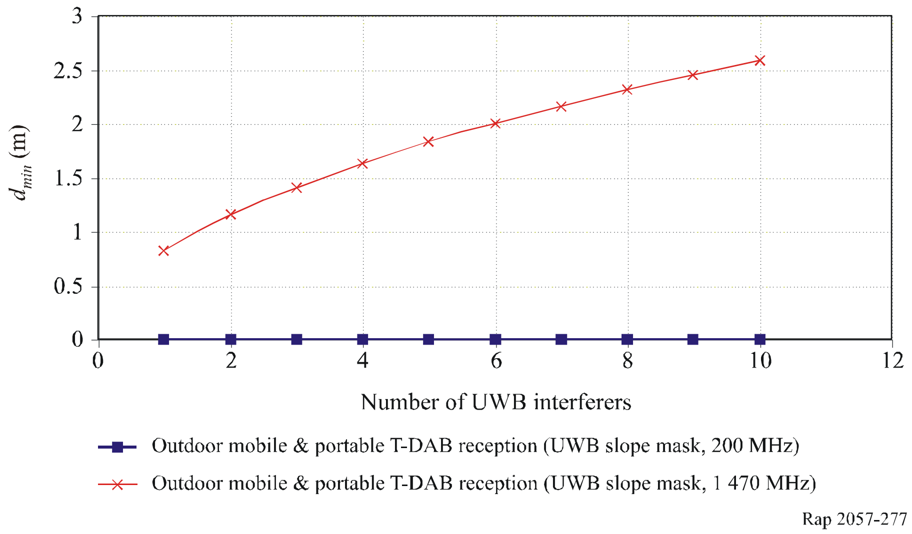


B) *Aggregate UWB interference case*

The aggregate UWB interference effect on d_{min} has been investigated by using a simple power aggregation low: 10 log*N*, where *N* is the number of interference. The obtained results are shown in Fig. 277. The results are presented in Table 190.

FIGURE 277

**T-DAB in outdoor/UWB in indoor aggregate interference scenario –
Mobile and portable T-DAB reception**



Summary of the results

TABLE 190

T-DAB/UWB impact assessment – Mobile and portable T-DAB reception in outdoor environment – Free space propagation

Single interference scenario (see Annex 6)			
Calculation based on:	**Calculated d_{min} (m)**	**d_{min}^{out} (m)**	**Impact**
Slope mask	0-0.55	1	No ($d_{min} << d_{min}^{out}$)
Aggregate interference scenario (see Annex 6)			
Calculation based on:	**Calculated d_{min} (m)**	**d_{min}^{out} (m)**	**Impact**
Slope mask	0-1.75	1	No ($d_{min} > d_{min}^{out}$) up to 3 interferers

1.1.7 Maximum UWB e.i.r.p density to provide adequate protection to the T-DAB system

Results of the calculations based on the MCL show that in case of the use of the US UWB emission limits, a d_{min} in the range of 0.79 m to 160 m is needed to prevent interference from UWB devices into the DVB-T system in the VHF/UHF bands, while the UWB slope emission masks used in this study reduce d_{min} significantly (<1.75 m).

In this section, the maximum UWB e.i.r.p density (UWB e.i.r.p.$_{max}$) to provide adequate protection to the T-DAB system has been calculated only for single interference case, which was considered the most critical case for T-DAB reception.

In indoor environment (free space propagation model), UWB e.i.r.p.$_{max}$ has been calculated by using equation (159):

$$\text{UWB e.i.r.p.}_{max}\,(\text{dBm/MHz}) = E_{max\_i}\,(\text{dB}\mu\text{V/m/1.536 MHz}) + 20\log_{10}(d_{min}) - 104.77 - 10\log_{10}(1.536)$$

where:

$d_{min} = d_{min}^{in} = 0.3$ m and $d_{min}^{out} = 1$ m in indoor and outdoor environments respectively, for fixed and portable reception (see § 1.1.4)

The results obtained are given in Table 191.

TABLE 191

Frequency band	UHF	VHF
Frequency (MHz)	1 470	200
Indoor environment		
E_{max-i} (dBµV/m/1.536 MHz)	32.29	20.12
d_{min} (m)	0.3	0.3
UWB e.i.r.p.$_{max}$ (dBm/MHz)	–85	–97
Outdoor environment		
E_{max-i} (dBµV/m/1.536 MHz)	32.29	20.12
d_{min} (m)	1	1
UWB e.i.r.p.$_{max}$ (dBm/MHz)	–75	–91

From these results, a maximum UWB e.i.r.p density has been defined to provide adequate protection to the T-DAB system both in indoor and outdoor environments, for fixed and portable reception:

UWB e.i.r.p.$_{max}$ = –85 dBm/MHz in the UHF band (1 452-1 492 MHz)

UWB e.i.r.p.$_{max}$ = –97 dBm/MHz in the VHF band (174-230 MHz)

1.1.8 Conclusion

A large number of interference scenarios have been simulated to assess the impact on the T-DAB from UWB systems, in the VHF/UHF bands. For each of the considered scenarios, the protection distance, d_{min}, from the T-DAB receiver to the UWB transmitter has been calculated by using alternatively, as UWB radiated power density level, the United States UWB emission limits and the UWB slope emission masks proposed for UWB applications in the band 3.1-10.6 GHz. The obtained protection distances have been compared with two threshold values d_{min}^{in} = 0.3 m and d_{min}^{out} = 1 m, which are respectively the protection distances required to ensure a high protection to the T-DAB system in indoor and outdoor environments, for mobile and portable receptions.

The analyses of the results clearly show that the United States UWB emission limits do not guarantee the protection of the T-DAB system in the VHF band (33 m ≤ d_{min} ≤ 160 m), while the UWB slope emission masks reduce significantly the interference probability (d_{min} ≈ 0). In the UHF band, the United States UWB emission limits do not guarantee the protection of the T-DAB system in the majority of the considered scenarios (0.79 m < d_{min} < 5.66 m), while the UWB slope emission masks still ensure a better protection to T-DAB system.

Finally, a maximum UWB e.i.r.p density (dBm/MHz) has been defined to provide adequate protection to the T-DAB system in indoor and outdoor environments, for fixed and portable reception:

UWB e.i.r.p.$_{max}$ = –85 dBm/MHz in the UHF band (1 452-1 492 MHz)

UWB e.i.r.p.$_{max}$ = –97 dBm/MHz in the VHF band (174-230 MHz)

1.2 ISDB-T$_{SB}$ system

1.2.1 Application system description

ISDB-T$_{SB}$ system is designed to provide high-quality sound and data broadcasting with high reliability even in mobile reception. ISDB-T$_{SB}$ is a rugged system which uses OFDM modulation, two-dimensional frequency-time interleaving and concatenated error correction codes. The OFDM modulation used in ISDB-T$_{SB}$ system is called band segmented transmission (BST)-OFDM. The bandwidth of an OFDM block called OFDM-segment is approximately 500 kHz. ISDB-T$_{SB}$ system consists of one or three OFDM-segment, therefore the bandwidth of the system is approximately 500 kHz or 1.5 MHz.

ISDB-T$_{SB}$ system has a wide variety of transmission parameters such as carrier modulation scheme, coding rates of the inner error correction code, and length of time interleaving.

1.2.2 Conclusions

An UWB e.i.r.p. limit has been calculated using the information in § 1.2.3 to guarantee the protection of the ISDB-T$_{SB}$ system in the presence of UWB emissions. This limit is:

– –114.7 dBm/MHz (e.i.r.p.) in the VHF band (at 200 MHz)

– –106.1 dBm/MHz (e.i.r.p.) in the UHF band (at 600 MHz)

1.2.3 Further information about the calculation for protection of the ISDB-T$_{SB}$

The purpose of this Annex is to provide more information to analyse the protection requirements of ISDB-T$_{SB}$ system from the interference by the UWB devices.

For this study, the following assumptions were made:

– Free-space loss propagation model was used.

– Protection criterion (*I*/*N*) of –20 dB.

– Deterministic methodology.

– Maximum average allowable power for UWB device.

– Interference power aggregating from multiple devices was assumed additive.

– The receiver noise temperature is 290 K.

– The receiver noise figure was 3 dB in VHF and UHF band.

– Protection distance was 0.5 m or 3 m.

Based on the above assumption and the result of the maximum permissible interference analysis, the required UWB e.i.r.p. emission limit to guarantee the protection of the ISDB-T system is driven as shown in Table 192.

TABLE 192

Protection requirements of ISDB-T$_{SB}$ system from interference by UWB devices

Parameter	ISDB-T$_{SB}$ requirement	
Band	VHF	UHF
Representative frequency	200 MHz	600 MHz
Temperature	290 K	290 K
Receiver noise figure	3 dB	3 dB
Receiver noise power in 1 MHz band	–111.0 dBm/MHz	–111.0 dBm/MHz

TABLE 192 (*end*)

Parameter	ISDB-T_{SB} requirement			
Urban noise	1.0 dB		–	
Receiver noise power + Urban noise	–110.0 dBm/MHz		–111.0 dBm/MHz	
Interference criterion (*I*/*N*)	–20.0 dB		–20.0 dB	
Maximum allowed interfering signal	–130.0 dBm/MHz		–131.0 dBm/MHz	
Reception type	Mobile/portable	Fixed	Mobile/portable	Fixed
Propagation distance	0.5 m	3 m	0.5 m	3 m
Propagation loss	12.4 dB	28.0 dB	22.0 dB	37.5 dB
Antenna gain	–0.85 dB	7.15 dB	–0.85 dB	12.15 dB
Feeder loss	2 dB	3 dB	2 dB	3 dB
UWB e.i.r.p. emission limit (1 devices)	–114.7 dBm/MHz	–106.1 dBm/MHz	–106.1 dBm/MHz	–102.6 dBm/MHz
UWB e.i.r.p. emission limit (2 devices)	–117.7 dBm/MHz	–109.1 dBm/MHz	–109.1 dBm/MHz	–105.6 dBm/MHz
UWB e.i.r.p. emission limit (4 devices)	–120.7 dBm/MHz	–112.1 dBm/MHz	–112.1 dBm/MHz	–108.6 dBm/MHz

1.3 Assessment of the impact of UWB systems on the DVB-T system

1.3.1 Summary

This section presents the results of the study which has been carried out, by using the MCL methodology, to assess the impact of UWB systems on the DVB-T system operating in the VHF/UHF bands (174-230 MHz/470-862 MHz).

A large number of interference scenarios have been considered (indoor, outdoor and indoor to outdoor). For each of the considered scenarios, the protection distance, d_{min}, from the DVB-T receiver to the UWB transmitter, has been calculated by using alternatively, as UWB radiated power density level, the United States UWB emission limits and the UWB slope emission masks proposed for UWB applications in the band 3.1-10.6 GHz. The calculated distances have been compared with two threshold values 0.5 m and 3 m, which are respectively the protection distances required to ensure a high protection to the DVB-T system in indoor and outdoor environments, for fixed and portable reception.

The free-space propagation model has been used for indoor and outdoor interference scenarios, while the propagation model defined in Recommendation ITU-R P.1411 has been used for outdoor interference scenarios. The *C*/*I* values of DVB-T receiver have been assumed to be equal to its *C*/*N*. A receiver antenna discrimination of 0/16 dB has been used depending on the considered scenarios. The activity factor of the interfering UWB devices has not been taken into consideration, because, for a given *C*/*I* value, d_{min} can only be calculated or measured when the interfering transmitter is operating. The aggregate interference effect has only been considered in the case of outdoor interference scenarios.

Finally, the obtained results have been analysed to estimate the interference potential from the UWB systems to the DVB-T system.

1.3.2 Introduction

UWB systems are based on pulse modulation techniques, which have recently gained importance in civil applications, thanks to current technology permitting to transmit and receive very narrow width pulses (*PW* = 10 ps to 10 ns). The modulations used by UWB systems are PAM, OOK, bi-phase or PPM, the later being the most popular. Generally, the resulting UWB signal has a relatively low psd that might mean a low probability of interference with other radio services.

Actually, the impact of an UWB system on a given radio service depends on the overall characteristics of the concerned UWB system: transmitter power (average and peak), modulation technique used, PW, PRF, density of UWB equipment, etc.

This Section presents the results of the study carried out to assess the impact of UWB systems on the DVB-T system operating in the VHF/UHF bands (174-230 MHz/470-862 MHz). Firstly, the relevant characteristics of the concerned systems have been determined. Then the protection distance (minimum separation distance) from the DVB-T receiver to the UWB transmitter has been calculated by applying respectively the United States UWB emission limits in force and the UWB slope emission masks. Finally, the obtained results have been analysed to estimate the interference potential from the UWB systems to the DVB-T system.

1.3.3 System characteristics and propagation models

This Section deals with the system characteristics and the propagation models used in this study. The relevant characteristics of the concerned systems are defined either in national or in international Recommendations and Agreements. As for the propagation models used, they are defined in ITU-R P. Recommendations.

1.3.3.1 Recommendations, agreements and documents used to determine the characteristics of the concerned systems

The following Recommendations and agreement have been used to determine the characteristics of the DVB-T system:

– Recommendation ITU-R BT.1368-3.

– Recommendation ITU-R BT.419-3.

– The Chester 1997 Multilateral Coordination Agreement.

FCC 02-45 and the UWB slope emission masks given in § 1.3.5 have been used to determine the UWB radiated power density levels below 3.1 GHz.

The following Recommendations have been used to define the propagation conditions:

– Recommendation ITU-R P.525.

– Recommendation ITU-R P.1411.

1.3.3.2 DVB system characteristics

Table 193 shows the relevant characteristics of the DVB-T system and the most popular modulation schemas with related coding rates. These characteristics have been used to simulate the behaviour of the victim DVB-T receiver in the presence of UWB emissions.

TABLE 193

DVB-T system characteristics

General characteristics	
Modulations	QPSK, 16-QAM or 64-QAM
Code rates	1/2, 2/3, 3/4, 5/6, 7/8
Access technique	FDM/OFDM (FFT mode: 2k or 8k)
Frequency bands	170-230 MHz (Band III) 470-582 MHz (Band IV) 582-862 MHz (Band V)
Channel width	7 or 8 MHz
Receiver characteristics	
Sensitivity (Gaussian channel) QPSK 16-QAM 64-QAM	 –90 dBm –85 dBm –80 dBm
Antenna characteristics	
Fixed antenna reception (outdoor reception) Height Coaxial cable loss Diagram Directivity discrimination Gain Polarization Vertical/horizontal polarization discrimination Portable antenna reception (indoor/outdoor reception) Height Coaxial cable loss Diagram Gain Polarization	 10 m 2 dB (Band III), 3 dB (Band IV), 5 dB (Band V) Directive (opening angle at –3 dB = 30) 0-12 dB (Band VHF), 0-16 dB (Band UHF) 9.15 dB (Band III), 12.15 dBi (Band IV), 14.15 dBi (Band V) Horizontal/vertical 3 dB 1.5 m 0 dB Omnidirectional (no directivity discrimination) 0 dBi (Band VHF), 2.15 dBi (Band UHF) Vertical (no vertical/horizontal discrimination)
C/N for most popular modulation schemas with related coding rates (Ricean channel)	
DVB-T (QPSK, 2k/8k, 1/2) DVB-T (16-QAM, 2k/8k, 2/3) DVB-T (16-QAM, 2k/8k, 3/4) DVB-T (64-QAM, 2k/8k, 2/3)	6.6 dB 14.6 dB 16 dB 20.1 dB

Note that, the choice of other DVB-T modulation schemas will not influence the results of this study (see § 1.3.3.3).

1.3.3.3 DVB-T carrier-to-interference ratio (*C*/*I*) in the presence of an interfering UWB emission

Table 194 shows the comparison of the *C*/*I* values, which have been measured in the presence of an interfering UWB emission, and the practical *C*/*N* values of DVB-T. We can easily see that these values are very close. As a result, the emissions of the tested UWB equipment, falling into a DVB-T channel, can be compared to an AWGN. Consequently, in this study, in the presence of an interfering UWB emission, the *C*/*I* values of DVB-T have been assumed to be equal to its *C*/*N* values, for fixed and portable reception through a Ricean channel (see Table 195). Given that $C/I = C/N$, we can write $I = N$. Expressed in power ratio ($10 \log_{10}(I/N)$), this equality becomes $I/N = 0$ dB, which is the protection criterion used in this study.

TABLE 194

Comparison of the measured *C*/*I* and the practical *C*/*N* values of DVB-T

DVB-T modulation schema with related code rate	$(C/I)_{DVB-T/UWB}$ (Gaussian channel)	$(C/N)_{DVB-T}$ (Gaussian channel)
QPSK, 2k/8k, 1/2	6.5 dB	6.1 dB
16-QAM, 2k/8k, 1/2	11.6 dB	11.8 dB
64-QAM, 2k/8k, 2/3	19.4 dB	19.5 dB

TABLE 195

Used $(C/I)_{DVB-T/UWB}$ values (Ricean channel)	
DVB-T (QPSK, 2k/8k, 1/2)UWB	6.6 dB
DVB-T (16-QAM, 2k/8k, 2/3)/UWB	14.6 dB
DVB-T (16-QAM, 2k/8k, 3/4)/UWB	16 dB
DVB-T (64-QAM, 2k/8k, 2/3)/UWB	20.1 dB

1.3.3.4 UWB equipment characteristics

Table 196 shows the basic characteristics of the UWB equipment used for *C*/*I* measurements. We should recall that in this study, the relevant characteristics of UWB equipment are its emission limits, which are given in § 1.3.5.

TABLE 196

UWB equipment characteristics

Modulations	PPM
Pulse width (PW)	≈ 500 ps
Pulse peak amplitude	8.5 V/50 Ω
Pulse train	Time dithered (randomized pulse train)
PRBS used for dithering	Unknown
Pulse repetition frequency (PRF)	1 MHz, 5 MHz and 10 MHz
f_{max_level}	≈ 1.38 GHz
Bandwidth (–15 dB below f_{max_level})	≈ 3.8 GHz
Antenna height	≥ 1.5 m (depending on how and where the equipment is used)
Activity factor	No use in MCL calculation

1.3.3.5 Protection distance

The protection distance (or minimum separation distance) is the distance necessary between the interfering transmitter and the victim receiver to protect the latter from the harmful emissions. This distance is usually calculated by using the MCL (minimum coupling loss) and an appropriate propagation model. In this section d_{min} is referred to the protection distance.

1.3.3.6 Minimum coupling loss

The *MCL*, which is in fact simply the transmission loss, A_{pro}, can easily be derived from the link budget between the interfering transmitter and the victim receiver:

$$MCL = e.i.r.p._i \text{ (dBW)} + G_{iso\_v} \text{ (dB)} - A_{cable\_v} \text{ (dB)} - P_{sens\_v} \text{ (dBW)} + (C/I)_v \qquad (165)$$

$$= ERP_i \text{ (dBW)} + G_{dip\_v} \text{ (dB)} + 4.3 - A_{cable\_v} \text{ (dB)} - P_{sens\_v} \text{ (dBW)} + (C/I)_v$$

where:

e.i.r.p.: effective isotropic radiated power

ERP: effective radiated power

G_{iso}: isotropic antenna gain

G_{dip}: dipole antenna gain

P_{sens}: receiver sensitivity

$()_I$: stands for the interfering transmitter

$()_v$: stands for to the victim receiver.

The *MCL* is then converted into d_{min} by using an appropriate propagation model.

1.3.3.7 Propagation models

Two propagation models have been used in this study. These models are:

– The free-space propagation model defined in Recommendation ITU-R P.525, which has been used for indoor and outdoor assessment.

– The propagation model defined in Recommendation ITU-R P.1411, which has been used for outdoor assessment.

1.3.3.7.1 Free-space propagation model

The free-space propagation model is often used in LoS situations thanks to its simplicity and reliability. d_{min} can be calculated in two different ways by using this propagation model:

– by the field strength equation given for a standard reference antenna (isotrope antenna):

$$E_t \text{ (V/m)} = \frac{\sqrt{30\, e.i.r.p._t}}{d} \qquad \text{V/m}$$

$$d \text{ (m)} = \log^{-1}((e.i.r.p._t \text{ (dBW)} - E_t \text{ (dBμV/m)} + 134.77)/20)$$

where :

$$e.i.r.p._t = \frac{G_{iso}^t P_t}{A_{cable}^t}$$

E: field strength at distance d (V/m)

G_{iso}: isotropic antenna gain (dB)

A_{cable}: antenna cable attenuation (dB)

d: distance (m)

$()_t$: stands for the transmitter.

d_{min} is calculated as follows:

$$d_{min} \text{ (m)} = \log^{-1}((e.i.r.p._i \text{ (dBW)} - E_{max\_i} \text{ (dBμV/m)} + 134.77)/20) \tag{166}$$
$$= \log^{-1}((ERP_i \text{ (dBW)} - E_{max\_i} \text{ (dBμV/m)} + 136.92)/20)$$

where:

E_{max}: maximum permissible interference field strength

$()_I$: stands for the interfering transmitter.

– by the free-space basic transmission loss equation:

$$A_0 = 20 \log\left(\frac{4\pi d}{\lambda}\right)$$

$$d \text{ (m)} = \log^{-1}((A_0 \text{ (dB)} - 20 \log f \text{ (Hz)} + 147.6)/20)$$

where:

d: distance (m)

λ: wavelength (m).

d_{min} is calculated as follows:

$$d_{min} \text{ (m)} = \log^{-1}((\text{MCL (dB)} - 20 \log f \text{ (Hz)} + 147.6)/20) \tag{167}$$

Note that in the present case where the *MCL,* defined by equation (165), is substituted for A_0, the equations (166) and (167) become identical.

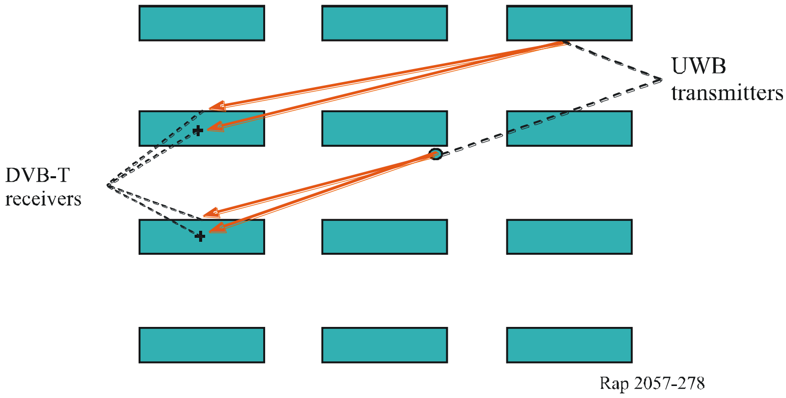
1.3.3.7.2 Recommendation ITU-R P.1411 propagation model

Recommendation ITU-R P.1411 provides information and methods for the assessment of the propagation characteristics of short-range outdoor radio systems operating between 300 MHz and 100 GHz. It defines categories for short propagation paths, and proposes methods for estimating path loss and delay spread over these paths.

In this study, regarding the foreseen applications of UWB systems in the field of communications and measurements, only the LoS situations within street canyons have been considered (see Fig. 278).

FIGURE 278

LoS situations within street canyons



According to Recommendation ITU-R P.1411, in the UHF frequency range, the basic transmission loss can be characterized by two slopes and a single breakpoint.

An approximate lower bound (LB) is given by:

$$L_{LoS,l} = L_{bp} + \begin{cases} 20 \log_{10}\left(\dfrac{d}{R_{bp}}\right) & \text{for } d \leq R_{bp} \\ 40 \log_{10}\left(\dfrac{d}{R_{bp}}\right) & \text{for } d > R_{bp} \end{cases} \tag{168}$$

where R_{bp} is the breakpoint distance and is given by:

$$R_{bp} \approx \frac{4 h_b h_m}{\lambda} \tag{169}$$

An approximate upper bound (UB) is given by:

$$L_{LoS,u} = L_{bp} + 20 + \begin{cases} 25 \log_{10}\left(\dfrac{d}{R_{bp}}\right) & \text{for } d \leq R_{bp} \\ 40 \log_{10}\left(\dfrac{d}{R_{bp}}\right) & \text{for } d > R_{bp} \end{cases} \tag{170}$$

L_{bp} is a value for the basic transmission loss at the break point, defined as:

$$L_{bp} = \left| 20 \log_{10}\left(\frac{\lambda^2}{8 \pi h_b h_m}\right) \right| \tag{171}$$

d_{min} is simply calculated by substituting the MCL for L_{LoS} in equations (168) and (170). The conditions $d \leq R_{bp}$ and $d > R_{bp}$ can also be expressed in terms of the MCL:

– for LB, $d \leq R_{bp} = MCL \leq L_{bp}$ and $d > R_{bp} = MCL > L_{bp}$,

– for UB, $d \leq R_{bp} = MCL \leq H_{bp}$ and $d > R_{bp} = MCL > H_{bp}$, where $H_{bp} = L_{bp} + 20$.

1.3.4 Considered scenarios

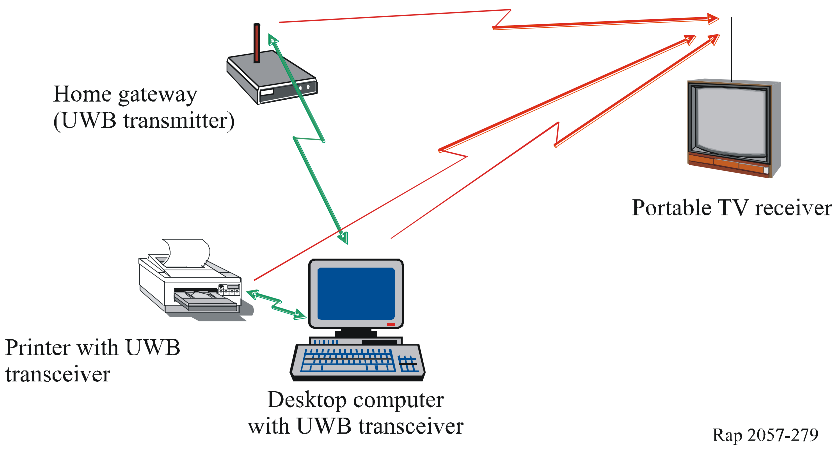
1.3.4.1 Both the victim DVB-T receiver end the interfering UWB transmitter are operating in indoor environment

In this scenario, the interfering UWB transmitter could be very close (less than a few metres) to the victim DVB-T receiver. Therefore, the victim receiver and the interfering transmitter have been assumed to be in LoS. This assumption justifies the use of the free-space propagation model in the calculation. Currently, short-range wireless communication links are increasingly used to transfer data (i.e. audio and/or video) from one electronic device to another. Within this new context, d_{min}^{in} required to provide adequate protection to DVB-T receiver in indoor environment, in the presence of UWB communications applications, has reasonably been fixed to 0.5 m.

Because of the wide range of indoor UWB applications foreseen, there is a strong likelihood that the DVB-T receiver is threatened by more than one UWB transmitter (see Fig. 278). Nevertheless, in domestic indoor environments, the dominant interferer would probably be the strongest one. Consequently, no aggregate effect has been assumed in the DVB-T/UWB indoor interference scenario. For the UWB system omnidirectional antenna with 0 dBi gain has been assumed (antenna height = 1.5 m).

FIGURE 279

DVB-T/UWB indoor interference scenario

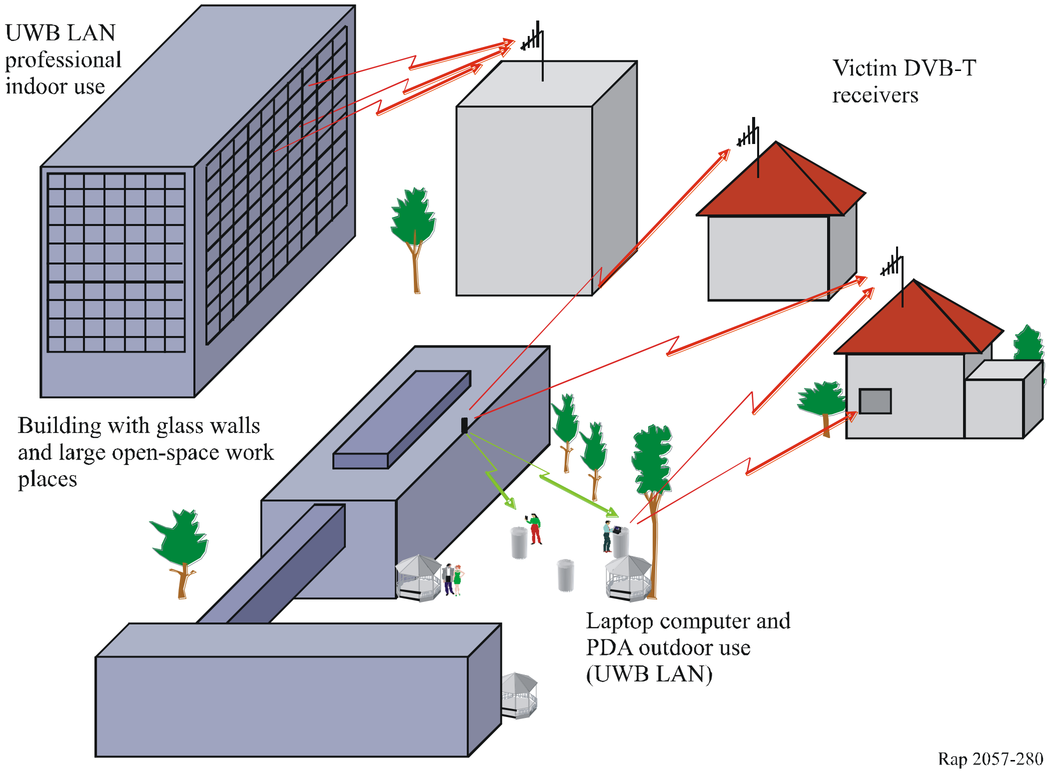


1.3.4.2 The victim DVB-T receiver antenna is situated at outdoor environment whereas the interfering UWB transmitter is operating in indoor/outdoor environment

In this scenario, the victim DVB-T receiver is fed by an external antenna. The interfering UWB transmitter could be located in indoor or outdoor environments. It has been assumed that the victim receiver and the interfering transmitter are always in LoS (see Fig. 280). Depending on the nearby environment of interfering transmitter and victim receiver, the propagation conditions can be defined by the free-space propagation or by Recommendation ITU-R P.1411 propagation model described in § 1.3.3.7.2. In this study both models have been used for the impact assessment.

FIGURE 280

Outdoor DVB-T/UWB interference scenarios



As in the indoor interference scenario, the victim DVB-T receiver could be threatened by more than one UWB transmitter. This time the multiple interference is due to the professional use of UWB LAN, for example in buildings having glass walls and large open-space work places (with negligible indoor to outdoor loss), which would potentially generate high aggregate interference to DVB-T receivers operating nearby. Consequently, unlike to the home indoor interfering scenario, both the single and multiple interference have been considered. d_{min} required to provide adequate protection to DVB-T receiver in outdoor environment (d_{min}^{out}) has reasonably been fixed to 3 m. This value corresponds to the half of a frequently encountered street width (6 m), in big and medium cities in France. Here, the main goal is to prevent interference from UWB devices into the DVB-T receivers in dense urban areas in indoor or outdoor environment. For the UWB system omnidirectional antenna with 0 dBi gain has been assumed (antenna height = 1.5 m).

In this study, no distinction has been made between "indoor to outdoor" and "outdoor to outdoor" interference scenarios, the indoor to outdoor loss has not been taken into consideration, for the following reasons:

– the indoor to outdoor loss has implicitly been taken into consideration in the definition of the outdoor UWB slope emission mask, which is 10 dB lower than the indoor UWB slope emission mask;

– for outdoor fixed DVB-T reception, the antenna directivity discrimination has been taken into consideration (16/12 dB) in d_{min} calculations, which can be compared to the indoor to outdoor loss (10 dB).

For the multiple interference case, assuming that all UWB equipment affecting a victim receiver are transmitting independent bursts and none of them are dominant, a simple power aggregation low has been used: 20 log$N$, where N is the number of UWB interference.

1.3.5 UWB emission limits

The UWB radiated power densities used to calculate the MCL has been derived from the UWB emission limits given in Fig. 281.

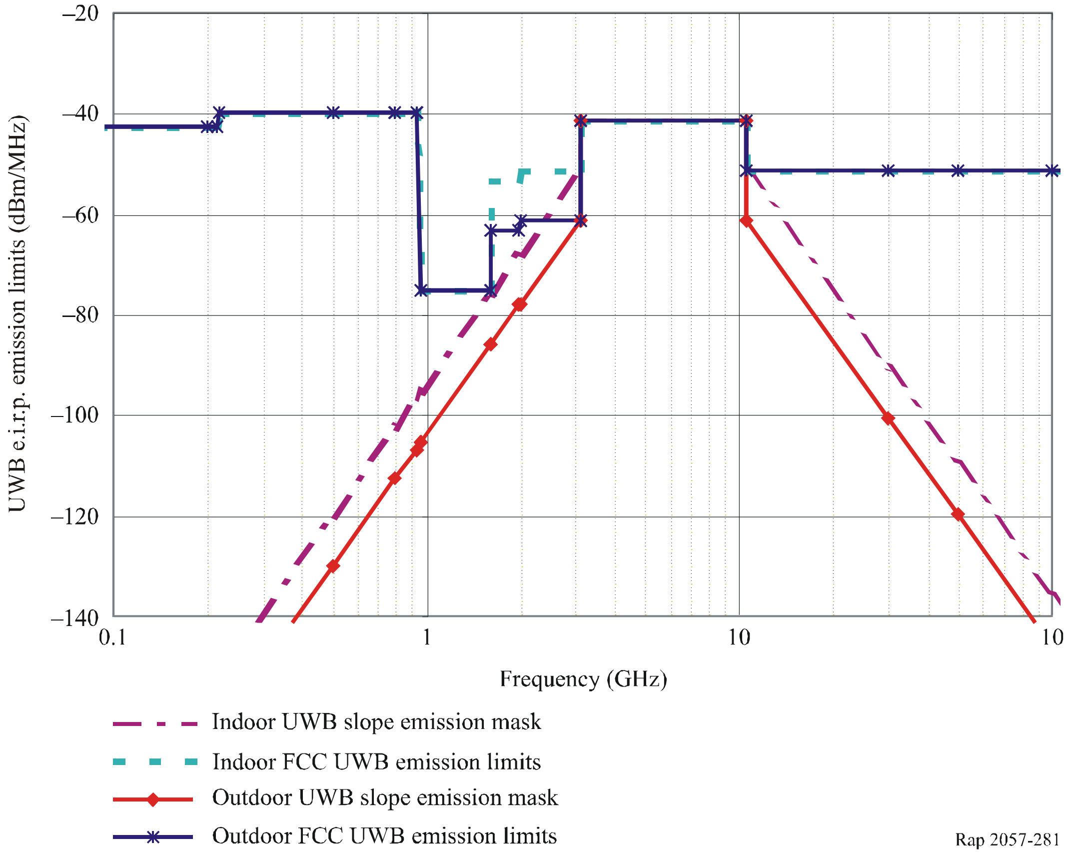
These limits are known as:

– the United States emission limits for indoor and outdoor communication and measurement systems. These limits are in force in the United States since 22 April 2002. In the VHF/UHF bands, the indoor and outdoor United States limits are identical and defined in Section 15.209 of Part 15 of the Commission's Rules;

– the slope emission masks for indoor and outdoor systems. These masks are proposed to ensure the protection of the services operating below 3.1 GHz and above 10.6 GHz. They meet the United States' requirement in the frequency range 3.1-10.6 GHz.

FIGURE 281

The United States emission limits and the slope emission masks



1.3.6 DVB-T/UWB interference scenario results

This Section presents the results of d_{min} calculations, between the victim DVB-T receiver and the interfering UWB transmitter. These results are based on the scenarios described in § 1.3.4. For the shake of clarity, they are presented in a graphical form. The detailed results of the calculations are given in § 1.3.9.

1.3.6.1 DVB-T/UWB indoor interference scenario

1.3.6.1.1 Portable DVB-T reception in indoor environment – Free-space propagation

d_{min} has been calculated according to the scenario described in § 1.3.5.1. Firstly, the MCL has been calculated by using equation (165), then d_{min} has been calculated by using equation (167), which represents the free-space propagation. The obtained results related to the United States emission limits and the slope emission masks are shown in Fig. 282. These results are presented in Table 197.

FIGURE 282

Indoor DVB-T/UWB single interference scenario – Portable DVB-T reception

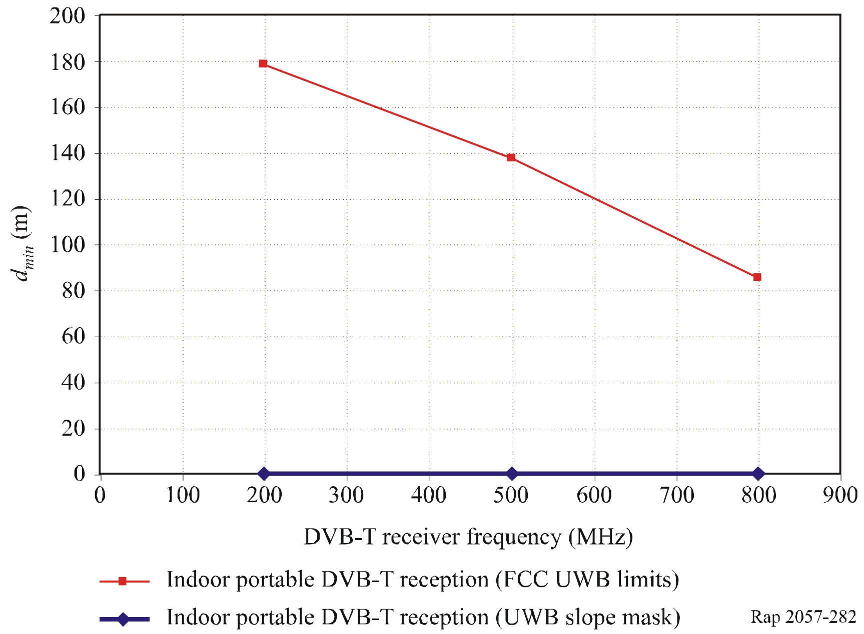


TABLE 197

DVB-T/UWB impact assessment
Portable DVB-T reception in indoor environment – Free-space propagation

Calculation based on:	Calculated d_{min} (m)	d^{in}_{min} (m)	Impact
United States limits	85-178	0.5	Yes ($d_{min} >> d^{in}_{min}$)
Slope mask	0-0.06	0.5	No ($d_{min} << d^{in}_{min}$)

1.3.6.2 DVB-T/UWB outdoor interference scenarios

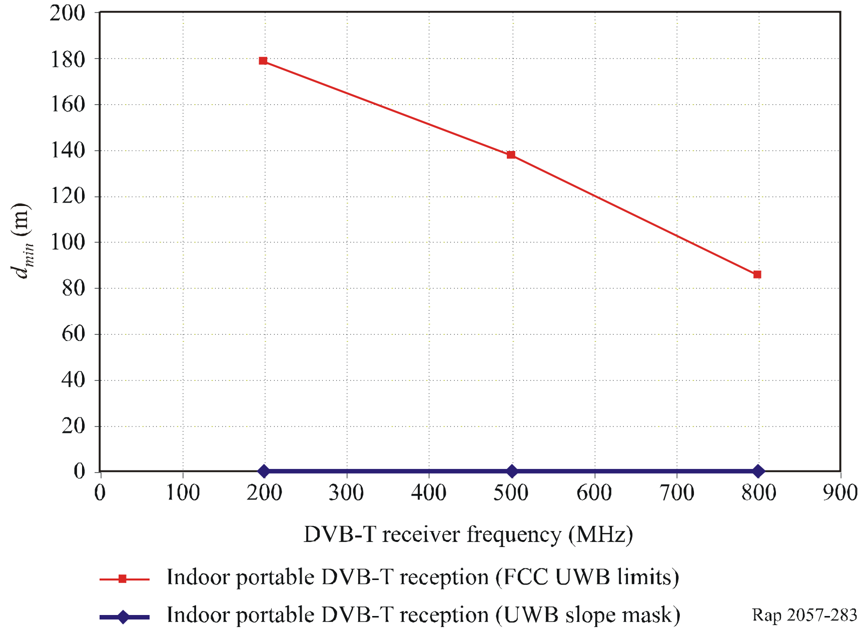
1.3.6.2.1 Portable DVB-T reception in outdoor environment – Free-space propagation

A) *Single UWB interference case*

d_{min} has been calculated according to the scenario described in § 1.3.5.2. Firstly, the MCL has been calculated by using equation (165), then d_{min} has been calculated by using equation (167), which represents the free-space propagation. The obtained results related to the United States emission limits and the slope emission masks are shown in Fig. 283. These results are presented in Table 198.

FIGURE 283

Outdoor DVB-T/UWB single interference scenario – Portable DVB-T reception



B) *Aggregate UWB interference case*

The aggregate UWB interference effect on d_{min} has been investigated by using a simple power aggregation low: 10 log*N*, where *N* is the number of interference. The obtained results are shown in Fig. 284 These results are presented in Table 198.

FIGURE 284

Outdoor DVB-T/UWB aggregate interference scenario – Portable DVB-T reception

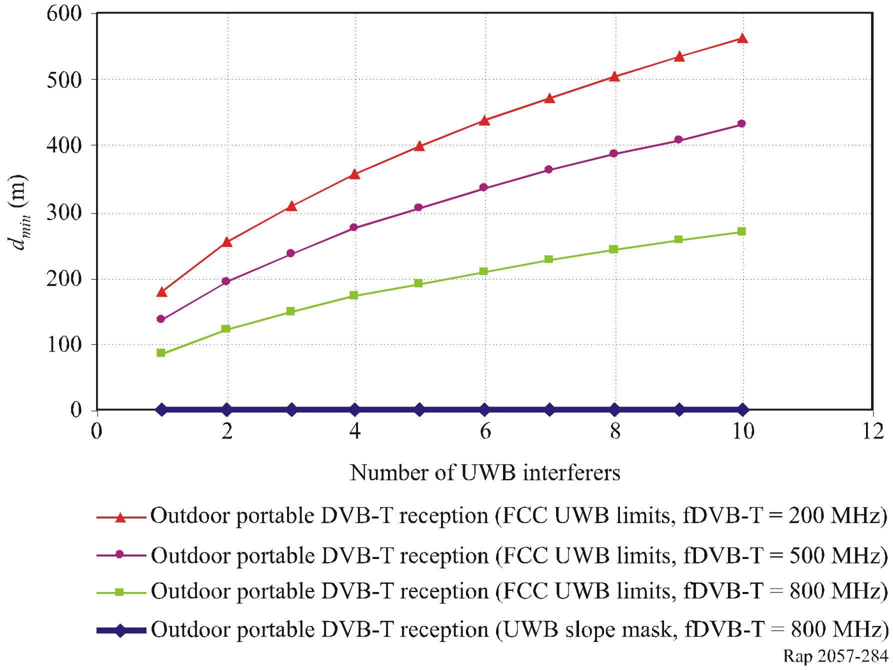


TABLE 198

DVB-T/UWB impact assessment
Portable DVB-T reception in outdoor environment – Free-space propagation

Single interference scenario			
Calculation based on:	**Calculated d_{min} (m)**	**d_{min}^{out} (m)**	**Impact**
United States limits	85-178	3	Yes ($d_{min} >> d_{min}^{out}$)
Slope mask	0	3	No ($d_{min} << d_{min}^{out}$)
Aggregate interference scenario			
Calculation based on:	**Calculated d_{min} (m)**	**d_{min}^{out} (m)**	**Impact**
United States limits	85-561	3	Yes ($d_{min} >> d_{min}^{out}$)
Slope mask	0-0.064	3	No ($d_{min} << d_{min}^{out}$)

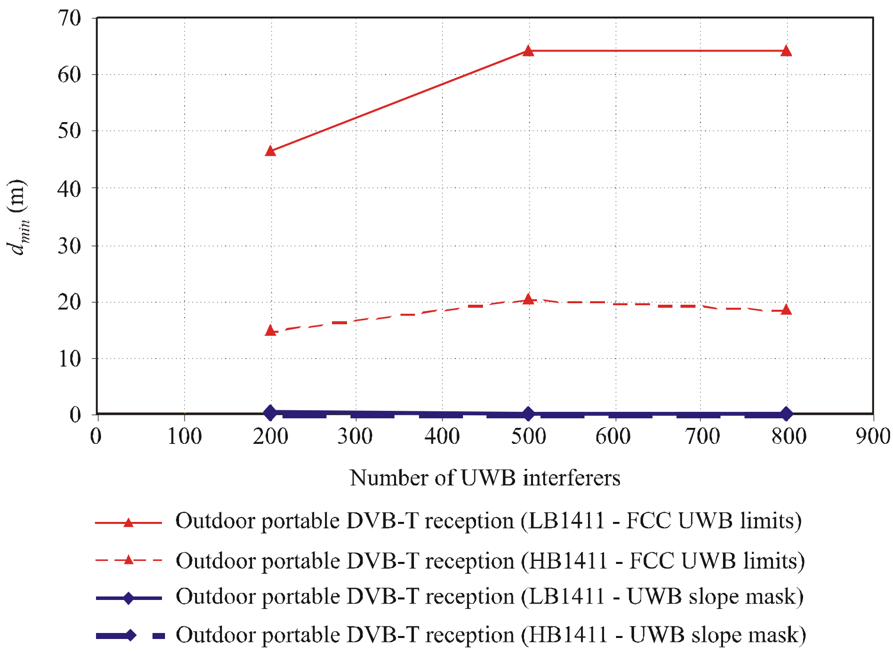
1.3.6.2.2 Portable DVB-T reception in outdoor environment – LoS situation within street canyons

A) *Single UWB interference case*

d_{min} has been calculated according to the scenario described in § 1.3.5.2. Firstly, the MCL has been calculated by using equation (165), then d_{min} has been calculated by using equations (168) and (170), which represent the Recommendation ITU-R P.1411-1 propagation model for LoS situation within street canyons. The obtained results related to the United States emission limits and the slope emission masks are shown in Fig. 285. The results are presented in Table 197.

FIGURE 285

Outdoor DVB-T/UWB single interference scenario – Portable DVB-T reception



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B) *Aggregate UWB interference case*

The aggregate UWB interference effect on d_{min} has been investigated by using a simple power aggregation low: 10 log*N*, where *N* is the number of interference. The obtained results are shown in Fig. 286. The results are presented in Table 199.

FIGURE 286

Outdoor DVB-T/UWB aggregate interference scenario – Portable DVB-T reception

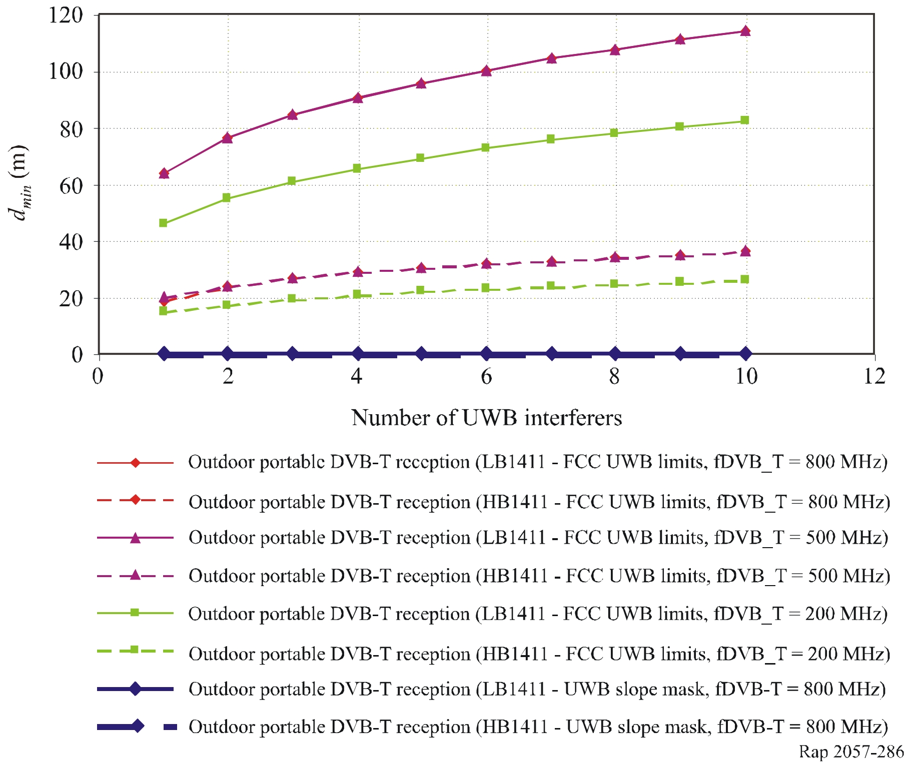


TABLE 199

DVB-T/UWB impact assessment
Portable DVB-T reception in outdoor environment – LoS situation within street canyons

Single interference scenario			
Calculation based on:	**Calculated d_{min} (m)**	**d_{min}^{out} (m)**	**Impact**
United States limits	LB = 46-64 UB = 15-20	3	Yes ($d_{min} >> d_{min}^{out}$)
Slope mask	LB = 0.06-0.24 UB = 0.03-0.07	3	No ($d_{min} << d_{min}^{out}$)

TABLE 199 (*end*)

Aggregate interference scenario			
Calculation based on:	**Calculated d_{min} (m)**	**d_{min}^{out} (m)**	**Impact**
United States limits	LB = 46-114 UB = 15-36	3	Yes ($d_{min} >> d_{min}^{out}$)
Slope mask	LB = 0.06-0.24 UB = 0.03-0.07	3	No ($d_{min} << d_{min}^{out}$)

1.3.6.2.3 Fixed DVB-T reception in outdoor environment – Free-space propagation

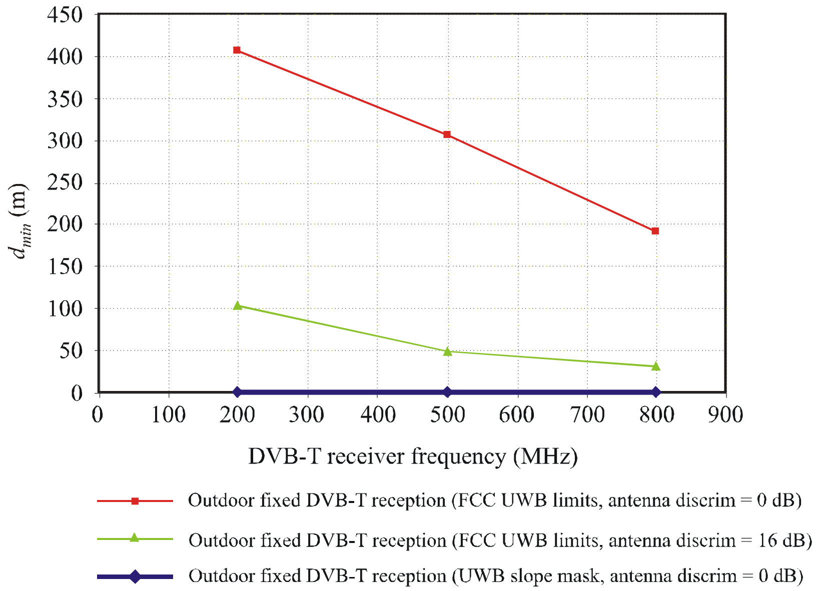
In the case of fixed DVB-T reception, a directional receiver antenna is used. Consequently, the antenna discrimination of the DVB-T receiver has been taken into consideration in d_{min} calculations. Moreover, both single and multiple interference scenarios have been considered.

A) *Single UWB interference case*

d_{min} has been calculated according to the scenario described in § 1.3.5.2. Firstly, the MCL has been calculated by using equation (165), then d_{min} has been calculated by using equation (167), which represents the free-space propagation. The obtained results related to the United States emission limits and the slope emission masks are shown in Fig. 287. These results are presented in Table 200.

FIGURE 287

Outdoor DVB-T/UWB single interference scenario – Fixed DVB-T reception



Rap 2057-287

B) *Aggregate UWB interference case*

The aggregate UWB interference effect on d_{min} has been investigated by using a simple power aggregation low: 10 log$N$, where N is the number of interference. The obtained results are shown in Fig. 288. These results are presented in Table 200.

FIGURE 288

Outdoor DVB-T/UWB aggregate interference scenario – Fixed DVB-T reception

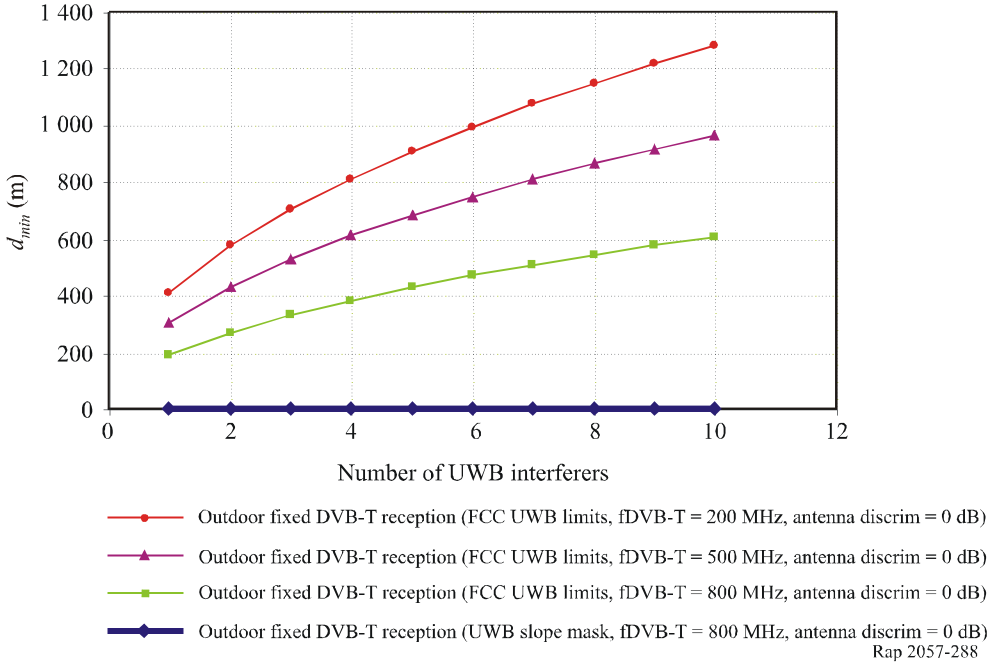


TABLE 200

DVB-T/UWB impact assessment
Fixed DVB-T reception in outdoor environment – Free-space propagation

Single interference scenario			
Calculation based on:	**Calculated d_{min} (m)**	**d^{out}_{min} (m)**	**Impact**
United States limits	30-406	3	Yes (d_{min}>> d^{out}_{min})
Slope mask	0-0.05	3	No (d_{min}<< d^{out}_{min})
Aggregate interference scenario			
Calculation based on:	**Calculated d_{min} (m)**	**d^{out}_{min} (m)**	**Impact**
United States limits	30-1 284	3	Yes (d_{min}>> d^{out}_{min})
Slope mask	0-0.143	3	No (d_{min}<< d^{out}_{min})

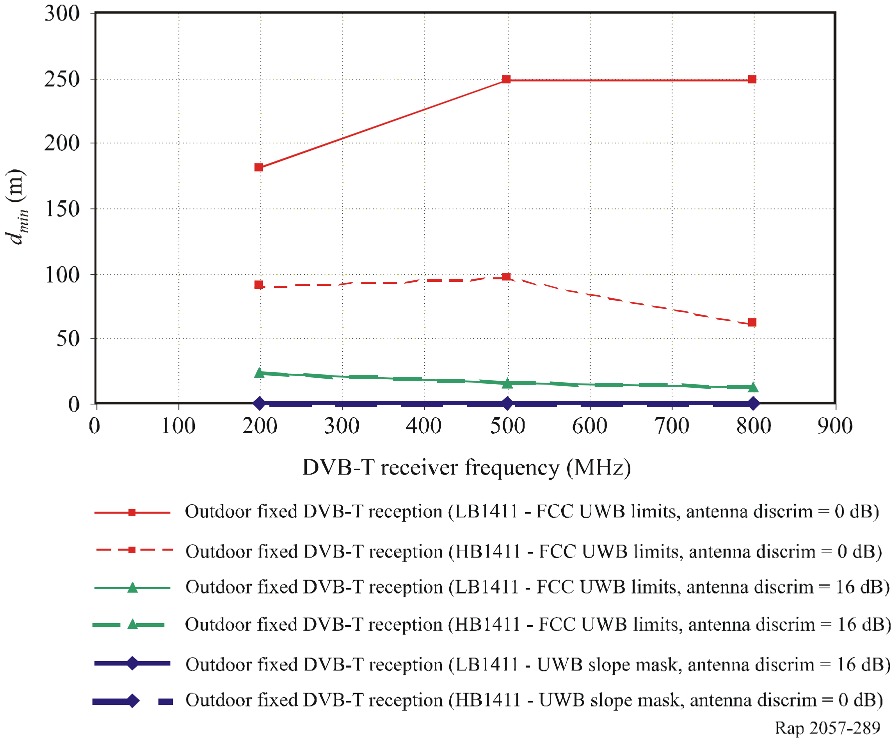
1.3.6.2.4 Fixed DVB-T reception in outdoor environment – LoS situation within street canyons

A) *Single UWB interference case*

d_{min} has been calculated according to the scenario described in § 1.3.5.2. Firstly, the MCL has been calculated by using equation (165), then d_{min} has been calculated by using equations (168) and (170), which represent the Recommendation ITU-R P.1411 propagation model for LoS situation within street canyons. The obtained results related to the United States emission limits and the slope emission masks are shown in Fig. 289. The results are presented in Table 201.

FIGURE 289

Outdoor DVB-T/UWB single interference scenario – Fixed DVB-T reception



B) *Aggregate UWB interference case*

The aggregate UWB interference effect on d_{min} has been investigated by using a simple power aggregation low: 10 log$N$, where N is the number of interference. The obtained results are shown in Fig. 290. The results are presented in Table 201.

FIGURE 290

Outdoor DVB-T/UWB aggregate interference scenario – Fixed DVB-T reception

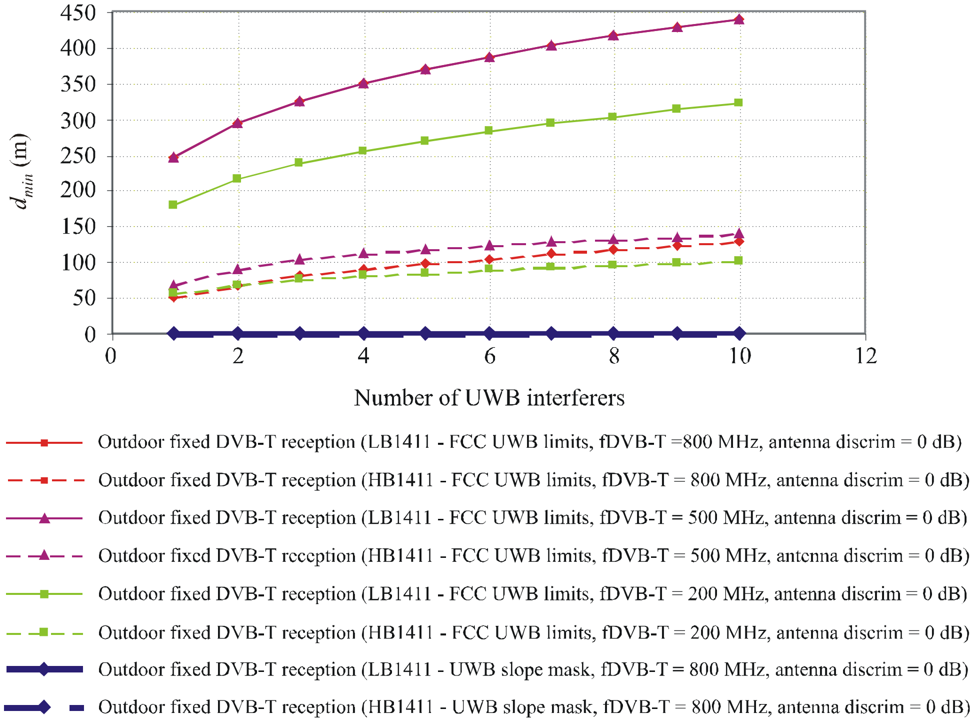


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TABLE 201

DVB-T/UWB impact assessment
Fixed DVB-T reception in outdoor environment – LoS situation within street canyons

Single interference scenario			
Calculation based on:	**Calculated d_{min} (m)**	**d_{min}^{out} (m)**	**Impact**
United States limits	LB = 61-247 UB = 12-57	3	Yes ($d_{min} >> d_{min}^{out}$)
Slope mask	LB = 0.06-0.24 UB = 0.05-0.11	3	No ($d_{min} << d_{min}^{out}$)
Aggregate interference scenario			
Calculation based on:	**Calculated d_{min} (m)**	**d_{min}^{out} (m)**	**Impact**
United States limits	LB = 61-440 UB = 12-139	3	Yes ($d_{min} >> d_{min}^{out}$)
Slope mask	LB = 0.06-0.29 UB = 0.046-0.16	3	No ($d_{min} << d_{min}^{out}$)

1.3.7 Maximum UWB e.i.r.p density to provide adequate protection to the DVB-T system

Results of the calculations based on the MCL show that in case of the use of the United States UWB emission limits, a d_{min} in the range of 85 m to 1 284 m is needed to prevent interference from UWB devices into the DVB-T system in the VHF/UHF bands, while the UWB slope emission masks used in this study reduce d_{min} significantly (< 0.5 m).

In this section, the maximum UWB e.i.r.p density (UWB e.i.r.p.$_{max}$) to provide adequate protection to the DVB-T system has been calculated only for single interference case, which was considered the most critical case for DVB-T reception.

In indoor environment (free space propagation model), UWB e.i.r.p.$_{max}$ has been calculated by using equation (166).

UWB e.i.r.p.$_{max}$ (dBm/MHz) = E_{max_i} (dBµV/m/7.61MHz) + 20 $\log_{10}(d_{min})$ – 104.77 – 10 $\log_{10}(7.61)$ where:

E_{max_i} is calculated as indicated in § 1.3.9

$d_{min} = d_{min}^{in} = 0.5$ m and $d_{min}^{out} = 3$ m in indoor and outdoor environments respectively, for fixed and portable reception (see § 1.3.4).

In outdoor environment (ITU-R P.1411 propagation model), UWB e.i.r.p.$_{max}$ has been calculated as follows. Firstly, MCL ($L_{LoS,l}$) is calculated by using equation (168). Then UWB *e.i.r.p.*$_{max}$ is calculated as:

$$\text{UWB } e.i.r.p._{max} \text{ (dBm/MHz)} = MCL + E_{max\_i} \text{ (dBµV/m/7.61.MHz)} + 20.\log_{10}(\lambda/2\pi) - 140.8 + 30 - 10 \log_{10}(7.61)$$

The results obtained are given in Table 202.

TABLE 202

Frequency band	UHF		VHF
Frequency (MHz)	500	800	200
Indoor environment (free space propagation model)			
E_{max-i} (dBµV/m/7.61 MHz)	37.48	41.56	32.67
d_{min} (m)	0.5		0.5
UWB *e.i.r.p.*$_{max}$ (dBm/MHz)	–89	–85	–94
Outdoor environment (ITU-R P.141-1 propagation model)			
E_{max-i} (dBµV/m/7.61 MHz)	23.88	27.96	18.92
d_{min} (m)	3		3
UWB *e.i.r.p.*$_{max}$ (dBm/MHz)	–86	–82	–91

From these results, a maximum UWB e.i.r.p density has been defined to provide adequate protection to the DVB-T system both in indoor and outdoor environments, for fixed and portable reception:

UWB *e.i.r.p.*$_{max}$ = –89 dBm/MHz in the UHF band (470-862 MHz)

UWB *e.i.r.p.*$_{max}$ = –94 dBm/MHz in the VHF band (174-230 MHz).

1.3.8 Conclusion

A large number of interference scenarios have been simulated to assess the impact on the DVB-T by UWB systems, in the VHF/UHF bands. For each of the considered scenarios, the protection distance, d_{min}, from the DVB-T receiver to the UWB transmitter has been calculated by using alternatively, as UWB radiated power density level, the United States UWB emission limits in force and the UWB slope emission masks. The obtained distances have been compared with two threshold values d_{min}^{in} =

0.5 m and d_{min}^{out} = 3 m, which are respectively the protection distances required to ensure adequate protection to the DVB-T system in indoor and outdoor environments, for fixed and portable reception.

The analyses of the results clearly show that the United States UWB emission limits do not guarantee the protection of the DVB-T system in the presence of UWB emissions (85 m ≤ d_{min} ≤ 1 284 m), while the UWB slope emission masks reduce d_{min} significantly (< 0.5 m).

Finally, a maximum UWB e.i.r.p density (dBm/MHz) has been defined to provide adequate protection to the DVB-T system in indoor and outdoor environments, for fixed and portable reception:

UWB $e.i.r.p._{max}$ = –89 dBm/MHz in the UHF band (470-862 MHz)

UWB $e.i.r.p._{max}$ = –94 dBm/MHz in the VHF band (174-230 MHz).

1.4 Assessment of the impact of UWB systems on ATSC digital television

1.4.1 Abstract

This interference analysis is performed to determine the required e.i.r.p. density limit that should be applied to transmitting devices using UWB technology so that the protection criterion for the ATSC DTV service is not exceeded. The e.i.r.p. density limits are determined for a single entry case and for an aggregate case or the single entry case, indoor and outdoor scenarios are examined. The transmitting UWB device is located 0.5 m away from the victim receiver for the indoor scenario and the UWB device is located 3 m away in the outdoor scenario. In the aggregate example, various numbers of UWB devices were uniformly, normally, and inverse normally distributed about the victim receiver at a range of 5 000 m and a range of 1 000 m. The results are dependent on several variables, including the distribution, the number of transmitting devices, the range or separation distance, and the propagation path loss mode assumed.

1.4.2 Introduction

The Advanced Television Systems Committee developed the ATSC standard for terrestrial broadcast digital television (DTV). There are currently over a thousand stations on-air broadcasting ATSC DTV in multiple countries.

UWB is a technology that makes low-power radiocommunication possible by spreading the transmitted energy over a very wide bandwidth. Since UWB is a low-power technology, it is possible for devices employing UWB to coexist under a primary service without causing more than acceptable interference to that primary service.

The e.i.r.p. density of UWB devices can be limited in order not to exceed the authorized protection criteria to other radiocommunication services. The e.i.r.p. limit for UWB devices is dependent on the authorized protection criteria specified for a radiocommunication service, the RF link budget operating parameters, and the assumptions of the operating environment.

The correct e.i.r.p. density limit for UWB devices needs to be determined through analysis in order to prevent additional interference caused by the UWB devices, along with other noise-like interference, from exceeding the authorized protection criteria stated for the ATSC DTV service. Radiocommunication Study Group 6 states that a total interference from devices with no corresponding frequency allocations in the Radio Regulations should not exceed 1% of the total system noise at all times. The stated protection criterion translates to an interference-to-noise ratio (I/N) of –20 dB.

1.4.3 Purpose

The purpose of this analysis is to determine the e.i.r.p. density limit for transmissions from devices using UWB technology to assure that the protection criteria for ATSC DTV terrestrial broadcast services is not violated.

The protection criteria used for ATSC DTV terrestrial broadcasting in the analysis is, I/N = –20 dB.

An e.i.r.p. density limit is determined for both single entry and aggregate interference scenarios.

1.4.4 Assumptions

– Federal Communications Commission (FCC) Office of Engineering and Technology (OET) Bulletin 69 DTV Planning Factors

TABLE 203

FCC OET 69 planning factors

Planning factor	Low VHF	High VHF	UHF
Antenna gain (dBd)	4	6	10
Downlead line loss (dB)	1	2	4
System noise figure (dB)	10	10	7
Front-to-back ratios (dB)	10	12	14

– Frequencies:

LVHF: 69 MHz, HVHF: 195 MHz, UHF: 615 MHz

– Thermal noise: –106.2 dBm
– Isotropic DTV receiving vertical antenna pattern
– Omnidirectional UWB transmitting antenna pattern
– No system noise contributed by any other sources.

1.4.4.1 Single entry scenario

– 3 m separation distance for outdoor receiving antenna
– 0.5 m separation distance for indoor receiving antenna
– Indoor receiving antenna has 0 dBi gain
– Indoor receiving antenna has 1 dB downlead line loss
– Single UWB device is located in the main lobe of the receiving antenna
– $1/r^2$ propagation path loss mode (free-space).

1.4.4.2 Aggregate scenario

– Outdoor DTV receiving antenna installation at 9 m AGL
– Aggregate methodology is modelled after § 1.3.4 in Annex 2 of this Report.
– Distributions:

Uniform, Normal, Inverse Normal

– Number of active UWB transmitters:

1 000, 500, 200, 100, 20, 10

– Ranges:
  5 000 m, 1 000 m
– Propagation path loss modes:

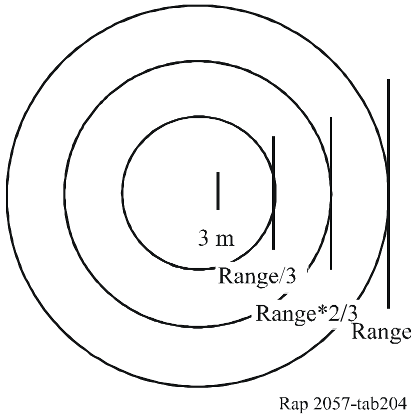


TABLE 204

Propagation path loss mode distribution by distance from victim receiver

Range bin	Propagation mode		
	Percent 1/r^2	**Percent 1/r^3**	**Percent 1/r^4**
3 m – range/3	50	30	20
range/3 – range*2/3	33.3	33.3	33.3
range*2/3 – range	20	30	50

– 3 m separation zone.

1.4.5 Procedure

The total system noise is calculated,

$$N = Nt\_\text{dBm} + Nf\_\text{dB} \quad (172)$$

where:

N: total system noise (dBm/6 MHz)
Nt_dBm: thermal noise (dBm/6 MHz)
Nf_dB: noise figure (dB).

1.4.5.1 Single entry scenario

One UWB device is positioned in the main lobe of the ATSC DTV receiver at either 3 m, for the outdoor antenna installation case, or 0.5 m, for the indoor antenna installation case.

The path loss is calculated by,

$$L_p = 20 * \log(d * f\_\text{MHz}) - 27.56 \quad (173)$$

where:

L_p: propagation path loss (dB)

d: distance (m)

f_MHz: frequency (MHz).

The UWB e.i.r.p. density level is determined by,

$$P\_dBm\_MHz = -20 + N - gain\_dBi + leadin\_loss\_dB + L_p - 10 * \log(6) \quad (174)$$

where:

P_dBm_MHz: UWB e.i.r.p. density (dBm/MHz)

*gain*_dBi: receiver isotropic antenna gain (dBi)

leadin_loss_dB: downlead line loss (dB)

L_p: propagation path loss (dB).

The UWB e.i.r.p. density limit for both outdoor and indoor ATSC DTV receiver antenna installations for each band examined is reported in Table 205.

1.4.5.2 Aggregate scenario

Depending upon the type of distribution requested, the modelled UWB devices are scattered surrounding the modelled victim ATSC DTV receiver. To enforce a 3 m separation distance from the victim receiver, any UWB device that is positioned closer than 3 m to the victim receiver is repositioned at 3 m.

The fractional receiver horizontal antenna pattern is determined based on the azimuth position of the UWB device relative to the victim receiver. The fractional horizontal antenna pattern is determined by,

$$|angle\_deg|<90: az\_pat = 20 * \log(front\_to\_back) \quad (175)$$

$$|angle\_deg| >90: az\_pat = 20 * \log(\max(\cos(angle\_rad)^4, front\_to\_back)) \quad (176)$$

where:

angle_deg: azimuth angle from victim receiver to UWB device (degrees)

az_pat: receiver fractional antenna pattern

front_to_back: front-to-back ratio

angle_rad: azimuth angle from victim receiver to UWB device (radians).

The propagation path loss is calculated by,

$$L_p = k * \log(r) + 20 * \log(f\_MHz) - 27.56 \quad (177)$$

where:

L_p: propagation path loss (dB)

k: 20, 30, or 40, depending on the propagation path loss mode (1/r2, 1/r3, 1/r4)

r: range (m)

f_MHz: frequency (MHz).

The received interference level is determined by,

$$I = 10\text{^}((P\_dBm + gain\_dBi + az\_pat - leadin\_loss\_dB - L_p)/10) \quad (178)$$

where:

I:	interference level (dBm/6 MHz)
P_dBm:	UWB e.i.r.p. density (dBm/6 MHz)
gain_dBi:	receiver antenna gain (dBi)
az_pat:	receiver fractional antenna pattern
leadin_loss_dB:	downlead line loss (dB)
L_p:	propagation path loss (dB).

The aggregate interference level is achieved by summing the interference levels from each of the UWB devices. Since the resulting aggregate interference level is so dependent on the actual position of the distributed UWB devices, the analysis is repeated 500 times for each distribution, at each TV band, and at each number of UWB devices considered. After 500 iterations, the resulting interference level reaches a stable condition and an accurate average aggregate interference level can be determined.

The final I/N ratio is calculated by,

$$IN = 10 * \log(\text{avg}(I\_\text{agg})) - N \tag{179}$$

where:

IN:	I/N ratio (dB)
I_agg:	aggregate interference level (dBm/6 MHz)
N:	Total system noise (dBm/6 MHz).

Several plots of I/N versus the individual UWB e.i.r.p. density are created and they are shown § 1.4.6.

1.4.6 Results

Table 205 tabulates the results for the impact of a single UWB device on the ATSC DTV receiver in the VHF and UHF TV bands. Both indoor and outdoor antenna installations were considered. Figures 291 through 314 illustrate the results of impact assessments for an aggregate of UWB devices in various distributions about an ATSC DTV receiver with an outdoor antenna. Each assessment represents the medium impact, resulting from a different scattering of UWB devices for each of the 500 times that the analysis was repeated. Table 206 summarizes the UWB e.i.r.p. density limit resulting in an I/N of –20 dB for the various aggregate distributions. Table 207 tabulates the results of the impact assessment for the normal distribution of 1 000 UWB devices over a 1 000 m radius about an ATSC DTV receiver with an outdoor antenna installation, which represents the most restrictive scenario examined in the analysis. Using assumptions similar to those used for the FSS service to incorporate into the table of Annex 1 of Annex 2 preliminary draft new Recommendation ITU-R SM.1757, Table 6 tabulates the results for the uniform distribution of 5 UWB devices 393 UWB devices over a 5 000 m radius (5 devices/km^2) about an outdoor antenna installation.

TABLE 205

UWB e.i.r.p. density limit (dBm/MHz) resulting in an *I*/*N* = –20 dB, single entry

	LVHF	**HVHF**	**UHF**
Outdoor	–110.37	–102.35	–97.37
Indoor	–121.94	–112.91	–105.93

FIGURE 291

Uniform distribution

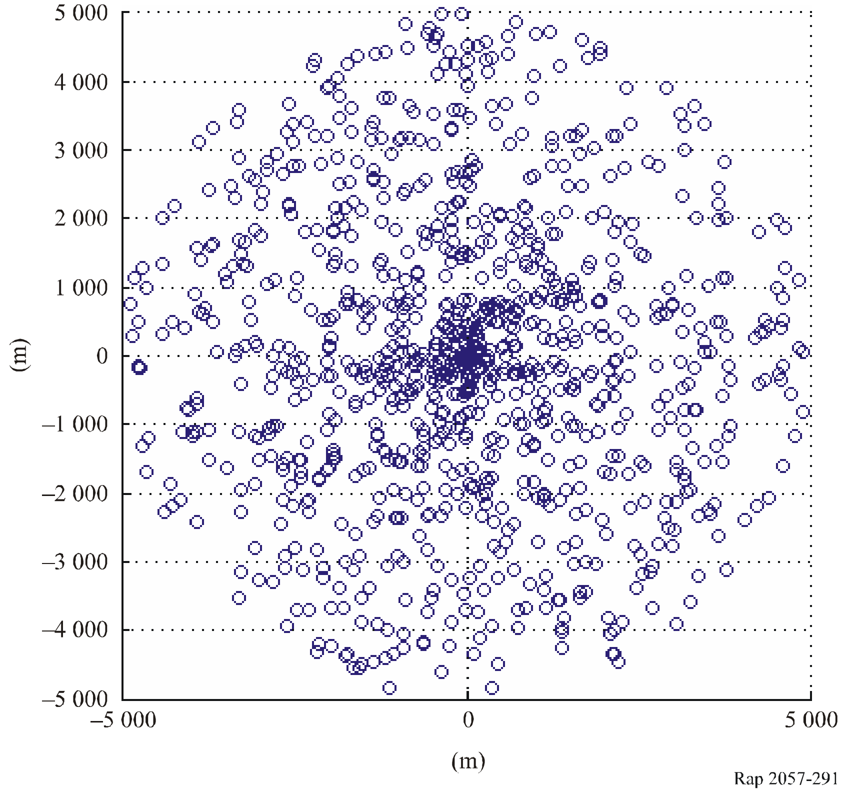


FIGURE 292

Aggregate UWB interference into outdoor LVHF DTV, range 5 000 m

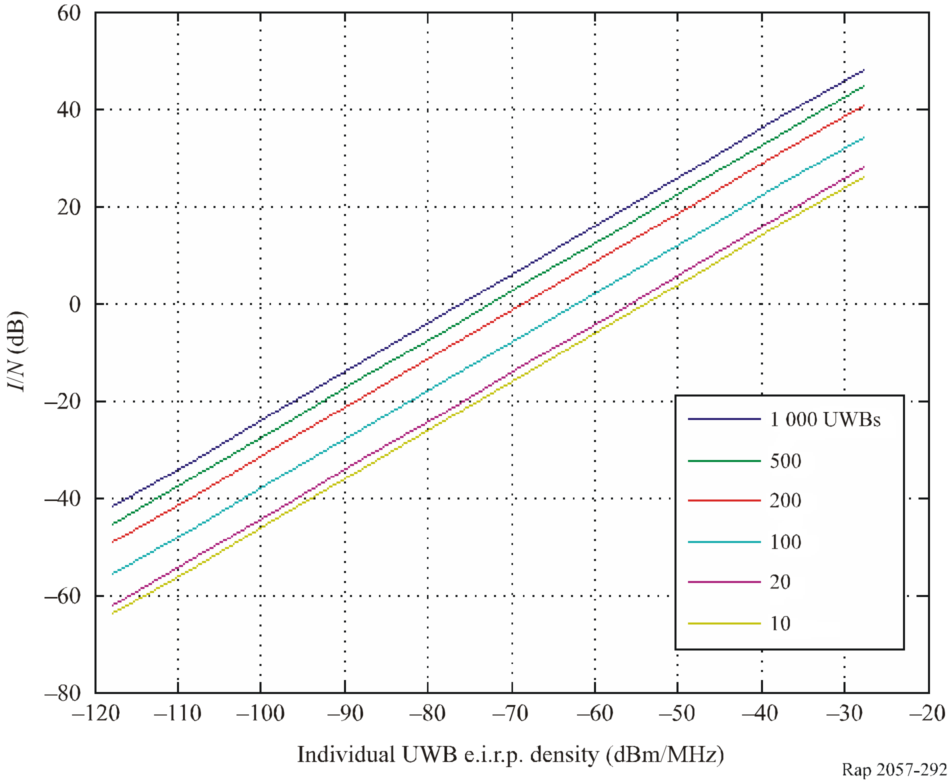


FIGURE 293

Aggregate UWB interference into outdoor HVHF DTV, range 5 000 m

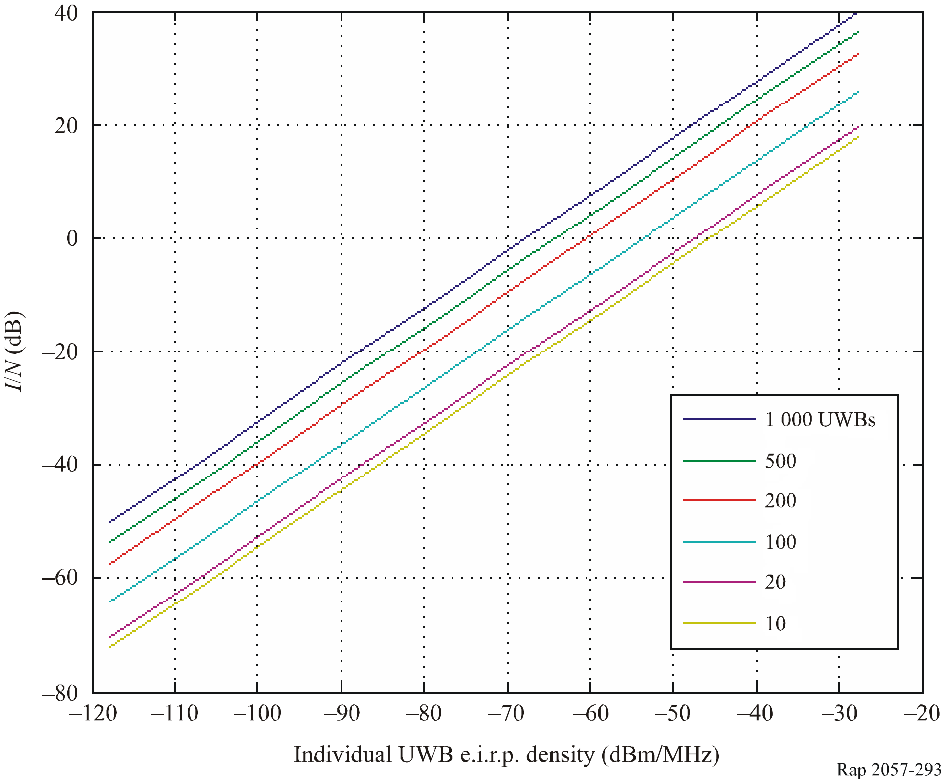


FIGURE 294

Aggregate UWB interference into outdoor UHF DTV, range 5 000 m

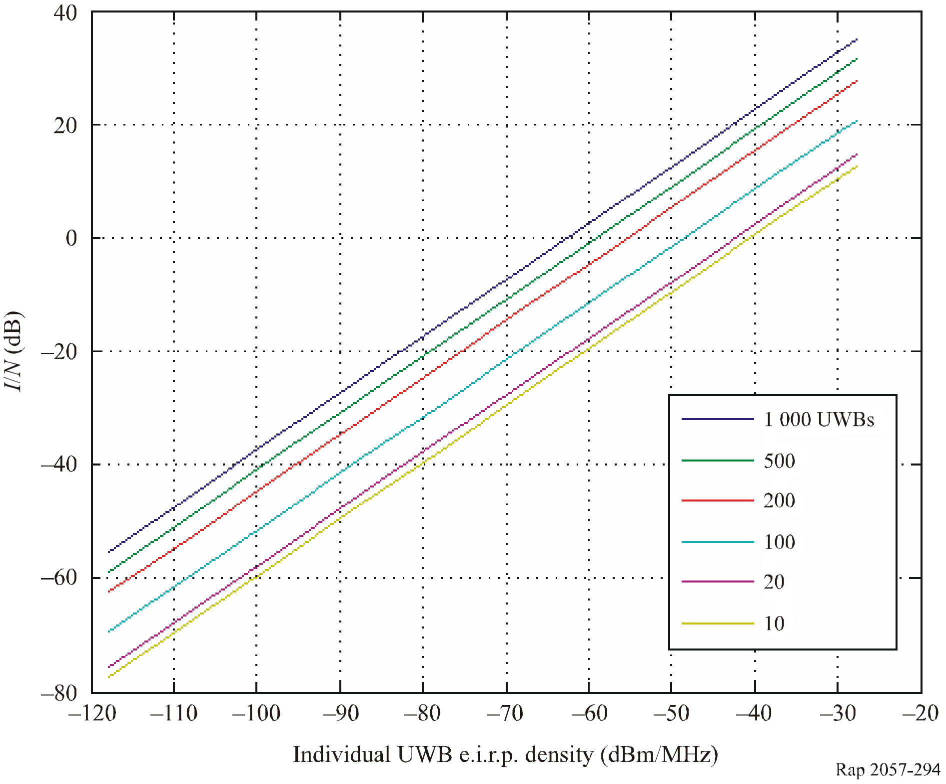


FIGURE 295

Normalized distribution

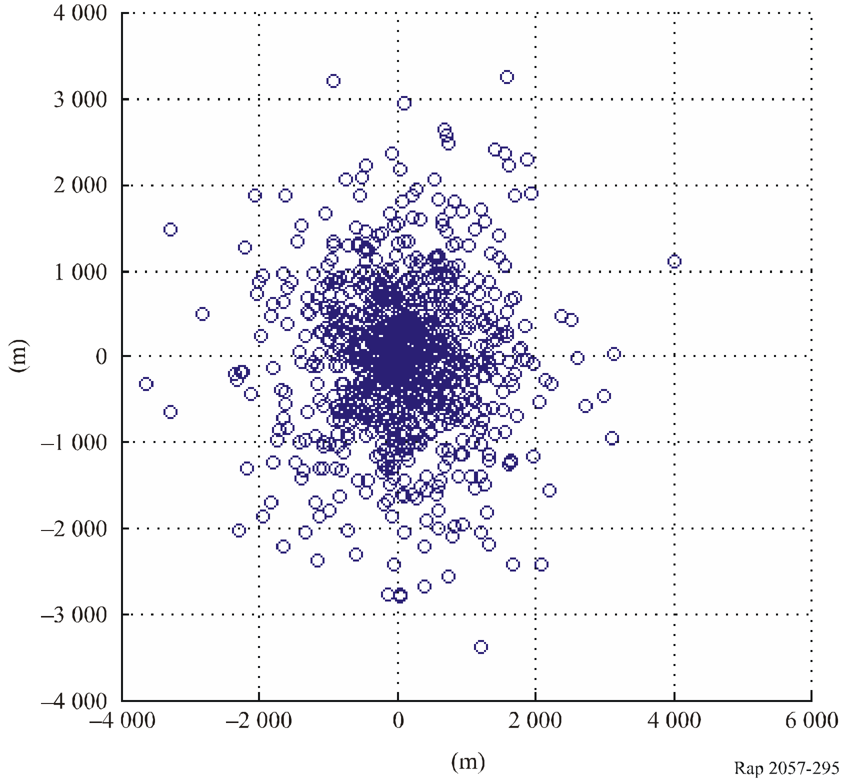


FIGURE 296

Aggregate UWB interference into outdoor LVHF DTV, range 5 000 m

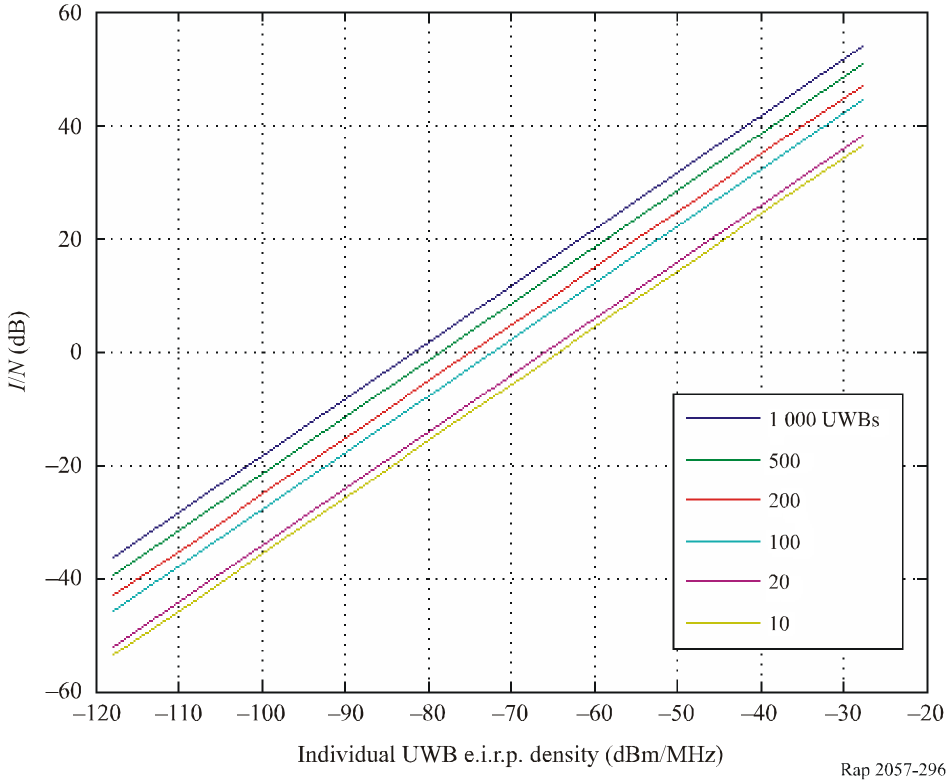
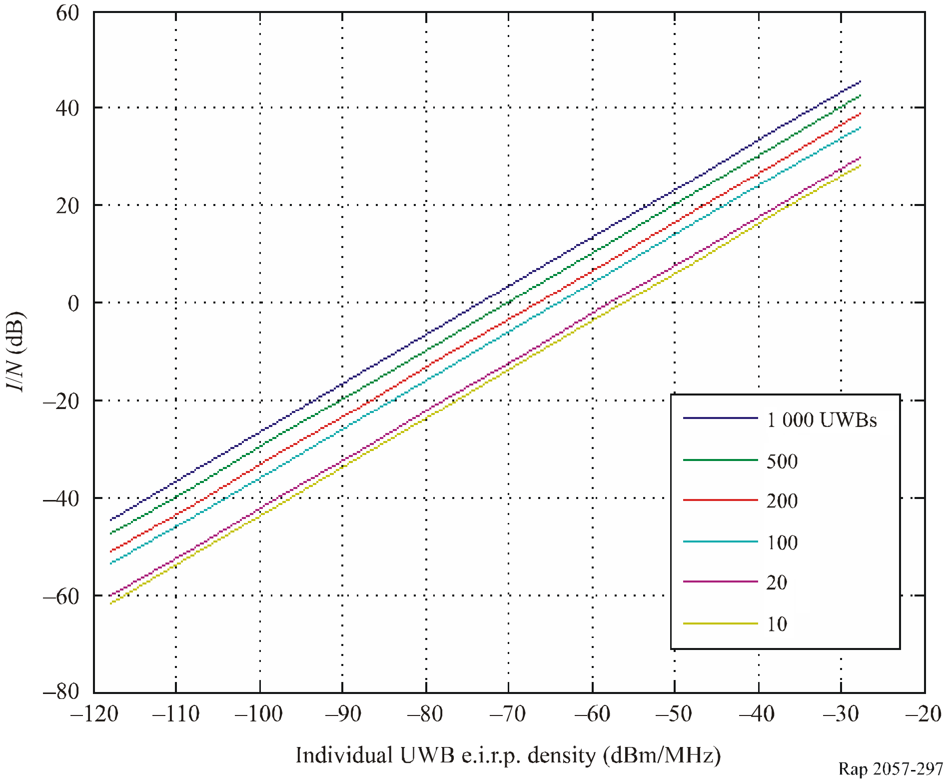


FIGURE 297

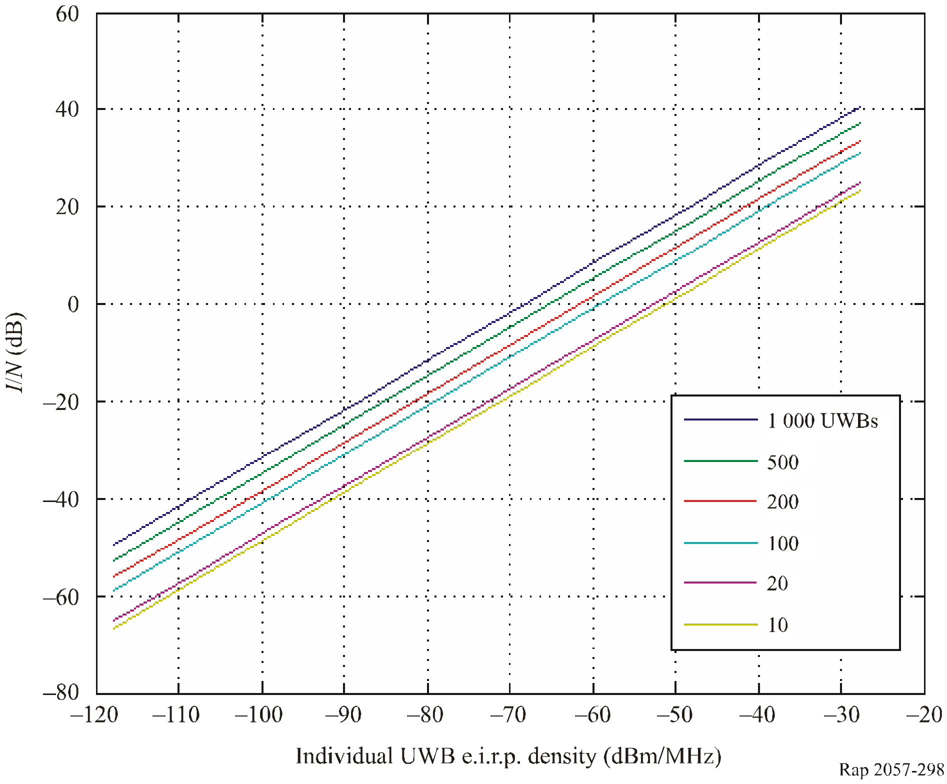
Aggregate UWB interference into outdoor HVHF DTV, range 5 000 m



Rap 2057-297

FIGURE 298

Aggregate UWB interference into outdoor UHF DTV, range 5 000 m



Rap 2057-298

FIGURE 299

Inverse normalized distribution

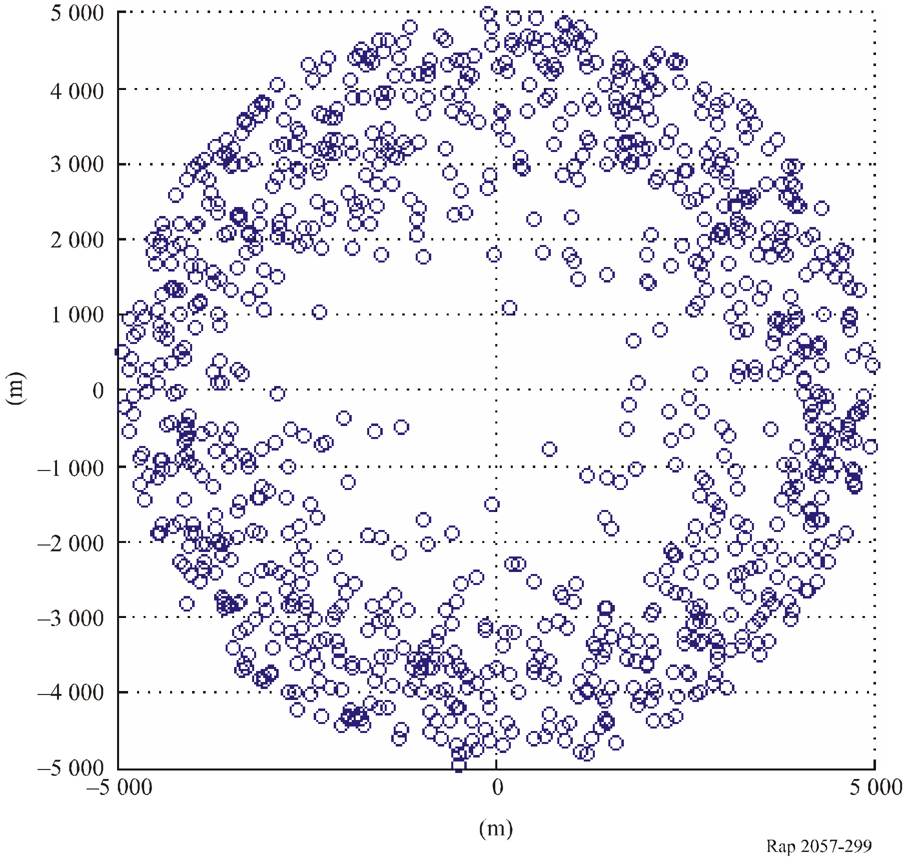


FIGURE 300

Aggregate UWB interference into outdoor LVHF DTV, range 5 000 m

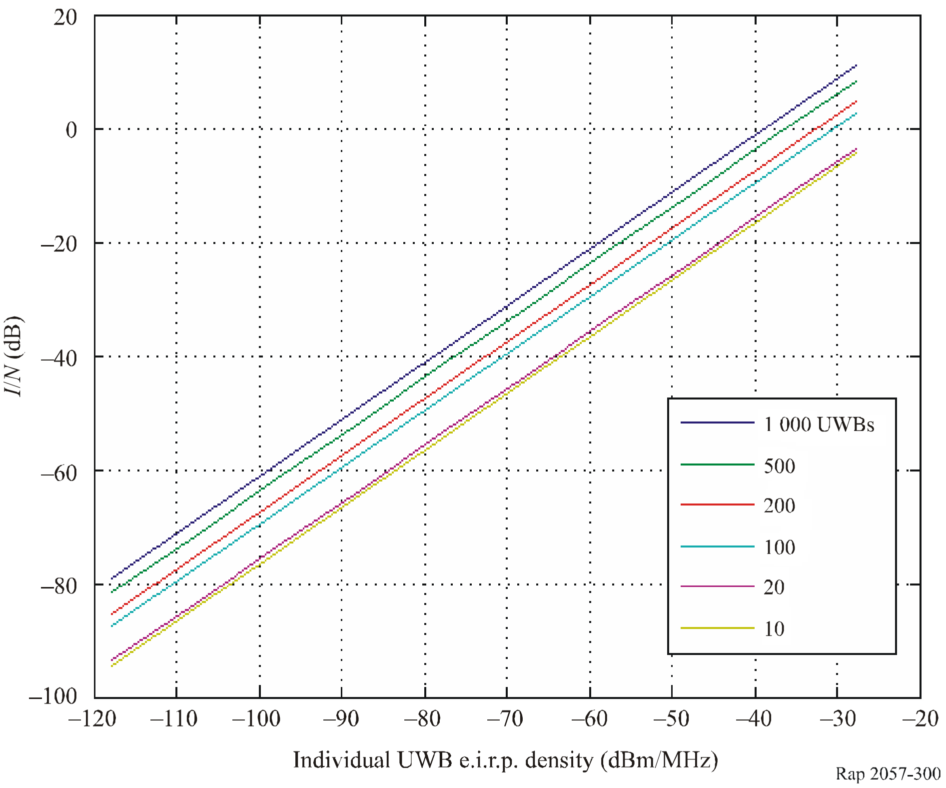


FIGURE 301

Aggregate UWB interference into outdoor HVHF DTV, range 5 000 m

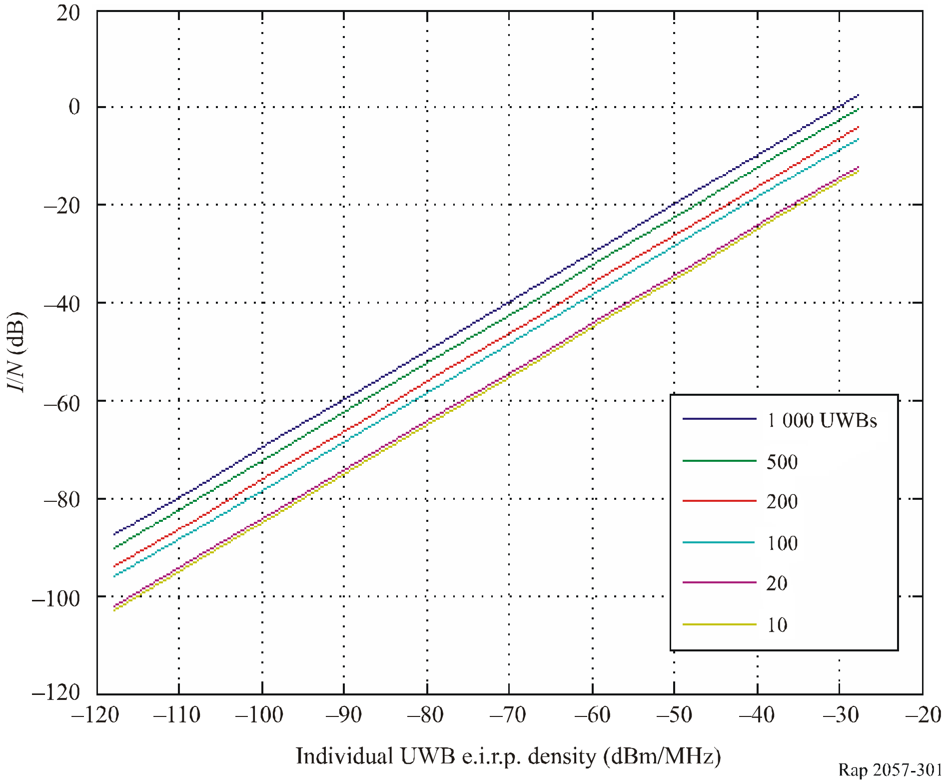


FIGURE 302

Aggregate UWB interference into outdoor UHF DTV, range 5 000 m

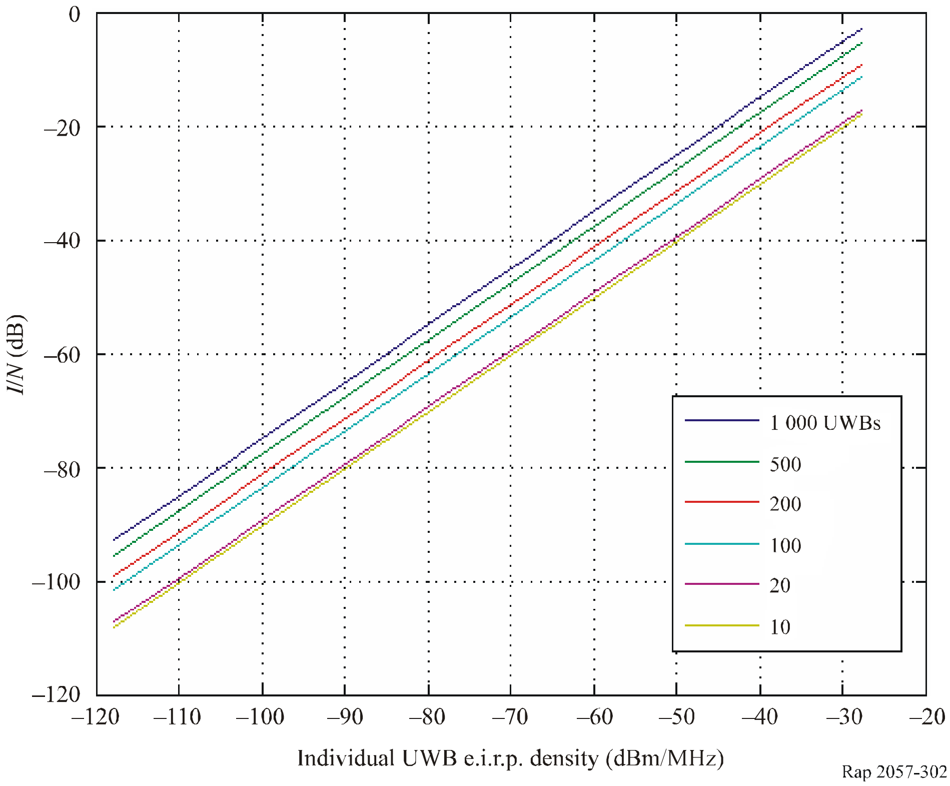
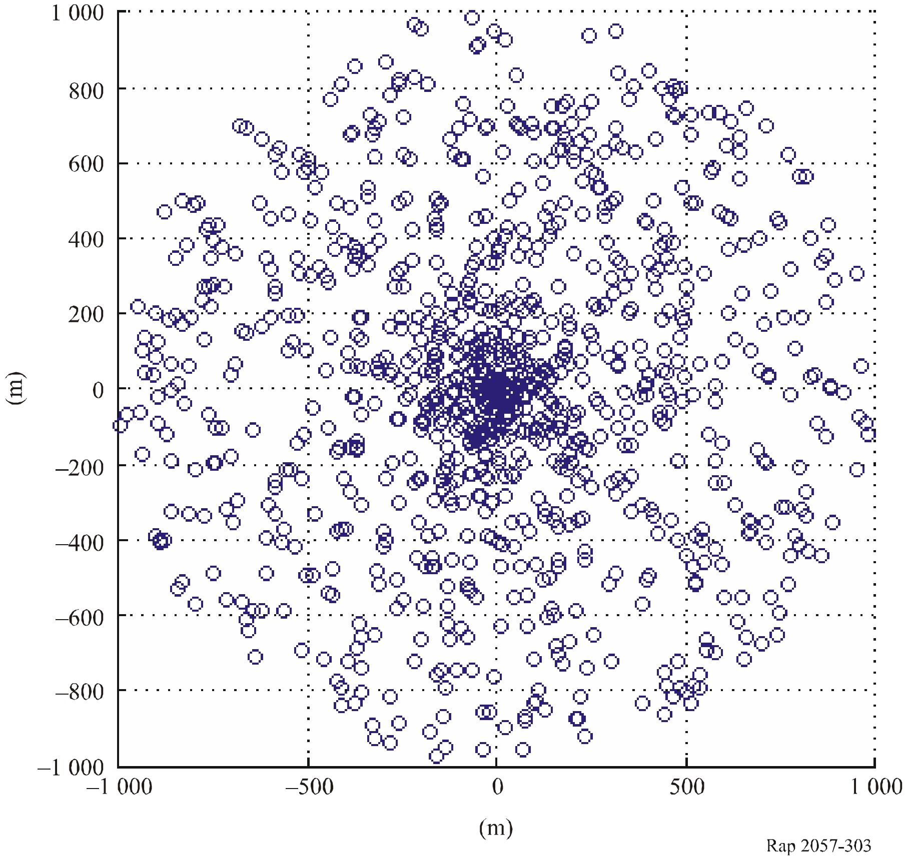


FIGURE 303

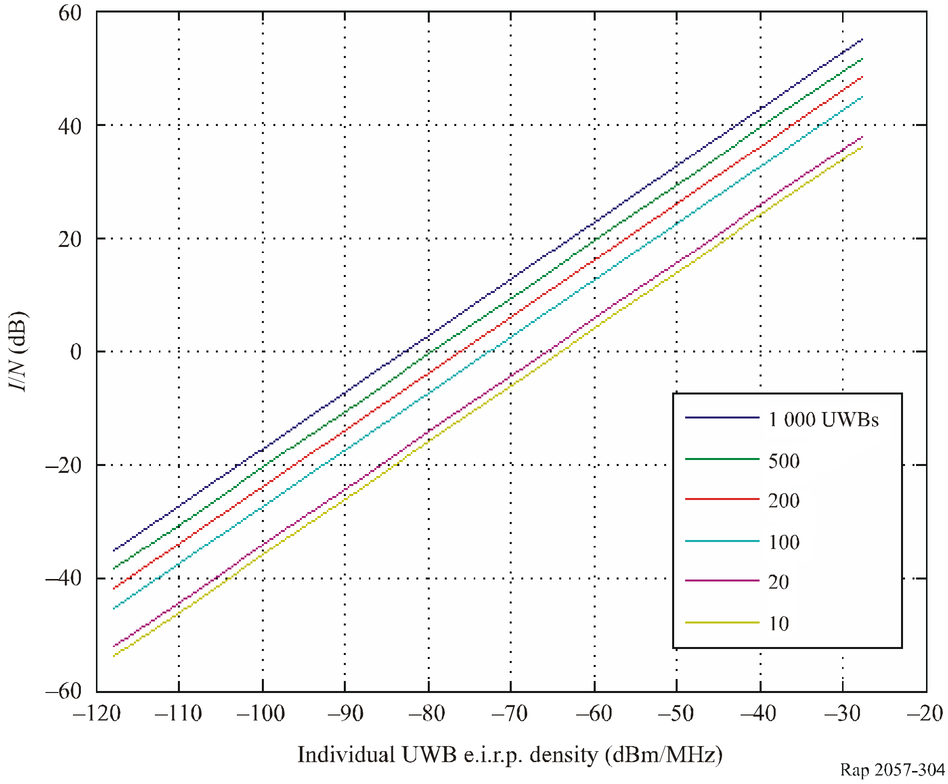
Uniform distribution



Rap 2057-303

FIGURE 304

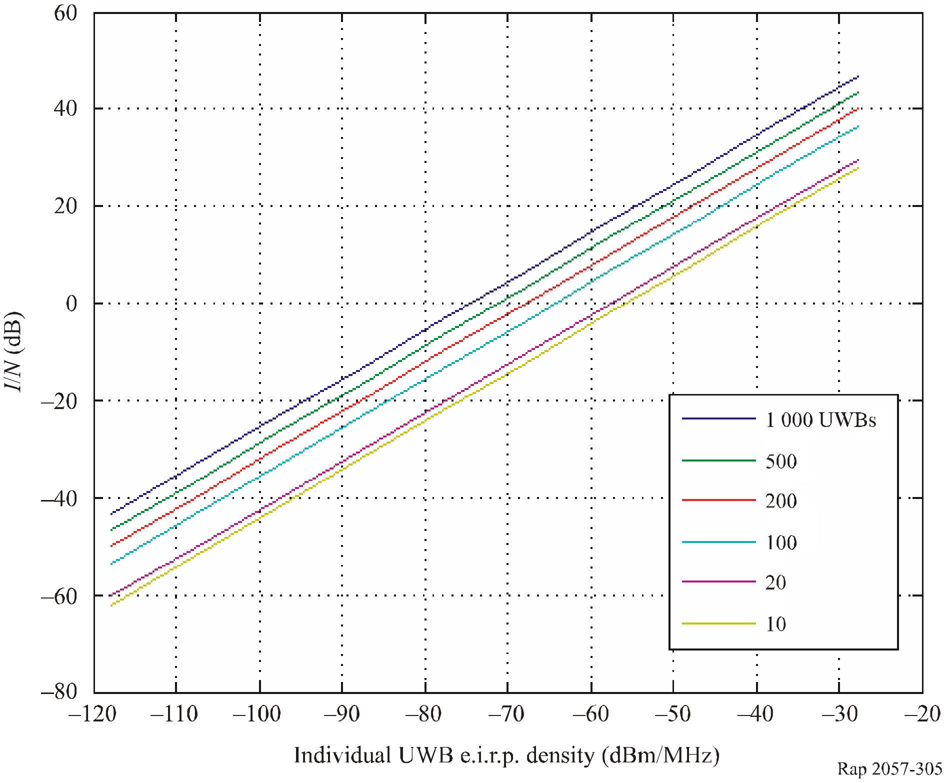
Aggregate UWB interference into outdoor HVHF DTV, range 1 000 m



Rap 2057-304

FIGURE 305

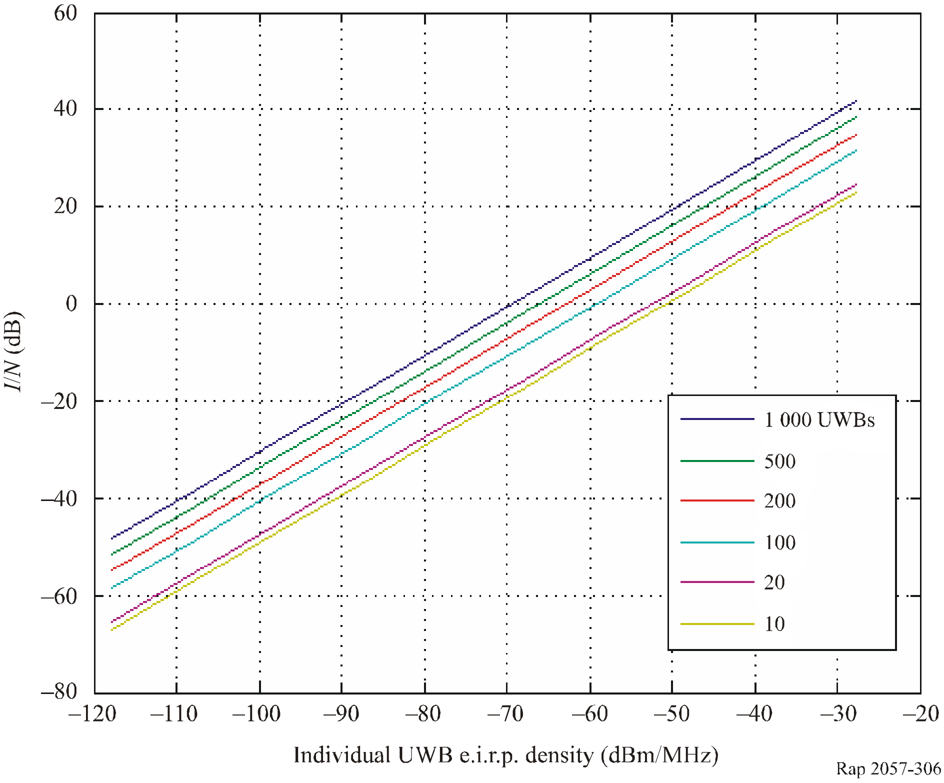
Aggregate UWB interference into outdoor HVHF DTV, range 1 000 m



Rap 2057-305

FIGURE 306

Aggregate UWB interference into outdoor UHF DTV, range 1 000 m



Rap 2057-306

FIGURE 307

Normalized distribution

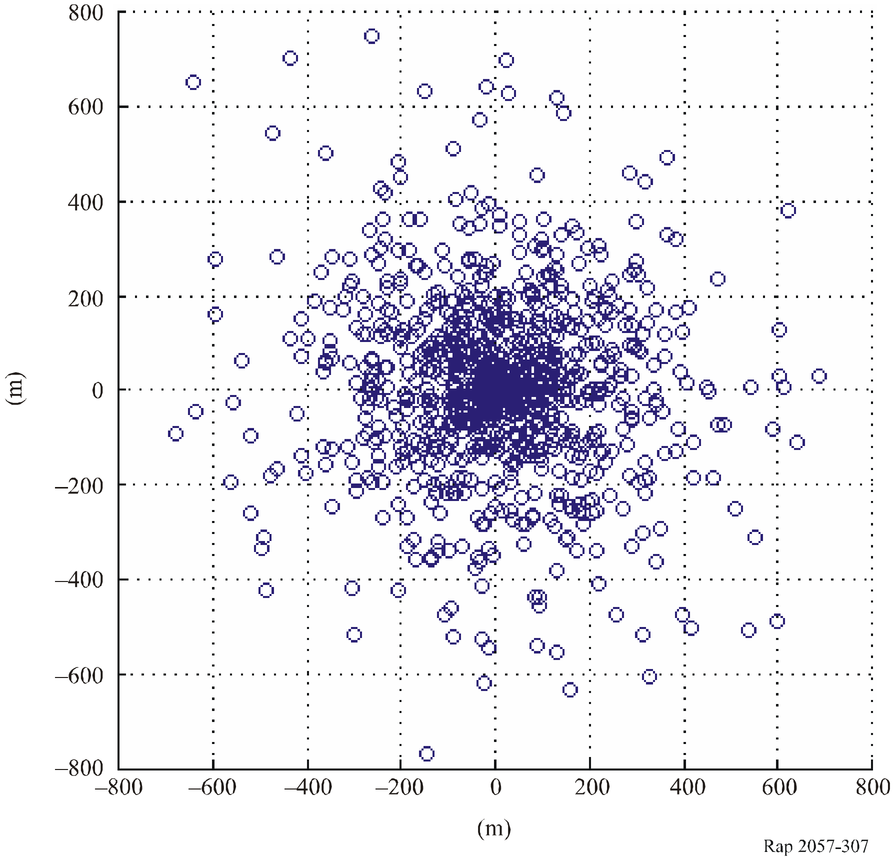


FIGURE 308

Aggregate UWB interference into outdoor LVHF DTV, range 1 000 m

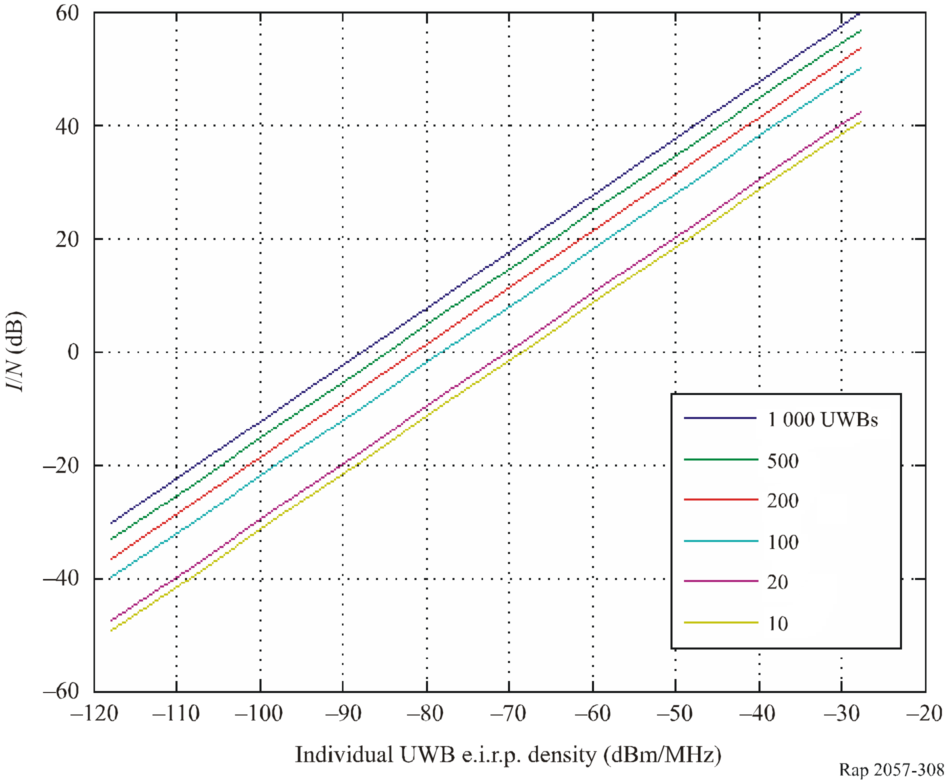
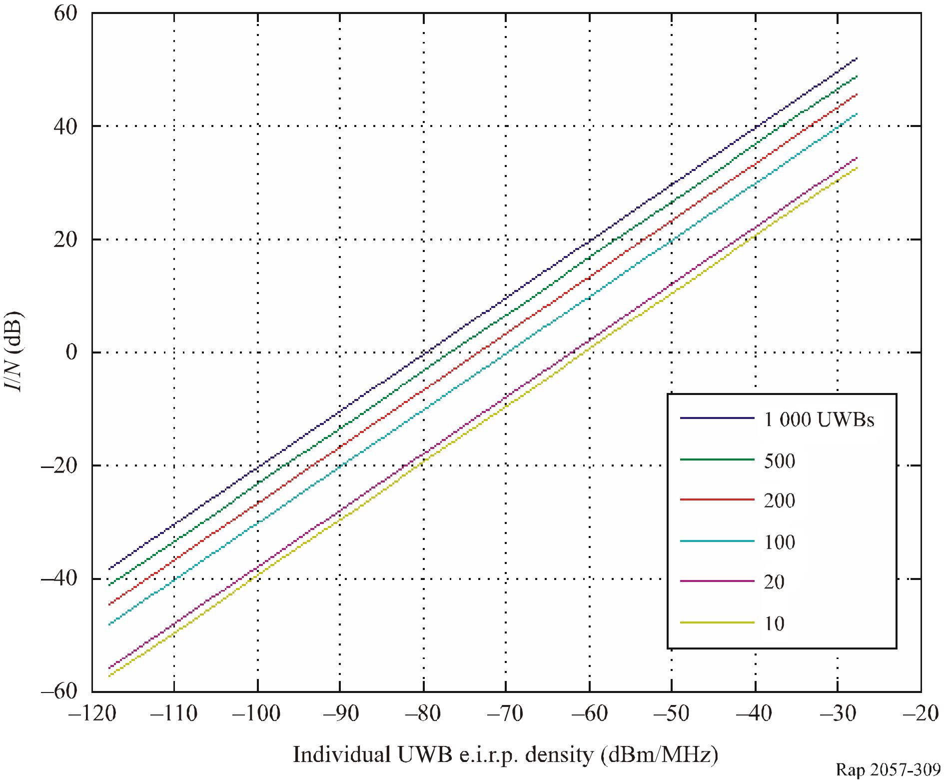


FIGURE 309

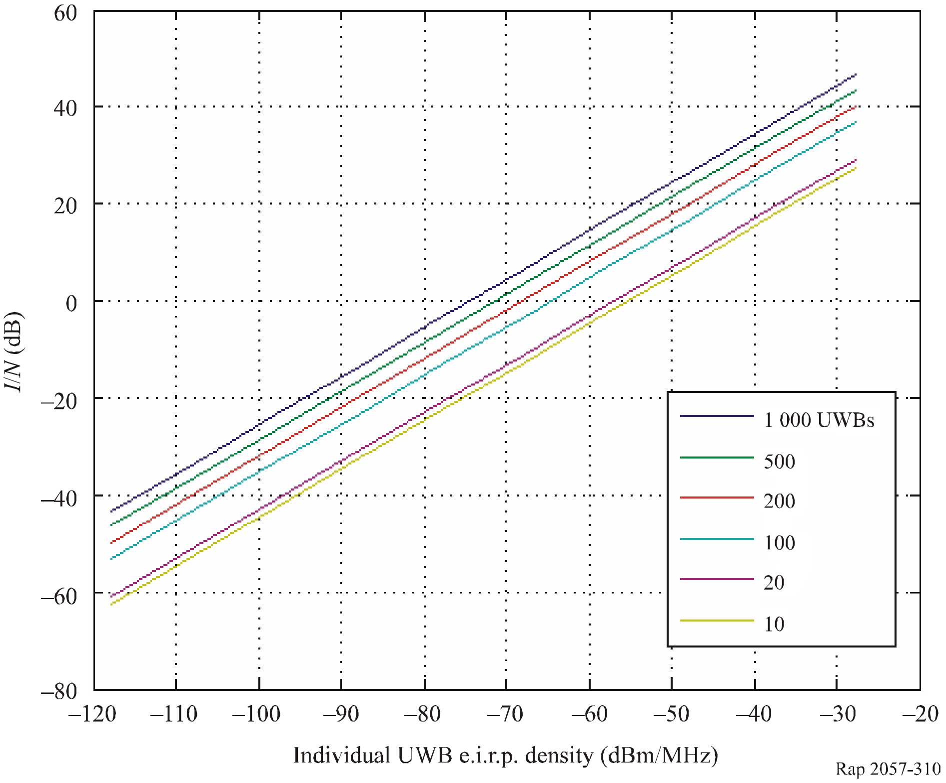
Aggregate UWB interference into outdoor HVHF DTV, range 1 000 m



Rap 2057-309

FIGURE 310

Aggregate UWB interference into outdoor UHF DTV, range 1 000 m



Rap 2057-310

FIGURE 311

Inverse normalized distribution

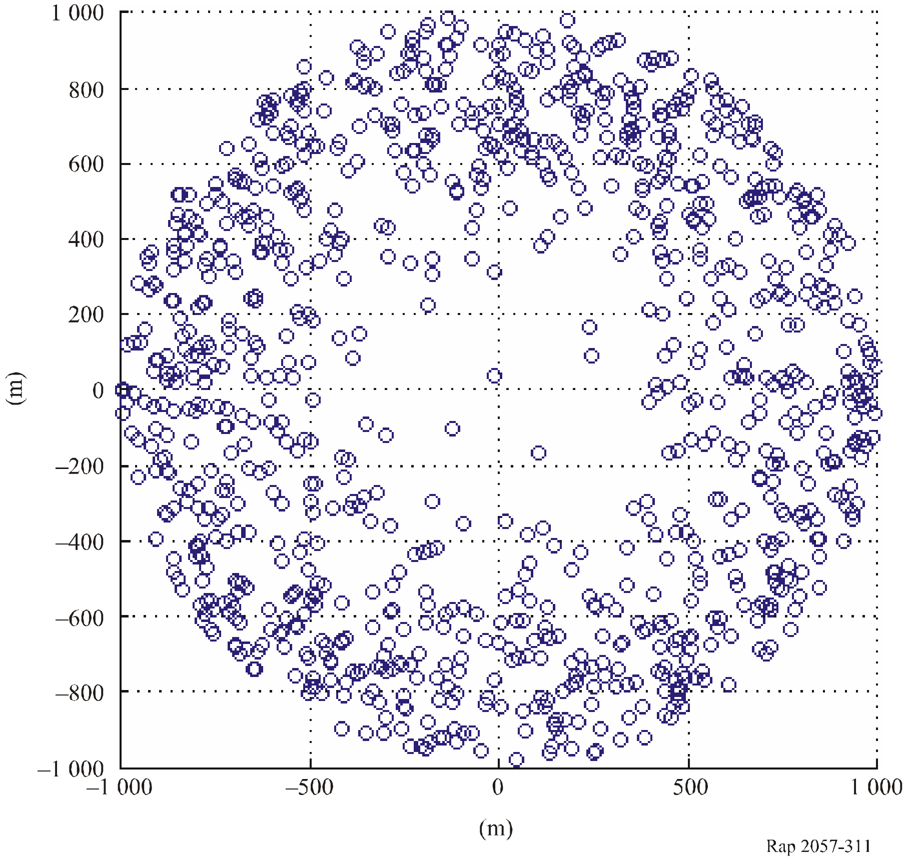


FIGURE 312

Aggregate UWB interference into outdoor LVHF DTV, range 1 000 m

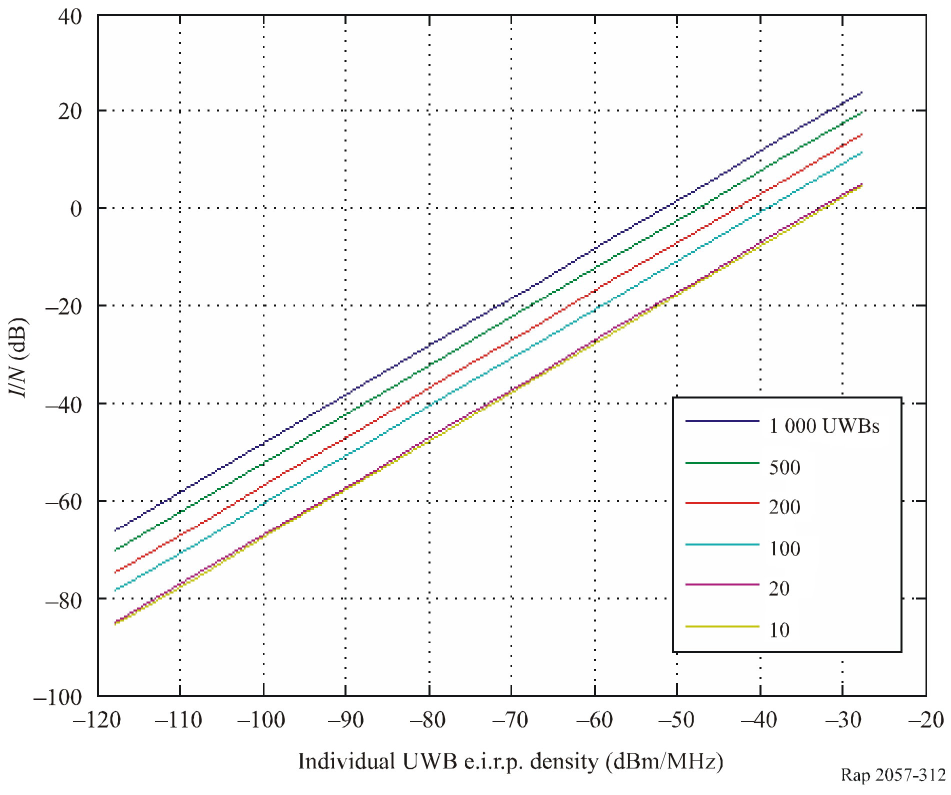


FIGURE 313

Aggregate UWB interference into outdoor HVHF DTV, range 1 000 m

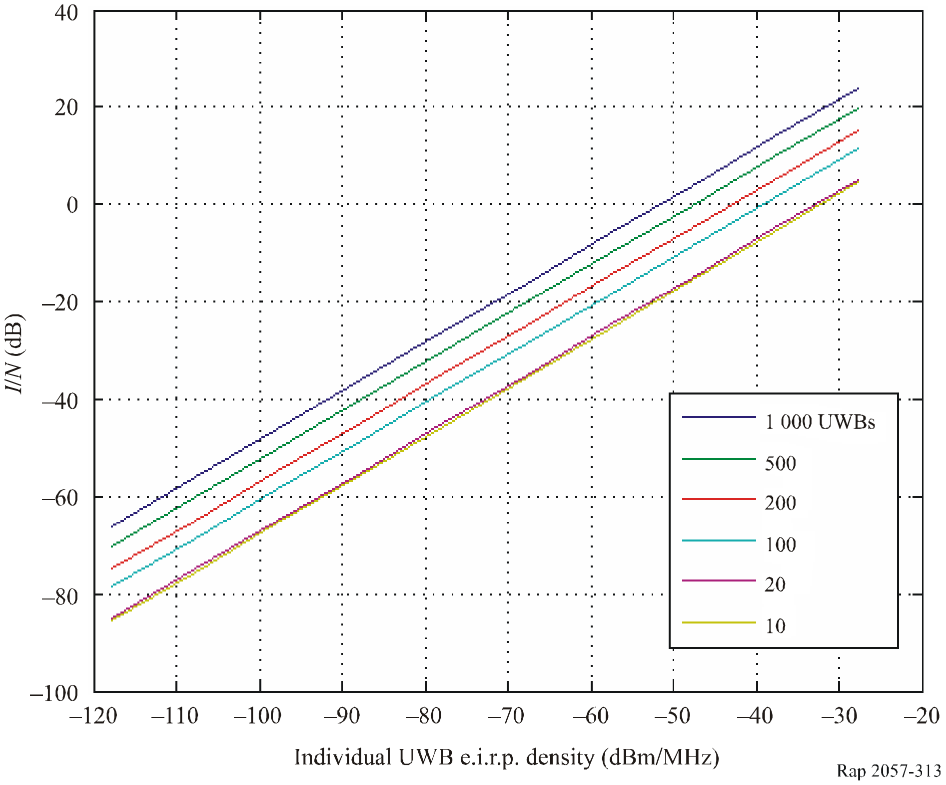


FIGURE 314

Aggregate UWB interference into outdoor UHF DTV, range 1 000 m

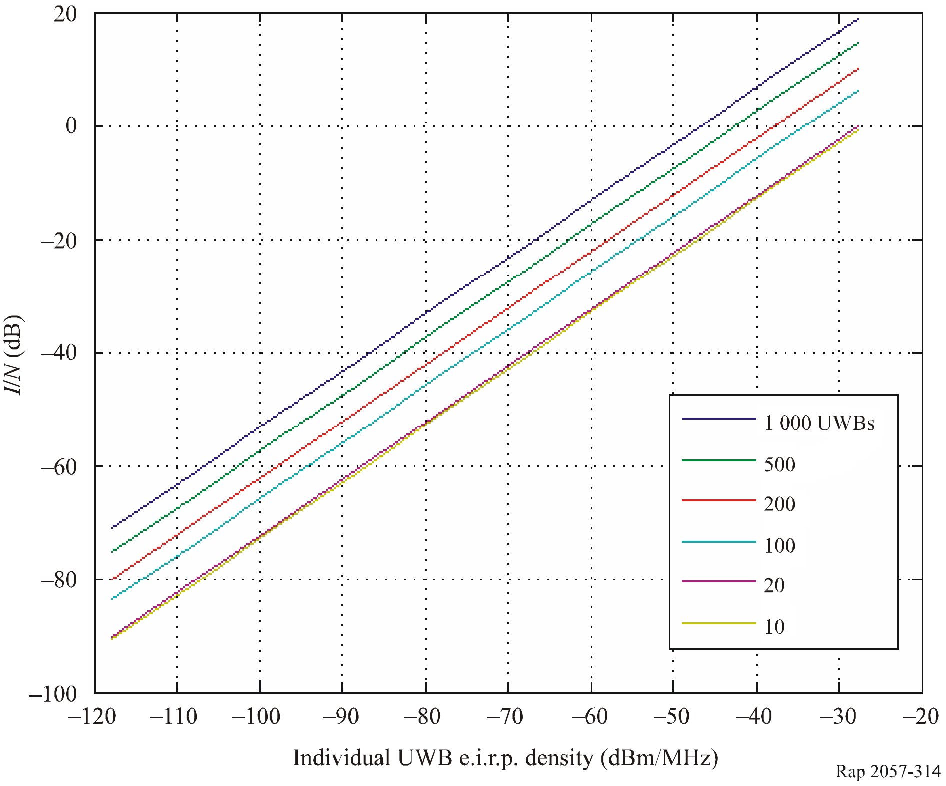


TABLE 206

UWB e.i.r.p. density limit (dBm/MHz) resulting in an *I*/*N* = –20 dB, aggregate

			Number of UWB devices					
			1 000	**500**	**200**	**100**	**20**	**10**
Band	**Range (m)**	**Distribution**						
LVHF	**5 000**	**Uniform**	–96	–93	–88	–83	–76	–74
		Normal	–103	–99	–95	–93	–87	–84
		Inverse normal	–59	–57	–53	–51	–45	–44
	1 000	**Uniform**	–104	–100	–97	–93	–86	–84
		Normal	–108	–105	–102	–98	–90	–89
		Inverse normal	–81	–77	–72	–68	–62	–61
HVHF	**5 000**	**Uniform**	–88	–85	–81	–74	–68	–66
		Normal	–94	–91	–87	–84	–78	–77
		Inverse normal	–51	–47	–44	–42	–36	–35
	1 000	**Uniform**	–95	–91	–88	–85	–78	–76
		Normal	–100	–98	–94	–90	–83	–81
		Inverse normal	–72	–68	–64	–59	–53	–52
UHF	**5 000**	**Uniform**	–83	–79	–76	–69	–63	–61
		Normal	–88	–86	–82	–79	–73	–72
		Inverse normal	–46	–43	–39	–37	–31	–30
	1 000	**Uniform**	–90	–87	–83	–79	–73	–71
		Normal	–95	–92	–88	–85	–78	–76
		Inverse normal	–67	–63	–58	–55	–48	–47

TABLE 207

The worst case UWB e.i.r.p. density limit required to protect the ATSC DTV receiver from aggregate interference

Band	UWB e.i.r.p. density limit (dBm/MHz)
Low VHF	–108
High VHF	–100
UHF	–95

TABLE 208

UWB e.i.r.p. density limit required to protect the ATSC DTV receiver from aggregate interference using assumptions accepted for other services

Band	UWB e.i.r.p. density limit (dBm/MHz)
Low VHF	–91
High VHF	–84
UHF	–78

1.4.7 Conclusions

The resulting UWB e.i.r.p. density limit required not exceeding the protection criteria of, I/N = – 20 dB, is dependent upon several variables and assumptions.

The worst single entry case is the indoor installation low VHF example where the UWB e.i.r.p. density limit would have to be –121.94 dBm/MHz. The single entry scenario is much worse in the case of an indoor installation because a UWB device can be located so closely to a victim ATSC DTV receiver and can directly affect the TV performance.

The worst aggregate case examined is the scenario where 1 000 UWB devices are normally distributed about a victim VHF ATSC DTV receiver out to a range of 1 000 m radius. In this case, the e.i.r.p. density limit for each UWB device is –108 dBm/MHz.

In the aggregate examples, the UWB e.i.r.p. density limit increases as the frequency increases, i.e., the band changes from low to high VHF and then to UHF. This is true due to the additional loss experienced at the higher frequencies of the TV band. The e.i.r.p. density limit would increase if the UWB devices were required to be positioned further away from the victim receiver. The e.i.r.p. limit would also increase if the density of simultaneously active UWB devices were limited.

It is noted that the results presented here are not the statistically worst case scenario but are the medium impact results obtained from repeating the analysis 500 times. As an agreement is formed and a convergence on the assumptions occurs for actual UWB deployments, a definite UWB e.i.r.p. density limit can be determined that would prevent a violation of the protection criteria of, I/N = –20 dB, stated for the ATSC DTV service.

1.5 ISDB-T system

1.5.1 Application system description

ISDB-T system has been designed to have enough flexibility to send not only television or sound programmes as digital signals but also offer multimedia services in which a variety of digital information such as video, sound, text and computer programmes will be integrated. ISDB-T provides flexible multi-program editing for different receiving conditions by hierarchical transmission in a transmission channel, which is composed of OFDM-segments in which transmission parameters can be independent of each other.

Each segment can have its individual error protection scheme and/or type of modulation (DQPSK, QPSK, 16-QAM or 64-QAM). Each segment can then meet requirements of service integrated, and a number of segments may be combined flexibly to integrate a wide-band service (HDTV for example).

1.5.2 Conclusions

An UWB e.i.r.p. limit has been calculated using the information in § 1.5.3 to guarantee the protection of the ISDB-T system in the presence of UWB emissions. This limit is:

– –114.7 dBm/MHz (e.i.r.p.) in the VHF band (at 200 MHz)

– –106.1 dBm/MHz (e.i.r.p.) in the UHF band (at 600 MHz).

1.5.3 Further information about the calculation for protection of the ISDB-T system

The purpose of this section is to provide more information to analyse the protection of ISDB-T system from the interference by the UWB devices.

For this study, the following assumptions were made:

– Free-space loss propagation model was used.

– Protection criterion (*I*/*N*) of –20 dB.

– Deterministic methodology.

– Maximum average allowable power for UWB device.

– Interference power aggregating from multiple devices was assumed additive.

– The receiver noise temperature is 290 K.

– The receiver noise figure was 3 dB in VHF and UHF band.

– Protection distance was 0.5 m or 3 m.

Based on the above assumption and the result of the maximum permissible interference analysis, the required UWB e.i.r.p. emission limit to guarantee the protection of the ISDB-T system is driven as shown in Table 209.

TABLE 209

Protection requirements of ISDB-T system from interference by UWB devices

Parameter	ISDB-T requirement			
Band	VHF		UHF	
Representative frequency	200 MHz		600 MHz	
Temperature	290 K		290 K	
Receiver noise figure	3 dB		3 dB	
Receiver noise power in 1 MHz band	–111.0 dBm/MHz		–111.0 dBm/MHz	
Urban noise	1.0 dB		–	
Receiver noise power + Urban noise	–110.0 dBm/MHz		–111.0 dBm/MHz	
Interference criterion (*I*/*N*)	–20.0 dB		–20.0 dB	
Maximum allowed interfering signal	–130.0 dBm/MHz		–131.0 dBm/MHz	
Reception type	Mobile/portable	Fixed	Mobile/portable	Fixed
Propagation distance	0.5 m	3 m	0.5 m	3 m
Propagation loss	12.4 dB	28.0 dB	22.0 dB	37.5 dB
Antenna gain	–0.85 dB	7.15 dB	–0.85 dB	12.15 dB
Feeder loss	2 dB	3 dB	2 dB	3 dB
UWB e.i.r.p. emission limit (1 devices)	–114.7 dBm/MHz	–106.1 dBm/MHz	–106.1 dBm/MHz	–102.6 dBm/MHz
UWB e.i.r.p. emission limit (2 devices)	–117.7 dBm/MHz	–109.1 dBm/MHz	–109.1 dBm/MHz	–105.6 dBm/MHz
UWB e.i.r.p. emission limit (4 devices)	–120.7 dBm/MHz	–112.1 dBm/MHz	–112.1 dBm/MHz	–108.6 dBm/MHz

1.6 Analogue television broadcasting

1.6.1 Introduction

Recommendation ITU-R BT.417 – Minimum field strengths for which protection may be sought in planning an analogue terrestrial television service recommends the minimum field strengths across the analogue television service bands. The median field strength for which protection against interference should not be lower than:

TABLE 210

Minimum field strengths for protection against interference (Recommendation ITU-R BT.417)

Band	I	III	IV	V
Frequency range (MHz)	41-68	162-230	470-582	582-960
Minimum field strength (dBμV/m)	+48	+55	+65	+70

Table 210 assumes that in the absence of interference from other television transmissions and man-made noise, the minimum field strengths at the receiving antenna will give a satisfactory grade of picture taking into consideration receiver noise, cosmic noise, antenna gain and feeder loss. The values refer to the field strength at a height of 10 m above ground level.

Table 211 tabulates the appropriate median field strength for rural districts having a low population density in the absence of interference other than noise.

TABLE 211

Minimum field strengths for rural districts (Rec. ITU-R BT.417)

Band	**I**	**III**	**IV**	**V**
Frequency range (MHz)	41-68	162-230	470-582	582-960
Minimum field strength (dBμV/m)	+46	+49	+58	+64

These recommended field strengths are comparable to those adopted by the United States, Canada, and Mexico for "acceptable" quality in typical outlying or near-fringe areas as tabulated in Table 212 [O'Connor, 2001].

TABLE 212

United States/Canada/Mexico minimum field strength requirements for analogue television reception in outlying or near-fringe areas

Band	**Low VHF**	**High VHF**	**UHF**
Frequency range	54-88 MHz	174-216 MHz	470-806 MHz
Minimum field strength (dBμV/m)	+47	+56	+64

1.6.2 Assessment of the impact of UWB systems on analogue television

The following calculations estimate the maximum allowable field strength for UWB emission, if permitted across the VHF and UHF analogue television bands. The calculations include both cases:

1 a single indoor UWB device 0.5 m distant to a portable or indoor analogue TV using an indoor antenna;

2 a single UWB device outdoors at a 3 m separation from an outdoor analogue TV antenna.

TABLE 213

Calculation worksheet to determine the maximum UWB e.i.r.p. for a single interferer into an analogue television receiver

	Low VHF	**High VHF**	**UHF**	**Unit**	**Notes**
Required minimum field strength	+47	+56	+64	dBμV/m	Based on FCC F (50,50) contour at 9.1 m
Frequency	69	195	615	MHz	
Available analogue TV isotropic power at receiver antenna	–62.0	–62.0	–64.0	dBm	

TABLE 213 (*end*)

	Low VHF	High VHF	UHF	Unit	Notes
Analogue TV minimum SNR	30	30	30	dB	Required for Grade 3 quality "slightly annoying" per Recommendation ITU-R BT.500
Effective analogue TV noise floor at receiver antenna	–92.0	–92.0	–94.0	dBm	
Analogue TV bandwidth	4	4	4	MHz	NTSC video bandwidth
I/*N* for UWB interference	–20	–20	–20	dB	Recommendation ITU-R S.1432
Allowable UWB interference at TV receiver antenna	–118.0	–118.1	–120.0	dBm/MHz	
Outdoor separation distance	3	3	3	m	
Free space path loss at outdoor 3 m separation distance	18.7	27.8	37.7	dB	Per Recommendation ITU-R PN.525
Outdoor UWB allowed output power density at 3 m	–99.3	–90.3	–82.3	dBm/MHz	
Indoor separation distance	0.5	0.5	0.5	m	
Free space path loss at indoor 0.5 m separation distance	3.2	12.2	22.2	dB	Per Recommendation ITU-R PN.525
Indoor UWB allowed output power density at 0.5 m	–114.8	–105.8	–97.8	dBm/MHz	

1.6.3 Conclusion

The worst single entry case is the indoor installation in the low VHF band where the UWB e.i.r.p. density limit would have to be –114.8 dBm/MHz. The single entry scenario is much worse in the case of an indoor installation because a UWB device can be located so closely to a victim analogue television receiver and can directly affect the TV performance. The worst single entry case for an outdoor installation with a 3 m separation is also in the low VHF band where the UWB e.i.r.p. density limit would have to be –99.3 dBm/MHz.

On the basis of the results, a single generic UWB e.i.r.p. density limit can be defined to ensure the protection of analogue TV, in both indoor and outdoor environments:

– –114.8 dBm/MHz (e.i.r.p.) in the low VHF band (54-88 MHz)

– –105.8 dBm/MHz (e.i.r.p.) in the high VHF band (174-216 MHz)

– –97.8 dBm/MHz (e.i.r.p.) in the UHF band (470-806 MHz).

2 Impact of devices using UWB technology on satellite broadcasting systems

Summary

The BSS is now in service in some parts of the world with millions of users and similar satellite broadcasting systems are under development. Receivers for these satellite digital broadcasting services are very sensitive and often employ near omnidirectional antennas operating with small transmission link margins. Such receivers for these satellite digital broadcasting services are, and will be, located in moving vehicles, on highways, in residential areas and in office buildings, and, thus,

may be in very close proximity to devices using UWB technology; particularly those in high density UWB areas, in vehicles, in hand held use, and in indoor systems. Coordination of interference between these devices will not be possible.

With regard to protection criteria, an appropriate interference protection criterion for the protection of the BSS in all cases under consideration is an aggregate interference value of $\Delta T/T$ of 1%, applicable to all interference sources not having primary status in the band. This criterion is identical to the value of 1% contained in Recommendation ITU-R S.1432, which is applicable to the feeder links associated with the BSS downlink. BSS characteristics for various frequency bands are listed in Table 214 to Table 218.

TABLE 214

Typical BSS (television) parameters in the 620-790 MHz band

Parameter	Typical value						
Range of operating frequencies	620-790 MHz						
Earth station off-axis gain towards the local horizon (dBi)(1)	Elevation angle(2)	5°	10°	20°	30°	48°	>85°
	Off-axis gain	19.4	19.0	11.5	7.1	2.0	–4.2
Earth station off-axis gain towards the local horizon (dBi)(3)	2.0 dBi for all elevation angles						
Range of emission bandwidths	8 to 170 MHz						
Noise temperature of Earth station receiver	100 K						
Earth station deployment	All Regions, in all locations (rural, semi-urban, urban)(4)						

(1) The antenna represented in this row has a directional beam. The values were derived by assuming a local horizon at 0° of elevation.

(2) 5° is considered as the minimum operational elevation angle.

(3) The antenna represented in this row is omnidirectional. The values were derived by assuming a local horizon at 0° of elevation.

(4) Mobile (vehicular) reception, portable and fixed reception.

TABLE 215

Typical BSS (sound) parameters

Parameter	Typical value
Range of operating frequencies(1)	1 452-1 492 MHz, 2 310-2 360 MHz, 2 535-2 655 MHz
Earth station off-axis gain towards the local horizon (dBi)(2)	5 dBi for all elevation angles
Range of emission bandwidths(1)	40 kHz – 25 MHz
Noise temperature of Earth station receiver	100 K
Earth station deployment	All Regions, in all locations (rural, semi-urban, urban)(3)

(1) See RR for details on the frequency allocations.

(2) The values were derived by assuming an omnidirectional antenna.

(3) BSS antennas in this band may be deployed in a variety of applications (mobile (vehicular) reception, portable and fixed reception). See the relevant footnotes in the RR for specific usage in each band.

TABLE 216

Typical BSS (television) parameters in the 2 520-2 670 MHz band(1)

Parameter	Typical value						
Range of operating frequencies	2 520-2 670 MHz						
Earth station off-axis gain towards the local horizon (dBi) (2)	Elevation angle(3)	5°	10°	20°	30°	48°	>85°
	Off-axis gain	22	21	19	10	3	0
Range of emission bandwidths	22 MHz – 27 MHz						
Noise temperature of Earth station receiver	100 K						
Earth station deployment	All Regions, in all locations (rural, semi-urban, urban)4						

(1) BSS Community reception, in accordance with RR No. 5.416.

(2) The values were derived by assuming a local horizon at 0° of elevation.

(3) 5° is considered as the minimum operational elevation angle.

(4) BSS antennas in this band may be deployed in a variety of applications, including at fixed locations and in mobile applications.

TABLE 217

Typical BSS (television) parameters in the 12 GHz band

Parameter	Typical value					
Range of operating frequencies	11.7-12.5 GHz (R1),12.2-12.7 GHz (R2),11.7-12.2 GHz and 12.5-12.75 GHz (R3)					
Earth station off-axis gain towards the local horizon (dBi)(1) (D = 60 cm)	Elevation angle(2)	5°	10°	20°	30-70°	>70°
	Off-axis gain	11.5	4.0	–3.5	–5.0	0.0
Range of emission bandwidths	24 MHz (R2) or 27 MHz (R1, R3)					
Noise temperature of Earth station receiver	110 K					
Earth station deployment(3)	All Regions, in all locations (rural, semi-urban, urban)					

(1) The values were derived by assuming a local horizon elevation angle of 0° and an antenna pattern as described in Recommendation ITU-R BO.1213.

(2) 5° is considered as the minimum operational elevation angle.

(3) BSS antennas in these bands can be deployed in urban, sub-urban, rural and remote environments. BSS individual reception antennas are commonly deployed near the ground, on roofs and chimneys of individual dwellings and on balconies of multiple dwellings (apartments). Community reception antennas are typically deployed on the ground or roofs of multiple dwelling units (apartments).

TABLE 218

Typical BSS (television) parameters in the 17/21 GHz band

Parameter	Typical value						
Range of operating frequencies	17.3-17.8 GHz (R2), 21.4-22 GHz (R1, R3)						
Earth station off-axis gain towards the local horizon (dBi)(1) (*D* = 45 cm)	Elevation angle(2)	5°	10°	20°	30°	40°	>70°
	Off-axis gain	11.5	4.0	–3.5	–5.0	–5.0	0.0
Range of emission bandwidths	27-600 MHz						
Noise temperature of Earth station receiver	160 K						
Earth station deployment	In all locations within the relevant Regions (rural, semi-urban, urban)						

(1) The values were derived by assuming a local horizon elevation angle of 0° and an antenna pattern as described in Recommendation ITU-R BO.1213.

(2) 5° is considered as the minimum operational elevation angle.

2.1 Satellite broadcasting service in the bands 1 452-1 492 MHz and 2 320-2 345 MHz

2.1.1 Introduction

The purpose of this study is to analyse the potential interference effect of devices using UWB technology on satellite radio automobile and home receivers based on the emission limits set forth by the Federal Communications Commission (FCC) in ET Docket 98-153, now referred to the United States mask. The analysis is performed for the two United States operating satellite radio systems utilizing the 2 320-2 345 MHz band. Mexico has allocated this band for a future satellite radio system and both Mexico and Canada have allocated the band 1 452-1 492 MHz for future satellite radio systems. The analysis at 2 320-2 345 MHz is believed to be applicable to a satellite radio system at 1 452-1 492 MHz.

For this study, the following assumptions were made:

– Free-space loss propagation model was used. Radiocommuniation SG 3 was requested to provide advice on appropriate propagation models for pulsed short-range UWB emissions for both outdoor and indoor environments.

– Protection criterion (I/N) of –20 dB.

– Deterministic methodology.

– Maximum average allowable power for UWB device.

– Interference power aggregating from multiple devices was assumed additive.

– The total receiver noise temperature is 158 K, for a total receiver noise power figure in 4.2 MHz of –110.4 dBm.

2.1.2 Scope

Satellite radio was licensed by the FCC in 1997 to operate satellite digital audio radio service (SDARS) systems in the frequency band 2 320-2 345 MHz. The allowable electronic emissions of various UWB devices as promulgated by the FCC in ET Docket 98-153 in 2002 have the potential of interfering with the performance of SDARS automobile and home receivers. Tables 219-222 present an analysis of the effect of various UWB devices based on the interference susceptibility of SDARS radios[59] and the emission limits established by the United States.

The primary concern is with the prospective interference of certain United States defined categories of UWB systems, particularly "Indoor communication", "Hand-held" and "Surveillance" because the practical use of these devices poses a probability of degrading the quality of service to SDARS subscribers. The other categories of UWB systems do not currently appear to present interference as a result of their specific application and proposed implementation.

2.1.2.1 Indoor communication UWB systems

The practical use of indoor communication UWB systems presents a potential interference risk to home SDARS systems as demonstrated in Table 219, resulting primarily from the probable proximity of the two systems. The United States has established an UWB OoB emission limit of –51.3 dBm/MHz in the frequency band of 1 990-3 100 MHz which includes the SDARS operating band; thus resulting in a probability of interference should the UWB device emissions approach the specified limits. It is believed that the likelihood of interference will be imminent, as the indoor scenario does not permit large separation distance between these systems.

2.1.2.2 Hand-held UWB systems

The hand-held UWB devices that are primarily intended to operate in a peer-to-peer mode without restriction on location is of concern to SDARS as this application poses an interference risk as is evident in Table 220. The United States has established an UWB OoB emission limit of −61.3 dBm/MHz in the frequency band of 1 990-3 100 MHz which includes the SDARS operating band; thus resulting in a probability of interference should the UWB device emissions approach the specified limits.

In addition, the likelihood of multiple hand-held UWB units operating in the immediate vicinity of a SDARS receiver compounds the interference issue. The unrestricted use and the potential high numbers of these units in the open market further exacerbate these concerns.

2.1.2.3 Surveillance devices

The surveillance UWB devices create a potential interference risk to SDARS receivers as the operating band (1 990-10 600 MHz) for these devices directly overlaps the satellite radio operating band (2 320-2 345 MHz) with United States established UWB emission limits –41.3 dBm/MHz. Table 221 demonstrates the level of potential interference and the large separation distance that would be required to overcome it. It is evident that, at the existing United States emission limit, the potential for interference from an UWB surveillance device to SDARS receivers is very high.

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[59] SDARS receivers typically have a G/T of −19 dB/K. Over half a million are currently operating throughout the United States and a high growth rate is anticipated.

2.1.3 Summary of studies

TABLE 219

SDARS requirements vs. Indoor UWB systems

SDARS centre frequency: 2 332 MHz
UWB device operating frequency band: 3.1 GHz to 10.6 GHz
Typical uses: Medical imaging, communication (high-speed networks) and measurement systems

Parameter	SDARS requirement	Initial assumptions for the studies: United States UWB emission limit at 1 990-3 100 MHz
Received power	–99.5 dBm	
Receiver noise power	–110.4 dBm/4.2 MHz	
Receiver noise power in 1 MHz band	–116.6 dBm/MHz	
Interference criterion (*I*/*N*)	–20.0 dB	1% allowed interference
Maximum allowed interfering signal	–136.6 dBm/MHz	
Propagation loss at 3 m	49.3 dB	
Multiple device allowance (2 devices)	–3.0 dB	
RFI emission from UWB device	–90.3 dBm/MHz	–51.3 dBm/MHz

TABLE 220

SDARS requirements vs. Hand-held UWB systems

SDARS centre frequency: 2 332 MHz
UWB device operating frequency band: 3.1 GHz to 10.6 GHz
Typical uses: Communication systems in/out doors, high-speed networks

Parameter	SDARS requirement	Initial assumptions for the studies: United States UWB emission limit at 1 990-3 100 MHz
Received power	–99.5 dBm	
Receiver noise power	–110.4 dBm/4.2 MHz	
Receiver noise power in 1 MHz band	–116.6 dBm/MHz	
Interference criterion	–20.0 dB	1% allowed interference
Maximum allowed interfering signal	–136.6 dBm/MHz	
Propagation loss at 3 m	49.3 dB	
Multiple device allowance (4 devices)	–6.0 dB	
RFI emission from UWB device	–93.3 dBm/MHz	–61.3 dBm/MHz

TABLE 221

SDARS requirements vs. UWB mid-frequency surveillance devices

SDARS centre frequency: 2 332 MHz
UWB device operating frequency band: 1.99 GHz to 10.6 GHz
Typical uses: Through-wall imaging and surveillance (limited to law enforcement), public utilities, public safety and commercial use

Parameter	SDARS requirement	Initial assumptions for the studies: United States UWB emission limit at 1 990-10 600 MHz
Received power	–99.5 dBm	
Receiver noise power	–110.4 dBm/4.2 MHz	
Receiver noise power in 1 MHz band	–116.6 dBm/MHz	
Interference criterion	–20.0 dB	1% allowed interference
Maximum allowed interfering signal	–136.6 dBm/MHz	
Propagation loss at 3 m	49.3 dB	
Multiple device allowance (4 devices)	–6.0 dB	
RFI emission from UWB device	–93.3 dBm/MHz	–41.3 dBm/MHz

2.1.4 Conclusion

The results of the studies show that, in order to protect the SDARS operating frequency bands from emission interference from the aforementioned UWB devices and to assure high quality of satellite radio service, the UWB emission band limits should be as follows:

Indoor communication UWB systems

UWB emission limit from 1 452 to 1 492 and from 2 320 to 2 345 MHz: −90.3 dBm/MHz.

Hand-held UWB systems

UWB emission limit from 1 452 to 1 492 and from 2 320 to 2 345 MHz: −93.3 dBm/MHz.

Surveillance devices

UWB emission limit from 1 452 to 1 492 and from 2 320 to 2 345 MHz: −93.3 dBm/MHz.

The above analyses are based on average power density emission in response to the U.S. specifications. However, peak power emissions from UWB systems could result in higher interference to SDARS systems depending on the UWB device’s specific pulse repetition frequency.

Table 222 highlights the UWB emission limits that should be considered in order to ensure compatible operation between UWB devices and satellite broadcasting services in the bands 1 452-1 492 MHz and 2 320-2 345 MHz.

TABLE 222

Maximum average power density of aggregate interference (dBm/MHz)

	Bands 1 452-1 492 MHz	Bands 2 320-2 345 MHz	Remarks
UWB separation	3 m	3 m	
Indoor UWB	−90.3 dBm/MHz	−90.3 dBm/MHz	2 UWB interferers
Hand-held UWB	−93.3 dBm/MHz	−93.3 dBm/MHz	4 UWB interferers
Surveillance UWB	−93.3 dBm/MHz	−93.3 dBm/MHz	4 UWB interferers

2.2 BSS(S) satellite system in the band 1 467-1 492 MHz

This study gives some elements for consideration in the assessment of suitable e.i.r.p. limits applicable to indoor UWB devices, for the protection of the reception of handheld terminals of a broadcasting satellite systems in the band 1 467-1 492 MHz.

The protection of BSS(S) systems in the band 1 467-1 492 MHz by UWB systems has not been fully taken into account Radiocommunication TG 1/8 as limits in this band are derived from BSS(S) systems in the 2 320-2 345 MHz band. Generic characteristics of a BSS(S) system to be considered in sharing studies in this band are listed below:

TABLE 223

Generic characteristics of a BSS(S) system in the band 1 467-1 492 MHz

System	E-SDR
Bandwidth per carrier	5 MHz
G/*T*	–24.6 dB/K
Receiver antenna height	1.5 m
Protection criteria	See below

Concerning adequate protection criteria, Radiocommunication SG 6 has stipulated that the value of 1% temperature degradation (*I*/*N* of –20 dB) should be used for both single-entry and aggregate interference analysis. Different interference scenarios have been considered for assessing interference. Results are listed below, considering free space loss propagation in an indoor environment:

TABLE 224

Results of the impact study for the band 1 467-1 492 MHz

Minimum distance (m)	Number of interferers	Maximum e.i.r.p. density (dBm/MHz)	
		I/*N* = –20 dB	
0.5	1	–104.2	
1	1	–98.2	
	3	–102.9	
3	3	–93.4	
10	3	–82.9	
	10	–88.2	

Table 224 shows that in the case of single entry interference, minimum separation distance of about 50 cm leads to a maximum e.i.r.p. less than about –104.2 dBm/MHz for the 10% degradation criteria, which is 19.2 dB below the value needed for the protection of T-DAB in the band (-85 dBm/MHz).

In the case of multiple entry interference, minimum separation distance of 3 m, when considering three potential interferers leads to a value of about –93.4 dBm/MHz for the 1% degradation criteria.

2.3 Satellite broadcasting service using code division multiplexing technology in the band 2 605-2 655 MHz[60]

2.3.1 Introduction

The purpose of this section is to analyse the potential interference effect of devices using UWB technology on satellite digital multimedia broadcasting (SDMB) radio receiver which uses code division multiplexing technology in the band 2 605-2 655 MHz.

2.3.2 Power received by an SDMB receiver

The e.i.r.p. of SDMB transmitter is required to be 67 dBW or more in the service coverage. The channel is theoretically 64 as the system uses 64-Walsh code. In this proposal, 30 channels are assumed for stable reception for multi-path environment. This leads the e.i.r.p. per channel ($e.i.r.p._{CH}$) to 52.29 dBW. The distance between transmitter and the receiver is assumed 38 000 km. Then the path loss would be 192.46 dB when the free space model is considered. The sum of other loss such as pointing losses, polarization loss, atmospheric absorption loss is assumed to be 0.53 dB. Then, the resultant receiving power, $P_{r,CH}$, at the receiver would be −110 dBm.

2.3.3 Noise spectral density (N_0)

Let the noise temperature of the receiving antenna, T_a, be 150 K or less for the automobile receiver. This leads to the total noise temperature (T_s) of the receiver to $T_s = T_a + T_{cas} = 150 + 290(10^{0.150.3} - 1) = 269.6438.6$ K, where T_{cas} represents the internal noise temperature of receiver assuming the noise figure is 15.3 dB. With the receiver antenna gain, G_r, 2.5 dBi, we can get $G_r/T_s = -21.81$ dB/K.

[60] This study should be redone with a *I*/*N* of –20 dB, in accordance with the criteria from Radiocommunication Study Group 6 for BSS.

2.3.4 Impact of single UWB interferer

To examine the effect of UWB interference to the SDMB system, the following assumptions are made; within the bandwidth of the SDMB system, UWB interference resembles white Gaussian noise and its path loss follows the free space model.

In this case, the PSD of UWB interference at the victim receiver, S_{uwb}, can be calculated by:

$$S_{uwb} = E_{uwb} - L_{uwb} + G_r$$
$$= E_{uwb} - 40.87 - 20 \log(d) + 2.5 \text{ dBi}$$

where:

- d: distance between the UWB device and the receiver
- E_{uwb}: UWB emission level
- L_{uwb}: path loss
- G_r: the receiver gain.

Now

$$\left(\frac{I}{N}\right)_{\text{dB}} = \left(\frac{S_{uwb}}{k\ T_s}\right)_{\text{db}} \cong E_{uwb} + 76 - 20\ \log d$$

For a case of protection distance d = 3 m, this equation can be tabulated by the Table 225.

TABLE 225

Parameter	Value	Unit
Antenna noise temperature	150.0	K
Noise figure	3.0	dB
Noise temperature	438.6	K
Noise spectral density (N_0)	–172.2	dBm/Hz
Interference criterion($I/N = I_0/N_0$)	–20.0	dB
Maximum allowable interference	–132.2	dBm/MHz
Distance	3.0	m
Propagation loss with free space model	50.3	dB
UWB emission limit	–81.9	dBm/MHz

The UWB emission limit that can protect the SDMB at d = 3 m is −81 dBm/MHz, which is approximately 20 dB lower than the United States limit (outdoor) of –61.3 dBm/MHz. Note that if UWB emits at the United States limit, it should be separated by 178 m. When the number of allowable interferer is 2 and 4 in the same distance, the UWB emission limit becomes –84 dBm/MHz and –87 dBm/MHz, respectively.

2.3.5 Impact of aggregate UWB interferers

The aggregate effect of UWB interferences is considered by including log-normal fading term in S_{uwb}, that is,

$$S_{UWB} = E_{UWB} - L_{UWB} + G_r + G(\sigma)$$

where $G(\sigma)$ is Gaussian distribution with standard deviation σ. This is added to reflect slow fading effect. Normally, σ ranges 3~9 dB in wireless channel. Some manipulation leads to

$$S_{UWB} = E_{UWB} - (20 \log (4\pi/\lambda) + 20 \log d_i) + 2.5 \text{ dBi} + G(\sigma)$$

where d_i is the distance between the *i*-th UWB device and the receiver. In order to draw out the UWB emission level, the following channel environment was assumed; the victim receiver is positioned at origin and M UWB interferers are uniformly distributed within an area of 1 km^2, centered at origin, and activity factor of UWB transmitters was 5% and log-normal fading standard deviation σ was 5 dB.

At each trial, it is judged that interference has occurred if $(I/N)_{dB}$ is larger than –20 dB. The UWB emission limit was determined at the point where the probability of interference reaches 1%. Table 226 is the simulation results.

TABLE 226

Aggregate interferences

Density of UWB transmitters ($/km^2$)	Activity factor (%)	Required UWB e.i.r.p. density limit (dBm/MHz)
100	5	–88
1 000	5	–94
10 000	5	–100

2.3.6 Conclusion

UWB interference to a SDMB receiver operated in the frequency band of 2 605 to 2 655 MHz has been investigated with the criteria $(I/N) = -20$ dB. To protect the SDMB apart from a single UWB interferer by $d = 3$ m, which was chosen as typical protection distance, UWB e.i.r.p. density emission limit was –81.9 dBm/MHz, which is approximately 20 dB lower than the United States emission limit. The minimum separation distance associated with United States emission limit was 178 m. In aggregate case, Monte Carlo method was used under the deployment scenario 1 of Recommendation ITU-R SM.1757 that assumes 100 UWB transmitters within 1 km^2 5% activity factor. The result shows that the required UWB e.i.r.p. limit should be –88 dBm/MHz.

2.4 Satellite broadcasting services in the bands 1 452-1 492 MHz, 2 310-2 360 MHz and 2 535-2 655 MHz

For this study, the following assumptions were made:

– Free-space loss propagation model was used. Radiocommunication SG 3 was requested to provide advice on appropriate propagation models for pulsed short-range UWB emissions for both outdoor and indoor environments.

– Separation distance of 36[61] cm.

[61] Separation distance of 36 cm is compatible with the one used for the impact study into GSO MSS in the 2.2 GHz band (Annex 1 of preliminary draft new Recommendation ITU-R SM.1757 (Annex 2 of Document 1-8/347) and § 7 of Report ITU-R SM.2057 (Annex 5 of Document 1-8/347)). The operational scenario of 2.6 GHz BSS (sound) earth stations will be similar to that of GSO MSS in the 2.2 GHz band (this system is called as S-DMB).

– Deterministic methodology.

– Interference power aggregating from multiple devices was assumed additive.

Based on the above assumptions and the result of the maximum permissible interference analysis, the maximum permitted e.i.r.p. of the interference device is derived as shown in Tables 227, 228 and 229.

TABLE 227

Maximum permitted e.i.r.p. of the interfering UWB device proposed by Radiocommunication WP 6S for the band 1 452-1 492 MHz

Parameter	Value	Units
Max permissible interference level per MHz	–143.6	dBm/MHz
Propagation path loss	26.8	dB
Max permitted e.i.r.p. of the interfering device (aggregate value)	–116.8	dBm/MHz

TABLE 228

Maximum permitted e.i.r.p. of the interfering UWB device proposed by Radiocommunication WP 6S for the band 2 310-2 360 MHz

Parameter	Value	Units
Max permissible interference level per MHz	–143.6	dBm/MHz
Propagation path loss	30.9	dB
Max permitted e.i.r.p. of the interfering device (aggregate value)	–112.5	dBm/MHz

TABLE 229

Maximum permitted e.i.r.p. of the interfering UWB device proposed by Radiocommunication WP 6S for the band 2 535-2 655 MHz

Parameter	Value	Units
Max permissible interference level per MHz	–143.6	dBm/MHz
Propagation path loss	31.9	dB
Max permitted e.i.r.p. of the interfering device (aggregate value)	–111.7	dBm/MHz

In case that the multiple interfering devices exist near the receiving earth station, the average emission level from the interfering device should be lower than the values in these tables.

2.5 Satellite broadcasting service in the 12 GHz and 17 GHz range

A study was also received that applied the Integral methodology to the 12 GHz satellite downlink frequency band, which is allocated to FSS and BSS depending on the band segment and Region. Results for the suburban (50 active devices per km^2, 40m exclusion zone, 10 km study radius) and urban (500 active devices per km^2, 20 m exclusion zone, 5 km study radius) scenarios, with common parameters of 11.7 GHz frequency, 80/20% indoor/outdoor ratio, 90 K noise temperature, and 1% protection criterion, give maximum UWB device e.i.r.p. densities of –52.1 dBm/MHz and –62.1 dBm/MHz respectively.

However, the services that are typically deployed in the 12 GHz band (i.e. DTH or VSAT systems) employ earth station receive antennas that may be mounted on residences or other smaller buildings, where UWB devices may be deployed in close proximity to the antennas, and are thus likely more susceptible to single entry interference than to the aggregate interference computed with the Integral methodology. Thus these aggregate results are included here for information only but have not been validated by more realistic single entry studies that would likely indicate a requirement for lower UWB e.i.r.p. densities to protect the services.

This principle that single entry interference is likely more the determining factor than aggregate interference to determine the maximum UWB e.i.r.p. device density to protect a service is expected also to be true for the 17 GHz downlink band, which is allocated to BSS (17.3-17.8 GHz in Region 2) and FSS (17.3-17.7 GHz in Region 1). Further study is required for the 12 and 17 GHz satellite downlink bands.

Annex 6

Studies related to the impact of devices using ultra-wideband technology on systems operating within the Earth exploration satellite, space research service

1 Earth exploration-satellite service (EESS)

1.1 EESS (active) in the 5 GHz band

1.1.1 Spaceborne altimeter at 5 GHz

The first EESS (active) system that is considered is the Spaceborne Radar Altimeter which determines the height of the Earth’s land and ocean surfaces. The current spaceborne altimeter uses 320 MHz between 5 140 and 5 460 MHz. Such a bandwidth is essential to provide continuous measurements of the topography of the ocean surface with an unprecedented accuracy (1 to 2.5 cm).

The altitude of the satellite is 1 347 km, with a maximum antenna gain of 32.2 dBi, with $\theta_{-3\ dB}$ of 3.3° with side lobes at about 2.2 dBi (–30 dB). This satellite is a project between NASA and CNES. The altimeter interference threshold is –113 dBm/MHz.

Following the decisions taken at WRC-03, this band is extended up to 320 MHz from 5 250 MHz to 5 570 MHz.

In Table 230, two cases are considered: indoor use and outdoor use. For the case of indoor use, an average building attenuation of 17 dB towards EESS (active) instruments is used in the aggregate model only. The rationale for such a figure can be found in Recommendation ITU-R SA.1632 – Sharing in the band 5 250-5 350 MHz between the Earth exploration-satellite service (active) and wireless access systems (including radio local area networks) in the mobile service.

Table 230 summarizes the interference study.

TABLE 230

Interference analysis between UWB and EESS (active: spaceborne altimeter) at 5 GHz

Frequency	5 300	MHz
Wavelength	0.06	m
Indoor/outdoor attenuation in dB	17	dB
Distance UWB – Satellite receiver	1 347	km
Satellite antenna gain	32.2	dBi
Half antenna beamwidth	1.7	°
Maximum interference level	−113	dBm/MHz

Spaceborne radar altimeter

Parameter	United States mask limit outdoor	United States mask limit indoor
Maximum e.i.r.p. (e.i.r.p. density) of a single UWB device (dBm/MHz)	−41.3	−41.3
Distance UWB – Satellite receiver (km)	1 347	1 347
Space attenuation (dB)	169	169
Satellite antenna gain (dBi)	32.2	32.2
Received power at the EESS sensor in 1 MHz bandwidth in dBm (dBm/MHz)	−179	−179
Threshold in dBm in 1 MHz bandwidth (dBm/MHz)	−113.0	−113.0
Margin with a single UWB device (dB)	65.6	65.6
Activity factor (%)	5	5
% Outdoor	20	20
% Indoor	80	80
Indoor/outdoor attenuation (dB)	0	17
Half antenna beamwidth (degrees)	1.70	1.70
Size of the satellite footprint: radius (km) assuming a flat Earth (km)	40	40
Maximum UWB density/km^2 corresponding to the above EESS footprint (UWB/km^2)	14 381	720 318
Received power of a single UWB device at the EESS sensor in 1 MHz bandwidth (dBm) for both indoor and outdoor usage (dBm/MHz)	−185.23	
Maximum UWB density/km^2 corresponding to the above EESS footprint for both indoor and outdoor usage (UWB/km^2)	66 589	

Table 231 indicates the maximum required UWB e.i.r.p. density (dBm/MHz) according to the density of UWB transmitters/km^2.

TABLE 231

Summary of interference analysis between UWB and EESS (active) for space-borne radar altimeters at 5 GHz

Density of UWB transmitters/km^2	Maximum required UWB e.i.r.p. (both indoor and outdoor) density (dBm/MHz)
1	7
10	−3
100	−13
1 000	−23
10 000	−33

1.1.2 Synthetic aperture radar at 5 GHz

The second EESS (active) system that is considered is the synthetic aperture radar (SAR). Spaceborne SARs remote sensing technology make it possible to acquire global-scale data sets that provide unique information about the Earth's continually changing surface characteristics. A SAR mission is essential to routinely provide valuable information about the dynamic characteristics of our planet, along with broad scientific, environmental preservation, operational, and commercial utility.

The current EESS (active) allocation at 5 GHz is from 5 250 MHz to 5 460 MHz (210 MHz bandwidth). The altitude of the satellite is 400 km, with a maximum antenna gain of 42.7 dBi.

The SAR interference threshold is –115.3 dBm/MHz.

Following the decisions taken at WRC-03, this band is extended up to 320 MHz from 5 250 MHz to 5 570 MHz.

Table 232 two cases are considered: indoor use and outdoor use. For the case of indoor use, an average building attenuation of 17 dB towards EESS (active) instruments is used in the aggregate model only. The rationale for such a figure can be found in Recommendation ITU-R SA.1632.

Table 232 summarizes the interference study.

TABLE 232

Interference analysis between UWB and EESS (active: SAR) at 5 GHz

Frequency (MHz)	5 355
Wavelength (m)	0.06
Indoor/outdoor attenuation (dB)	17
Altitude of the satellite (km)	400
Satellite antenna gain (dBi)	42.7
Satellite nadir angle (degrees)	32.5
Maximum interference level (dBm/MHz)	−115.3

Synthetic aperture radar (SAR)

Parameter	United States mask limit outdoor	United States mask limit indoor
Maximum e.i.r.p. (e.i.r.p. density) of a single UWB device (dBm/MHz)	−41.3	−41.3
Distance UWB – Satellite receiver (km)	474	474
Space attenuation (dB)	160	160
Satellite antenna gain (dBi)	42.7	42.7
Received power at the EESS sensor in 1 MHz bandwidth (dBm) (dBm/MHz)	−159	−159
Threshold in dBm in 1 MHz bandwidth (dBm/MHz)	−115.3	−115.3
Margin with a single UWB device (dB)	43.8	43.8
Activity factor (%)	5	5
% Outdoor	20	20
% Indoor	80	80
Indoor/outdoor attenuation (dB)	0	17
Size of the satellite footprint: radius (km)	8.4	8.4
Maximum UWB density/km^2 corresponding to the above EESS footprint (UWB/km^2)	2 162	108 368
Received power of a single UWB device at the EESS sensor in 1 MHz bandwidth (dBm) for both indoor and outdoor usage (dBm/MHz)	−165.75	
Maximum UWB density/km^2 corresponding to the above EESS footprint for both indoor and outdoor usage (UWB/km^2)	10 012	

Table 233 indicates the maximum required UWB e.i.r.p. density (dBm/MHz) according to the density of UWB transmitters/km^2.

TABLE 233

Summary of interference analysis between UWB and EESS (active) for synthetic aperture radars at 5 GHz

Density of UWB transmitters/km^2	Maximum required UWB e.i.r.p. (both indoor and outdoor) density (dBm/MHz)
1	−1
10	−11
100	−21
1 000	−31
10 000	−41

1.1.3 Conclusion for interference between EESS (active) and UWB

The above calculations have shown that the EESS (active) bands at 5 GHz may be sensitive to UWB devices, especially the synthetic aperture radars if large densities of UWB devices are deployed.

However, using a rural deployment density of 100 UWB/km^2 would imply that EESS (active) at 5 GHz is compatible with UWB devices operating at an e.i.r.p. of –41.3 dBm/MHz.

1.2 Earth exploration-satellite

1.2.1 Earth exploration-satellite, space research and space operation in 2 025-2 110 MHz and 2 200-2 290 MHz frequency bands

1.2.1.1 2 025-2 110 MHz band

The band 2 025-2 110 MHz is allocated to the following services: Earth exploration-satellite (Earth-to-space), space research (Earth-to-space) and space operation (Earth-to-space). Space research communications are required for several kinds of several functions: telecommand, maintenance telemetering, stored scientific data and real-time scientific data. According to Recommendation ITU-R SA.609, the protection criteria for the above services is −177 dBW/kHz at the input terminal of the spaceborne receiver. The average gain of a quasi omnidirectional antenna for this frequency band is around 0 dBi. Therefore, with a 0 dBi antenna, the acceptable interference at the antenna input is −207 dBW/Hz or −117 dBm/MHz.

Typical altitudes of those kinds of satellites are around 700 km.

Table 234, two cases are considered: indoor use and outdoor use. For the case of indoor use, an average building attenuation of 12 dB is used in the aggregate model only. According to Recommendation ITU-R P.1238, it appears that such an indoor attenuation is conservative and is able to cover most cases.

TABLE 234

Interference analysis between UWB and EESS in the band 2 025-2 110 MHz

Frequency	2 025	MHz (2 025-2 110 MHz band)	
Wavelength	0.15	m	
Protection criteria (Recommendation ITU-R SA.609)	−177	dBW/kHz	At the spaceborne receiver
Satellite antenna gain	0	dBi	
Minimum elevation angle at the ground station	5	degrees	
Maximum interference level at the antenna level of the spaceborne receiver	−117.0	dBm/MHz	

Parameter	United States mask (outdoor)	United States mask (indoor)	Mask (indoor and outdoor)
Maximum e.i.r.p. (e.i.r.p. density) of a single UWB device (dBm/MHz)	−62	−52	−35
Distance UWB – Satellite receiver (km) at the nadir (km)	700	700	700
Space attenuation in dB (dB)	155	155	155

TABLE 232 (*end*)

Parameter	United States mask (outdoor)	United States mask (indoor)	Mask (indoor and outdoor)
Satellite antenna gain (dBi)	0	0	0
Received power at the EESS in 1 MHz bandwidth (dBm) (dBm/MHz)	−217	−207	−190
Threshold (dBm/MHz)	−117.0	−117.0	−117.0
Margin with a single UWB device (dB)	100.4	90.4	73.4
Activity factor (%)	5	5	5
% Outdoor	20	20	20
% Indoor	80	80	80
Indoor/outdoor attenuation (dB)	0	12	12
Half geocentric angle (degrees)	21.15	21.15	21.15
Size of the satellite footprint: radius (km) for a minimum ground station elevation angle of 5° assuming a flat Earth (km)	2 354	2 354	2 354
Maximum UWB density/km^2 corresponding to the above EESS footprint (UWB/km^2)	12 686	20 107	401
Received power of a single UWB device at the EESS receiver in 1 MHz bandwidth (dBm) for both indoor and outdoor usage (dBm/MHz)	−218.95		−196, 44 279
Maximum UWB density/km^2 corresponding to the above EESS footprint for both indoor and outdoor usage (UWB/km^2)	18 001		101

Table 235 indicates the maximum required UWB e.i.r.p. density (dBm/MHz) according to the density of UWB transmitters/km^2.

TABLE 235

Summary of interference analysis between UWB and EESS in the band 2 025-2 110 MHz

Density of UWB transmitters/km^2	Maximum required UWB e.i.r.p. density (dBm/MHz)		Maximum required UWB e.i.r.p. density (dBm/MHz)
	Indoor density (dBm/MHz)	Outdoor density (dBm/MHz)	Density (dBm/MHz) for both outdoor and indoor
1	−9	−19	−15
10	−29	−29	−25
100	−39	−39	−35
1 000	−49	−49	−45
10 000	−59	−59	−55

1.2.1.2 2 200-2 290 MHz band

The band 2 200-2 290 MHz is allocated to the following services: Earth exploration-satellite (space-to-Earth), space research (space-to-Earth) and space operation (space-to-Earth). Space research communications are required for several kinds of several functions: telecommand, maintenance telemetering, stored scientific data and real-time scientific data. According to Recommendation ITU-R SA.609, the protection criteria for the above services is −216 dBW/Hz at the input of the earth station receiver. Typical antenna gain for earth station is 46 dBi. For this case, in order to take into account more realistic situations, the fixed gain of the antenna gain of the earth station which is directional because the ground station is tracking a LEO satellite in azimuth and in elevation, is replaced with the gain in the first side lobes, that is to say 31 dBi.

Therefore, with a 31 dBi antenna, the acceptable interference at the antenna input is −247 dBW/Hz or –157 dBm/MHz.

Typical altitudes of science satellites are around 700 km.

In Table 236, for the aggregate case, the integral method is used to compute the minimum radius R_0 for a given maximum radius R_1 = 10 km and for various average densities/km^2. This table provides the corresponding protection distances for the Earth exploration-satellite service. In this table, two cases are considered: indoor use and outdoor use. For the case of indoor use, an average building attenuation of 12 dB is used in the aggregate model only. According to Recommendation ITU-R P.1238), it appears that such an indoor attenuation is conservative and is able to cover most cases.

TABLE 236

Interference analysis between UWB and EESS in the band 2 200-2 290 MHz

Frequency **2 200** MHz		(2 200-2 290 MHz band)

UWB density (UWB/km²)	**UWB spectrum mask**	**United States outdoor mask −62**	**United States indoor mask −52**	**Mask outdoor and indoor −60**	**Mask outdoor and indoor −70**
	e.i.r.p. limit (dBm/MHz)				
10	Protection distance, maximum radius of 30 km	13 km	8 km	5 km	10 m
100	Protection distance, maximum radius of 30 km	28 km	27 km	25 km	4 km

dBm/MHz	**UWB e.i.r.p. limit**	**−62**	**−52**	**−70**
m	Wavelength	0.14	0.14	0.14
dBi	Antenna gain	0	0	0
dBm/MHz	α = e.i.r.p. $(\lambda/4\pi)^2 \cdot G_r$	−101.29	−91.29	−109.29
%	Activity factor	5%	5%	5%
UWB/km^2	UWB density	100	100	100

TABLE 236 (*end*)

km	**Minimum radius used for aggregate interference**	**28**	**27**	**N/A**
km	Maximum radius	30	30	30
dBm/MHz	$A = 2\alpha\eta\rho 1n(R_1/R_0)$	−157.9	−146.1	N/A
dB	**Indoor/outdoor attenuation**	**0**	**12**	**12**
%	% Outdoor	20	20	20
%	% Indoor	80	80	80
dBm/MHz	Aggregate interference	−157.9	−158.1	N/A
dBm/MHz	PSD protection level: this protection level includes the ground station antenna gain	−157	−157	−157
dB	**Margin for aggregate interference**	**0.9**	**1.1**	**N/A**

km	**Minimum radius used for aggregate interference for both indoor and outdoor UWB devices**	**27**	**4**
dBm/MHz	Aggregate interference for both indoor and outdoor UWB devices	−157.6	−157.3
dB	**Margin for aggregate interference for both indoor and outdoor UWB devices**	**0.6**	**0.3**

Tables 237 and 238 summarize the above results as a function of the UWB density: they compute the minimum protection distances around the Earth station.

TABLE 237

Computation of the protection distance for a maximum radius of 10 km for the band 2 200-2 290 MHz

Density of UWB transmitters/ km²	**Required UWB e.i.r.p. density (dBm/MHz)** **Outdoor = −52 Indoor = −42**	**Required UWB e.i.r.p. density (dBm/MHz)** **Outdoor = −62 Indoor = −52**	**Required UWB e.i.r.p. density (dBm/MHz)** **Outdoor = −72 Indoor = −62**	**Required UWB e.i.r.p. density (dBm/MHz)** **Outdoor = −82 Indoor = −72**	**Required UWB e.i.r.p. density (dBm/MHz)** **For both Outdoor and indoor = −70**
1	3 km	10 m	10 m	10 m	10 m
10	9 km	3 km	10 m	10 m	10 m
100	9.9 km	9 km	3 km	10 m	2 km
1 000	Not available	9.9 km	9 km	3 km	9 km
10 000	Not available	Not available	9.9 km	9 km	9.9 km

TABLE 238

Computation of the protection distance for a maximum radius of 30 km for the band 2 200-2 290 MHz

Density of UWB transmitters/ km²	Required UWB e.i.r.p. density (dBm/MHz) Outdoor = −52 Indoor = −42	Required UWB e.i.r.p. density (dBm/MHz) Outdoor = −62 Indoor = −52	Required UWB e.i.r.p. density (dBm/MHz) Outdoor = −72 Indoor = −62	Required UWB e.i.r.p. density (dBm/MHz) Outdoor = −82 Indoor = −72	Required UWB e.i.r.p. density (dBm/MHz) For both Outdoor and indoor = −70
1	9 km	10 m	10 m	10 m	10 m
10	27 km	9 km	10 m	10 m	10 m
100	29.9 km	27 km	9 km	10 m	4 km
1 000	29.99 km	29.9 km	27 km	9 km	25 km
10 000	Not available	29.99 km	29.9 km	27 km	29.9 km

1.2.1.3 Conclusion about the bands 2 025-2 110 and 2 200-2 290 MHz

The above calculations have shown that quite a coordination distance is required around each earth station. Therefore, due to the fact the characteristics of the UWB deployment are not correctly known, it is recommended that a specific attention must be paid to the band 2 200-2 290 MHz. This analysis tends to conclude that UWB systems should avoid those bands in order not to create additional noise damaging to the existing ITU-R services, in order not to cause any interference to the earth stations.

1.2.2 Earth exploration-satellite (space-to-Earth) in the band 8 025-8 400 MHz

The band 8 025-8 400 MHz is allocated to the Earth exploration-satellite service (space-to-Earth). The 8 025-8 400 MHz band is used to transfer data directly from non-geostationary EESS satellites to receiving earth stations. Earth stations may have large steerable antennas (i.e. 10 m), while earth stations with smaller (i.e. 2 m) antennas may also be considered. In some cases the observations are scientific in nature and can be measured on the next pass of the satellite over the same or similar territory hours to days later. Other information, for example weather information affecting navigation, must be available as soon as possible, within minutes to hours of the time that the observations are made. For this purpose a highly reliable space-to-Earth path with low interference from UWB devices is necessary for the transmission of measured data from EESS space stations to their associated Earth stations.

1.2.2.1 Characteristics and protection criteria

According to Recommendation ITU-R SA.1026, interference criteria for space-to-earth data transmission systems in the Earth exploration satellite and meteorological-satellite-services using satellites in low Earth orbit, the protection criteria to be used for sharing analysis is −134 dBW/ 100 MHz at the input of the ground station antenna. The Earth station antenna gain of 55 dBi (9 m antenna dish, $\theta_{3\,dB} = 0.3°$) is already included in the protection criteria. It is important to note that the above sharing criterion is a long term criteria which has been determined for terrestrial systems. Therefore, the acceptable interference at the antenna input is −214 dBW/Hz or −124 dBm/MHz: this figure is an overall protection criterion against harmful terrestrial interferences which is valid at the input of the antenna of the ground station.

Typical altitudes of science satellites are around 700 km.

Another set of characteristics for use in studies of the impact of devices using UWB technology on stations operating in the EESS 8 GHz downlink band is provided in Table 239.

TABLE 239

Typical downlink EESS parameters in the 8 GHz band

Parameter	Typical value						
Range of operating frequencies	8 025-8 400 MHz						
Earth station off-axis gain towards the local horizon (dBi)(1)	Elevation angle(2)	5°	10°	20°	30°	48°	>85°
	Off-axis gain	14.5	7.0	–0.5	–4.9	–10	0
Range of emission bandwidths	60 MHz – 100 MHz						
Noise temperature of ES receiver	130 K						
Earth station deployment	All regions, in all locations (rural, semi-urban, urban)(3)						

(1) The values were derived by assuming a local horizon at 0° of elevation.

(2) 5° is considered as the minimum operational elevation angle.

(3) EESS antennas in this band may be deployed in a variety of environments. Smaller steerable antennas (1.8-3.8 m) are commonly deployed on the roofs of buildings or on the ground in urban, semi-urban or rural locations, whereas larger steerable antennas up to 10 m in diameter are typically mounted on the ground and deployed in semi-urban or rural locations.

1.2.2.2 Computation of the protection distances

TABLE 240

Protection distances between UWB devices and a space science ground station in the band 8 025-8 400 MHz in the aggregate case

Frequency	**8 025 MHz**	**(8 025-8 400 MHz band)**	
UWB density (UWB/km^2)	**UWB spectrum mask**	**United States outdoor mask**	**United States indoor mask**
	e.i.r.p. limit (dBm/MHz)	**−41.3**	**−41.3**
1 000	Protection distance for a maximum radius of 10 km	10 m	10 m
10 000	Protection distance for a maximum radius of 10 km	5 km	10 m

Aggregate interference calculation

dBm/MHz	**UWB e.i.r.p. limit**	**−41.3**	**−41.3**
m	Wavelength	0.04	0.04
dBi	Antenna gain	0	0
dBm/MHz	α = e.i.r.p. $(\lambda/4\pi)^2 \cdot G_r$	−91.83	−91.83
%	Activity factor	5	5
UWB/km^2	UWB density	10 000	10 000
km	**Minimum radius used for aggregate interference**	**8**	**0.01**
km	Maximum radius	10	10
dBm/MHz	$A = 2\alpha\eta\rho 1n(R_1/R_0)$	−123.4	−108.5
dB	**Indoor/outdoor attenuation**	**0**	**17**
%	% Outdoor	20	20
%	% Indoor	80	80
dBm/MHz	Aggregate interference	−123.4	−125.5
dBm/MHz	PSD protection level: the protection level already includes the 55 dBi ground station antenna gain	−124	−124
dB	**Margin for aggregate interference**	**−0.6**	**1.5**
km	**Minimum radius used for aggregate interference for both indoor and outdoor UWB devices**	**5**	
dBm/MHz	Aggregate interference for both indoor and outdoor UWB devices	−125.1	
dB	**Margin for aggregate interference for both indoor and outdoor UWB devices**	**1.1**	

The above calculations have shown that a protection distance is required around each ground station.

According to the above calculated separation distances and due to the fact the characteristics of the UWB deployment are not correctly known, careful attention must be paid to the band 8 025-8 400 MHz for which the analysis tends to conclude that UWB devices should avoid such band in order not to cause any interference to the ground stations.

TABLE 241

Computation of the protection distance for a maximum radius of 10 km

Density of UWB transmitters/km^2	**Required UWB e.i.r.p. density (dBm/MHz)** **Outdoor and indoor = −41.3**	**Required UWB e.i.r.p. density (dBm/MHz)** **Outdoor and indoor = −51.3**	**Required UWB e.i.r.p. density (dBm/MHz)** **Outdoor and indoor = −61.3**
1	10 m	10 m	10 m
10	10 m	10 m	10 m
100	10 m	10 m	10 m
1 000	10 m	10 m	10 m
10 000	5 km	10 m	10 m

TABLE 242

Computation of the protection distance for a maximum radius of 30 km

Density of UWB transmitters/km²	Required UWB e.i.r.p. density (dBm/MHz) Outdoor and indoor = −41.3	Required UWB e.i.r.p. density (dBm/MHz) Outdoor and indoor = −51.3	Required UWB e.i.r.p. density (dBm/MHz) Outdoor and indoor = −61.3
1	10 m	10 m	10 m
10	10 m	10 m	10 m
100	10 m	10 m	10 m
1 000	10 m	10 m	10 m
10 000	10 km	10 m	10 m

TABLE 243

Application of the integral methodology to the 8 GHz EESS to calculate maximum UWB e.i.r.p. density with parameters from Table 239

	8 GHz EESS downlink	
Parameter	**Urban**	**Suburban**
Frequency, c/λ (GHz)	8.1	8.1
Indoor/outdoor UWB ratio f_i/f_0 (%)	80/20	80/20
UWB device density, ρ (per km^2)	10 000	1 000
Exclusion zone, R_0 (m)	20	40
Maximum radius of study, R_1 (km)	5	10
Indoor-to-outdoor attenuation, *a* (dB)	10	10
UWB activity factor, η (%)	5	5
Number of simultaneously active devices	500	50
Effective ES antenna gain, G_r (dBi)	0	0
System noise temperature (K)	130	130
I/*N* protection criterion (dB)	–20	–20
Calculated maximum UWB e.i.r.p. density (dBm/MHz)	–63.7	–53.7

1.3 Description of an EESS (passive) system

Passive sensors are measuring natural transmitted radiation in the microwave spectrum and have a global coverage. Radiometric imaging of a scene of interest is accomplished by scanning the main beam of the antenna. For a moving platform, scanning in the cross track dimension is sufficient to produce an image. Both mechanical and electronic (beam-steering) scanning techniques are used in microwave radiometry. In mechanical scanning, the direction of the antenna beam is changed by mechanical rotation or angular movement of the radiating aperture of the antenna system. Alternatively, phased array antennas can be used to steer the direction of the antenna beam electronically (no mechanical motion in the scanning process).

Various types of radiometer instruments are flying depending on the requirements.

– Atmospheric sounders which provide information about vertical profiles of temperature and molecular constituent concentrations in the atmosphere by making measurements near the molecular resonance frequencies (resonance method with nadir pointing).

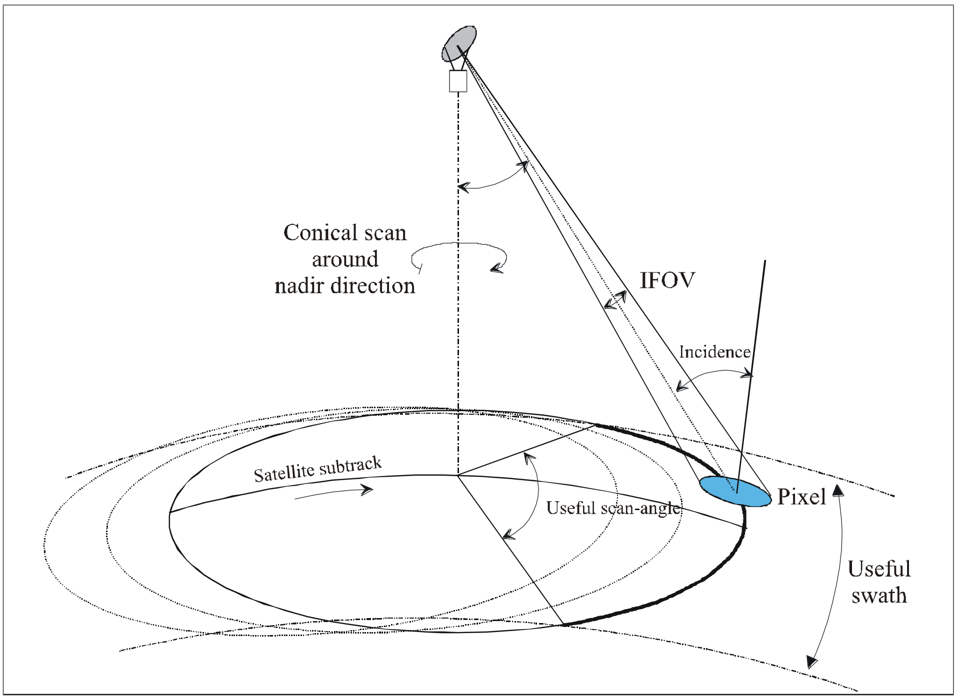
– Surface imaging sensors operate primarily at window frequencies where atmospheric absorption is low and surface features can be imaged or measured quantitatively. The nadir viewing technique is employed for surface imaging. Radiometric measurements are affected to some extent by water vapour, clouds and rainfall. Hence, most surface sensing radiometers include frequency channels sensitive to atmospheric water vapour and liquid water, to measure global distributions of these parameters and to correct for their effects on the measurement of the surface parameters.

The above two kinds of passive observations can be performed either using a conical scan sensor or a nadir sensor. Those two kinds of sensors are explained below.

1.3.1 Conical scan passive sensors

FIGURE 315

Geometry of conical scan passive microwave radiometers



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The typical geometrical parameters of this kind of instruments are the following (for an altitude of about 850 km).

– Ground incidence angle *i* at footprint centre: around 50°.

– EESS offset angle to the nadir or half cone angle α to the nadir direction (also called antenna offset angle or off nadir angle): about 44°.

– Useful swath of about 1 600 km.

– The scanning period is chosen in order to ensure full coverage and optimum integration time (radiometric resolution).

1.3.2 Cross track passive sensors

Figure 316 shows a nadir sounder using a mechanical scan.

Figure 317 shows a nadir sounder using an electronic scan, which means that it is possible for the radiometer to see at the same time the whole line of pixels within a single swath, because all the beams are simultaneously in operation.

FIGURE 316

Geometry of mechanical scan passive nadir microwave radiometers

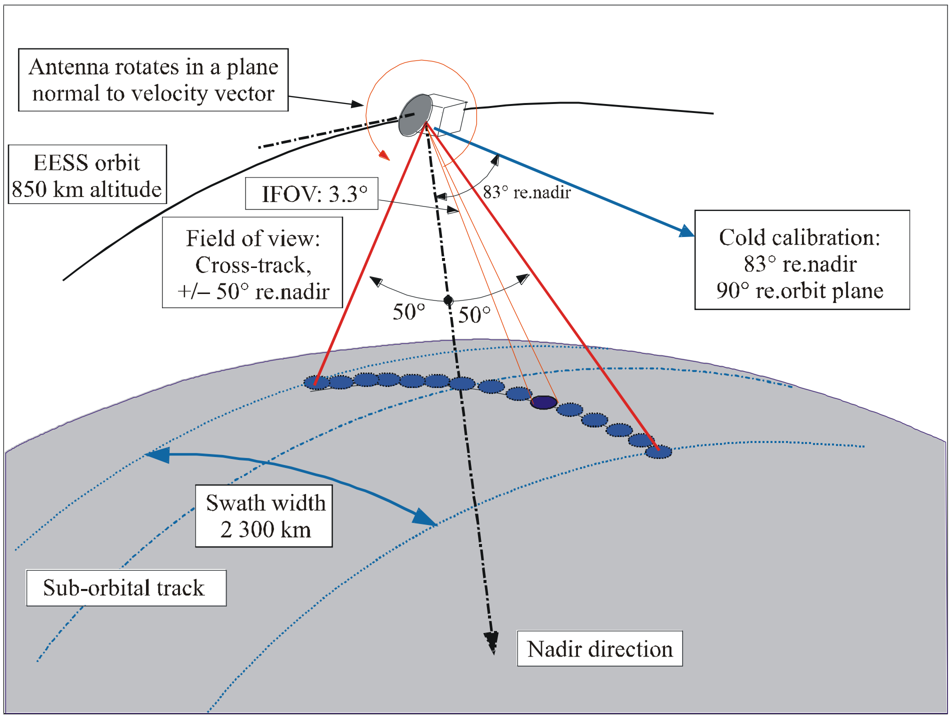

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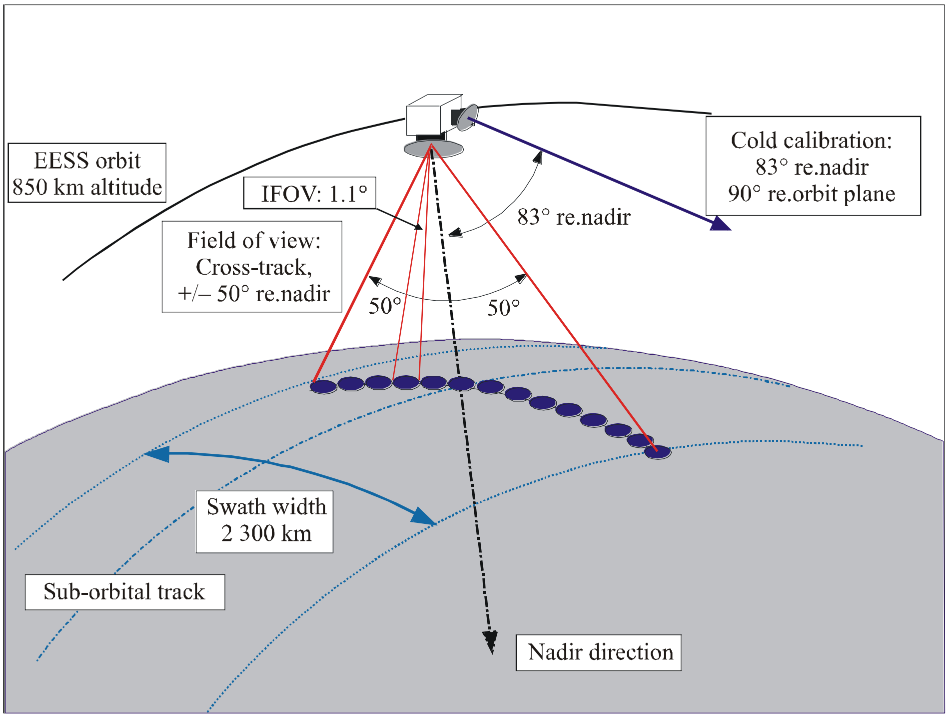
FIGURE 317

Geometry of electronic scan passive nadir microwave radiometers



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1.4 EESS (passive) except the band 23.6-24 GHz

1.4.1 1 400-1 427 MHz band

1.4.1.1 Analysis

In compliance with Recommendation ITU-R SA.1029, the acceptable interference power received by the EESS sensor in the 1.4 GHz band by unwanted emissions for this band is –174 dBW in the reference bandwidth of 27 MHz, which is equivalent to –158.3 dBm/MHz. This interference criterion has to be understood as an aggregate basis from all sources of interference and therefore needs to be apportioned for UWB devices. This corresponds to a measurement sensitivity of $\Delta T = 0.05$ K. It is important to note that this band is protected by RR No. 5.340 which states that "all emissions are prohibited".

Radiocommunication WP 7C has provided information regarding apportionment of interference criteria to apply to interference from UWB devices that would be necessary to protect the EESS (passive): the interference criteria to be used for in band emissions in purely passive bands protected by RR No. 5.340 is based on an apportionment of 1% to 5% of the total interference criteria, that is to say −178.3 dBm/MHz for a 1% apportionment factor. This information was not derived from an ITU-R Recommendation and was provided through a liaison statement, the reason for this is that no Recommendation can be developed on apportionment for active in band emissions in band listed in RR No 5.340.

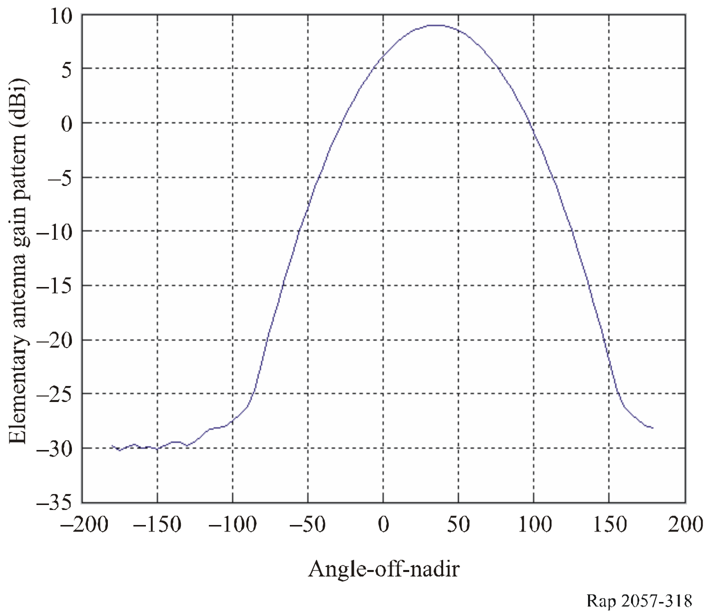
There are three projects that are currently planned. NASA/JPL is currently developing two instruments for measuring Soil Moisture and Sea Salinity (the HYDROS and AQUARIUS), which will collect measurements in the entire passive microwave band under consideration (1 400-1 427 MHz). The European Space Agency (ESA) jointly with CNES is developing a separate instrument (the SMOS mission), using a different technological approach, for measurements of soil moisture and ocean salinity. HYDROS and SMOS are complementary missions, both requiring high-precision radiometric measurements globally and continuously in time. Frequencies near 1 400 MHz are ideal for measuring soil moisture, and also for measuring sea surface salinity and vegetation biomass. Soil moisture is a key variable in the hydrologic cycle with significant influence on evaporation, infiltration and runoff. In the vadose zone, soil moisture governs the rate of water uptake by vegetation. Sea surface salinity has an influence on deep thermohaline circulation and the meridional heat transport. Variations in salinity influence the near surface dynamics of tropical oceans. To date, there is no capability to measure soil moisture and sea surface salinity directly on a global basis, so the protection of this passive band is essential.

The SMOS (Soil Moisture and Ocean Salinity) mission uses interferometric antennas (planar, Y shaped antenna), while the HYDROS and AQUARIUS use high antenna gain.

The SMOS antenna pattern is plotted in Fig. 318. One can notice that the total beamwidth equals 75° at –3 dB.

FIGURE 318

SMOS sensor antenna pattern as a function of the off-axis angle (degrees)



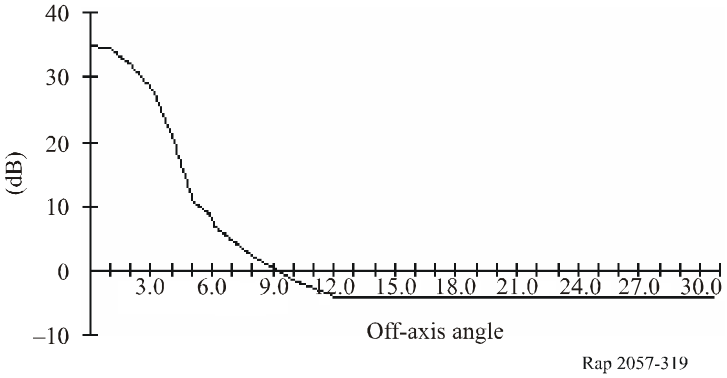
The SMOS orbit altitude is 760 km.

For the HYDROS project, the antenna is an offset fed parabolic, deployable mesh reflector antenna. The maximum antenna gain is about 35 dBi with a $\theta_{-3\text{ dB}}$ of about 2.6° with side lobes down to −4 dBi. The HYDROS orbit altitude is 670 km with an inclination of 98°. HYDROS is a conical scan instrument having a 40° off-nadir with a scanning rate around nadir of 6 rpm.

In addition to the normal Earth-viewing mode of HYDROS, the sensor will periodically be required to perform hot and cold calibration measurements that involve different geometries than those described below. The current baseline calibration scheme for the HYDROS spacecraft is to observe the AMAZON rain forest and open ocean every three days. The beam pattern for the HYDROS sensor is illustrated in Fig. 319.

FIGURE 319

HYDROS antenna pattern



AQUARIUS uses a three-beam push-broom radiometer configuration and each beam represents a single pixel.

Table 244 indicates the main characteristics of the three beams of AQUARIUS.

TABLE 244

Main characteristics of the AQUARIUS satellite operating in the band 1 400-1 427 MHz

	AQUARIUS beam 1	**AQUARIUS beam 2**	**AQUARIUS beam 3**
Altitude (km)	600	600	600
Antenna gain (dBi)	31	31	31
Incidence angle at footprint centre (degrees)	41.42	31.92	22.75
Equivalent radius of the beam (km)	32	25	20

TABLE 245

Interference analysis between UWB and EESS (passive) in the band 1 400-1 427 MHz

Frequency	1 400	MHz
Wavelength	0,21	m
Indoor/outdoor attenuation (dB)	9	dB
Interference level (sensitivity of 0,05 K): Rec. ITU-R SA.1029-2	–158.3	dBm/MHz
Interference level with apportionment of 1%	–178.3	dBm/MHz

Parameter		Current SMOS		Future SMOS		HYDROS		AQUARIUS: beam 1	
		United States mask –75 dBm/MHz **Outdoor**	**United States mask –75 dBm/MHz** **Indoor**	**United States mask –75 dBm/MHz** **Outdoor**	**United States mask –75 dBm/MHz** **Indoor**	**United States mask –75 dBm/MHz** **Outdoor**	**United States mask –75 dBm/MHz** **Indoor**	**United States mask –75 dBm/MHz** **Outdoor**	**United States mask –75 dBm/MHz** **Indoor**
Maximum e.i.r.p. (power spectral density) of a single UWB device	dBm/MHz	–75	–75	–75	–75	–75	–75	–75	–75
Distance UWB – Satellite EESS sensor (km)	km	760	760	760	760	865.8	865.8	800.1	800.1
Space attenuation (dB)	dB	153	153	153	153	154	154	153	153
Satellite antenna gain (dBi)	dBi	9	9	20	20	35	35	31	31
Received power at the EESS sensor in 1 MHz bandwidth (dBm)	dBm/MHz	–219	–219	–208	–208	–194	–194	–197	–197
Threshold in dBm in 1 MHz bandwidth (sensitivity 0.05 K with 1% apportionment)	dBm/MHz	–178.3	–178.3	–178.3	–178.3	–178.3	–178.3	–178.3	–178.3
Margin with a single UWB device (dB)	dB	40.6	40.6	29.6	29.6	15.8	15.8	19.1	19.1
Activity factor	%	5	5	5	5	5	5	5	5
% Outdoor	%	20	20	20	20	20	20	20	20
% Indoor	%	80	80	80	80	80	80	80	80
Indoor/outdoor attenuation (dB)	dB	0	9	0	9	0	9	0	9
Half antenna beamwidth	(degrees)	37.5	37.5	20.0	20.0	1.30	1.30	2.75	2.75
Size of the satellite footprint: radius (km) assuming a flat earth	km	583	583	277	277	20	20	32	32
UWB density/km² corresponding to the above EESS footprint	UWB/km²	0	2	0.08	1	1	5	1	4
Received power of a single UWB device at the EESS sensor in 1 MHz bandwidth in dBm for both indoor and outdoor usage	dBm/MHz	–224.16		–213.16		–199.29		–202.60	
UWB density/km² corresponding to the above EESS footprint for both indoor and outdoor usage with 1% apportionment	UWB/km²	0.72		0.25		2.07		2	

When a single UWB device is operating with the e.i.r.p. expressed above, the receiver on board the satellite wouldn’t be affected by an UWB emission. On the other hand, on an aggregate basis and depending on the UWB density/km^2, the 1 400-1 427 MHz passive band can experience harmful interference. On this basis, the following table provides the maximum required UWB e.i.r.p. density (versus UWB density) to ensure protection of EESS(passive) from UWB devices in the band 1 400-1 427 MHz.

It should be noted RR No. 5.340 applies.

TABLE 246

Summary of interference analysis between UWB and EESS (passive) in the band 1 400-1 427 MHz with 1% apportionment of the interference criteria

Density of UWB transmitters/km²	Maximum required UWB e.i.r.p. (both indoor and outdoor) density (dBm/MHz)
1	−81
10	−91
100	−101
1 000	−111
10 000	−121

A 5% apportionment of the interference criteria would provide power density levels 7 dB higher than those noted in Table 244.

1.4.1.2 Conclusion on interference analysis for the 1 400-1 427 MHz band

This analysis concludes that UWB devices should avoid this exclusive and essential passive band using any adequate technique. Taking into account typical characteristics of EESS sensors, and in particular the quite large size of the beams, it is proposed to base the conclusions on scenario deployment consistent with rural/suburban (i.e. a density of 100 UWB transmitters/km^2) and that hence a maximum UWB e.i.r.p. density of –101 dBm/MHz would be adequate to ensure protection of EESS (passive) in the 1 400-1 427 MHz band.

1.4.2 Interference study around 6.9 GHz

1.4.2.1 Interference analysis

According to RR No. 5.458, the bands 6 425-7 075 MHz and 7 075-7 250 MHz are used for EESS (passive) measurements. Specifically, the band 6 725-7 075 MHz (350 MHz bandwidth) is currently used by AMSR-E, a conical scan microwave radiometer mounted on the Aqua satellite. A similar instrument will be used by CIMIS mounted on NPOES satellite. This band is used over oceans in order to measure the sea surface temperature and the sea surface wind speed, but also over lands to measure soil moisture in combination with other channels. An interference study is shown in Table 246. Table 245 indicates the main characteristics of the AMSR-E radiometer which is currently flying.

According to Recommendation ITU-R SA.1029, the interference threshold is −166 dBW for a bandwidth of 200 MHz, which is equivalent to −159 dBm/MHz. This interference criterion has to be understood as an aggregate basis from all sources of interference and therefore need to be apportioned for UWB devices.

Radiocommunication WP 7C has provided information regarding apportionment of interference criteria to apply to interference from UWB devices that would be necessary to protect the EESS (passive): the interference criteria to be used for in band emissions in shared passive bands is based on a 5% apportionment of the total interference criteria, that is to say −172 dBm/MHz for a 5% apportionment factor. This information was not derived from a ITU-R Recommendation and was provided through a liaison.

TABLE 247

Main characteristics of the AMSR-E radiometer operating around 6.9 GHz

	AMSR-E
Altitude (km)	705
Incidence angle (degrees)	55
Antenna beam width at −3 dB (degrees)	2.21
Antenna gain (dBi)	38.8

TABLE 248

Interference analysis between UWB and EESS (passive) in 6.925 GHz according to United States UWB emission limit

Frequency	6 925	MHz
Wavelength	0.04	m
Indoor/outdoor attenuation (dB)	17	dB
Interference level: Rec. ITU-R SA.1029-2	–159.0	dBm/MHz
Rec. ITU-R SA.1029-2 level, 5% apportionment	–172.0	dBm/MHz

		AMSR-E	
Parameter		**United States mask outdoor**	**United States mask indoor**
Maximum e.i.r.p. (power spectral density) of a single UWB device	dBm/MHz	–41.3	–41.3
Distance UWB – Satellite EESS sensor (km)	km	1 229.13	1 229.13
Space attenuation (dB)	dB	171	171
Satellite antenna gain (dBi)	dBi	38.8	38.8
Received power at the EESS sensor in 1 MHz bandwidth (dBm)	dBm/MHz	–174	–174
Threshold (dBm) in 1 MHz bandwidth with a 5% apportionment	dBm/MHz	–172.0	–172.0
Margin with a single UWB device (dB)	dB	1.5	1.5
Activity factor	%	5	5
% Outdoor	%	20	20
% Indoor	%	80	80
Indoor/outdoor attenuation (dB)	dB	0	17
Half antenna beamwidth	(degrees)	1 105	1 105
Size of the satellite footprint: radius (km) assuming a flat Earth	km	23.70	23.71
Actual size of the satellite footprint	km^2	2 496.00	2 496.00

TABLE 248 (*end*)

Parameter		AMSR-E	
		United States mask outdoor	**United States mask indoor**
Maximum UWB density/km² corresponding to the above EESS footprint	UWB/km²	0.0	0.6
Received power of a single UWB device at the EESS sensor in 1 MHz bandwidth (dBm) for both indoor and outdoor usage	dBm/MHz	–180.16	
UWB density/km² corresponding to the above EESS footprint for both indoor and outdoor usage with 5% apportionment	UWB/km²	0.1	

Table 249 indicates the maximum required UWB e.i.r.p. density (dBm/MHz) according to the density of UWB transmitters/km^2.

TABLE 249

Summary of interference analysis between UWB and EESS (passive) at 6 GHz with a 5% apportionment criteria

Density of UWB transmitters/km²	Maximum required UWB e.i.r.p. (both indoor and outdoor) density (dBm/MHz)
1	−54
10	−64
100	−74
1 000	−84
10 000	−94

1.4.2.2 Conclusion of the interference analysis at 6 GHz

This analysis concludes that UWB devices should avoid this exclusive and essential passive band using any adequate technique. Taking into account typical characteristics of EESS sensors, it is proposed to base the conclusions on scenario deployment consistent with rural/suburban (i.e. a density of 100 UWB transmitters/km^2) and that hence a maximum UWB e.i.r.p. density of –74 dBm/MHz would be adequate to ensure protection of EESS (passive) at 6 GHz.

1.4.3 10.6-10.7 GHz band

1.4.3.1 Interference analysis

According to Recommendation ITU-R SA.1029, the acceptable interference power received by the EESS sensor for this band is –166 dBW in the reference bandwidth of 100 MHz, which is equivalent to –156 dBm/MHz. This interference criterion has to be understood as an aggregate basis from all sources of interference and therefore need to be apportioned for UWB devices.

Radiocommunication WP 7C has provided information regarding apportionment of interference criteria to apply to interference from UWB devices that would be necessary to protect the EESS (passive): the interference criteria to be used for in band emissions in shared passive bands is based on a 5% apportionment of the total interference criteria, that is to say −169 dBm/MHz for a 5% apportionment factor. This information was not derived from an ITU-R Recommendation and was provided through a liaison.

It is important to note that the band 10.6-10.7 GHz is divided into two specific parts.

– The band 10.6-10.68 GHz is equally shared with MS and FS on a primary status.

– The band 10.68-10.7 GHz is quoted in RR No. 5.340 which states that "all emissions are prohibited".

Table 248 summarizes the parameters of conical scanning passive sensors that are or will be operating in the 10.6-10.7 GHz band. Figures 320 to 323 show the various antenna patterns valid for each radiometer.

The band 10.6-10.7 GHz is of primary interest to measure rain, snow, sea state and ocean wind.

These EESS sensors have a conical scan configuration centred around the nadir direction. It is important for the interpretation of surface measurements to maintain a constant ground incidence angle along the entire scan lines. The in orbit configuration of conically scanned instruments is described in the Fig. 315. At its altitude, the conical scan radiometer measures the upwelling scene brightness temperatures over an angular sector (useful scan angle in Fig. 315). The pixel size across track is computed from the –3 dB contour of the antenna pattern taking into account the satellite altitude and the incidence angle of the beam boresight.

The rotation speed of the instrument is between 20 revolutions per minute (rpm) and 40 rpm.

TABLE 250

Passive sensor parameters

Channel 10.6-10.7 GHz	**SENSOR1-10 GHz**	**AMSR-E**	**AMSR**	**CMIS**
Channel bandwidth (MHz)	100	100	100	100
Pixel size across track (diameter) (km)	56.7	34	23	42.9
Offset angle to the nadir or half cone angle α (degrees)	44.3	47.5	45.2	48.6
Incidence angle *i* at footprint centre (degrees)	52	55	53	58.1
Polarization	H, V	H, V	H, V	H, V, R, L
Altitude of the satellite (km)	817	705	800	833
Maximum antenna gain (dBi)	36	42	45	45
Reflector diameter (m)	0.9	1.6	2	2.2
Useful swath (km)	1 594	1 539	1 611	1 893
Half power antenna beam width $\theta_{3\text{-dB}}$ (degrees)	2.66	1.4	1.1	1.77

FIGURE 320

Antenna pattern of the conical scan passive microwave radiometer SENSOR1_10 GHz

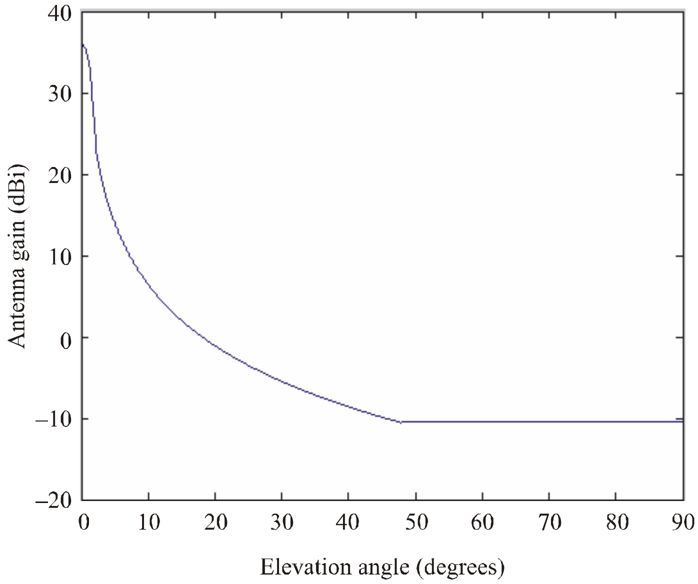


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FIGURE 321

Antenna pattern of the conical scan passive microwave radiometer AMSR-E

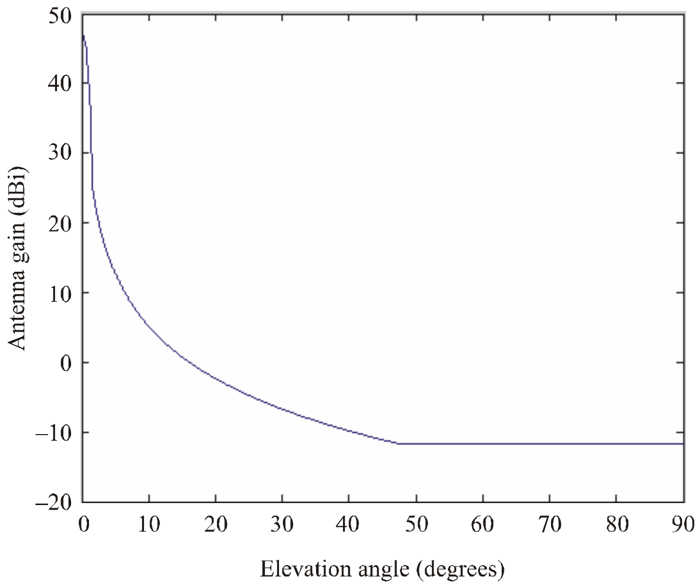

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FIGURE 322

Antenna pattern of the conical scan passive microwave radiometer AMSR

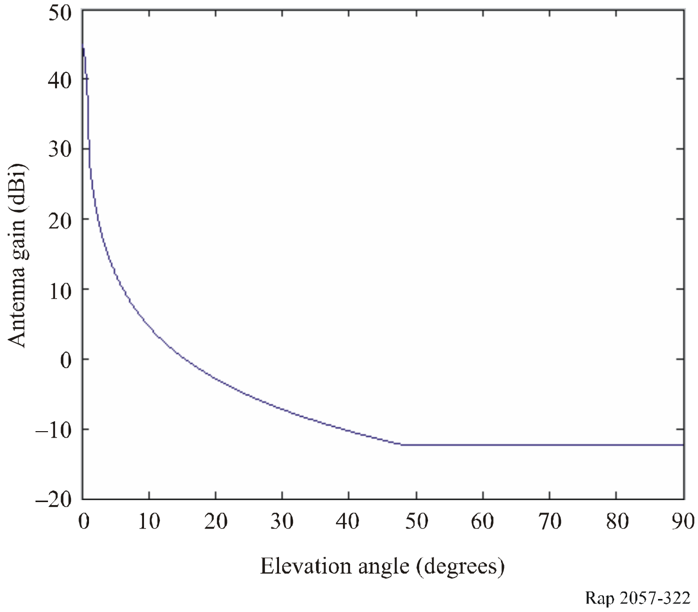
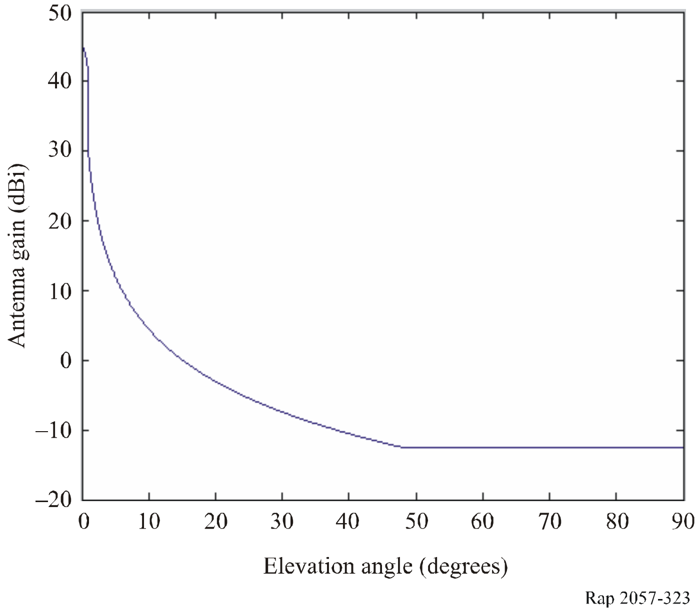


FIGURE 323

Antenna pattern of the conical scan passive microwave radiometer CMIS



According to the United States regulations, the proposed e.i.r.p. values are the following:

– outdoor: −61.3 dBm/MHz;

– indoor: −51.3 dBm/MHz.

TABLE 251

Interference analysis between UWB and EESS (passive) in the band 10.6-10.7 GHz

Frequency	10 600	MHz
Wavelength	0.03	m
Indoor/outdoor attenuation in dB	17	dB
Interference level: Rec. ITU-R SA. 1029-2	–156.0	dBm/MHz
Rec. ITU-R SA. 1029-2.5 % apportionment	–169.0	dBm/MHz

Parameter		AMSR		AMSR-E		CMIS		SENSOR1		CMIS
		United States mask –61 dBm/MHz Outdoor	United States mask –51 dBm/MHz Indoor	United States mask –61 dBm/MHz Outdoor	United States mask –51 dBm/MHz Indoor	United States mask –61 dBm/MHz Outdoor	United States mask –51 dBm/MHz Indoor	United States mask –61 dBm/MHz Outdoor	United States mask –51 dBm/MHz Indoor	United States mask –57 dBm/MHz Indoor and outdoor
Maximum e.i.r.p. (power spectral density) of a single UWB device	dBm/MHz	–61.3	–51.3	–61.3	–51.3	–61.3	–51.3	–61.3	-51,3	–57
Distance UWB – Satellite EESS sensor (km)	km	1 329.31	1 329.31	1 229.13	1 229.13	1 576.34	1 576.34	132 703	1 327.03	1 576.34
Space attenuation (dB)	dB	175	175	175	175	177	177	175	175	177
Satellite antenna gain (dBi)	dBi	45	45	42	42	45	45	36	36	45
Received power at the EESS sensor in 1 MHz bandwidth (dBm)	dBm/MHz	–192	–182	–194	–184	–193	–183	–201	–191	–189
Threshold (dBm) in 1 MHz bandwidth with a 5% apportionment	dBm/MHz	–169.0	–169.0	–169.0	–169.0	–169.0	–169.0	–169.0	–169.0	–169.0
Margin with a single UWB device (dB)	dB	22.7	12.7	25.0	15.0	24.1	14.1	31.7	21.7	19.8
Activity factor	%	5	5	5	5	5	5	5	5	5
Indoor/outdoor attenuation (dB)	dB	0	17	0	17	0	17	0	17	17
% Outdoor	%	20	20	20	20	20	20	20	20	20
% Indoor	%	80	80	80	80	80	80	80	80	80
Half antenna beamwidth	(degrees)	0.540	0.540	0.700	0.700	0.885	0.885	1.330	1.330	0.885
Size of the satellite footprint: radius (km) assuming a flat Earth	km	13	13	15	15	24	24	31	31	24
UWB density/km^2 corresponding to the above EESS footprint	UWB/km^2	7	38	9	45	3	14	10	49	Not available
Received power of a single UWB device at the EESS sensor in 1 MHz bandwidth (dBm) for both indoor and outdoor usage	dBm/MHz	–196.12		–198.44		–197.60		–205.11		–195.5
UWB density/km^2 corresponding to the above EESS footprint for both indoor and outdoor usage with 5% apportionment	UWB/km^2	21		25		8		27		5

When a single UWB device is operating with the e.i.r.p. expressed above, the receiver on board the satellite would not be affected by an UWB emission. On the other hand, on an aggregate basis and depending on the UWB density/km^2, the 10.6-10.7 GHz passive band can experience harmful interference. On this basis, Table 252 provides the required UWB e.i.r.p. density (versus UWB density) to ensure protection of EESS (passive) from UWB devices in the band 10.6-10.7 GHz.

TABLE 252

Summary of interference analysis between UWB and EESS (passive) at 10.6 GHz with 5% apportionment of the interference criteria

Density of UWB transmitters/km^2	Maximum required UWB e.i.r.p. density (dBm/MHz)	Maximum required UWB e.i.r.p. density (dBm/MHz)	
	Both outdoor and indoor	Outdoor	Indoor
1	−50	−51	−41
10	−60	−61	−51
100	−70	−71	−61
1 000	−80	−81	−71
10 000	−90	−91	−81

Eventually, it should also be noted that the 10.6-10.68 GHz band is shared on a co-primary basis with the fixed and mobile services and that these services will have to account for most of the interference allowed under the interference protection criteria specified in Recommendation ITU-R SA.1029.

1.4.3.2 Conclusion of interference analysis at 10.6 GHz

This analysis concludes that UWB devices should avoid this exclusive and essential passive band using any adequate technique. Taking into account typical characteristics of EESS sensors, it is proposed to base the conclusions on scenario deployment consistent with rural/suburban (i.e. a density of 100 UWB transmitters/km^2) and that hence a maximum UWB e.i.r.p. density of –70 dBm/MHz would be adequate to ensure protection of EESS (passive) in the 10.6-10.7 GHz band.

1.5 Interference analysis between EESS (passive) and vehicular radar systems at 24 GHz

This section contains the interference analysis between 24 GHz automotive short-range radars (SRR) and EESS (passive) in the 23.6-24 GHz band.

It represents a long-term scenario for which 100% vehicles would be equipped with SRR devices with an assumed SRR e.i.r.p. of –41.3 dBm/MHz.

1.5.1 Status of the 23.6-24 GHz frequency band

As summarized in Table 253, the 23.6-24 GHz frequency band is exclusively allocated to passive services, among of which EESS (passive), and is quoted in RR No. 5.340 that stipulates that all emissions are prohibited.

TABLE 253

Band allocations around the 23.6-24 GHz band

Services in lower allocated bands		Passive band	Service in upper allocated band
22.55-23.55 GHz	23-23.6 GHz	23.6-24 GHz	24-24.05 GHz
Fixed inter-satellite mobile	Fixed mobile	Earth exploration-satellite (passive) Radio astronomy space research (passive) RR No. 5.340	Amateur Amateur-satellite RR No. 5.150

It should be emphasized that, despite the fact that interference may be suffered by the passive sensor near the lower and upper edges of the allocated passive band due to out-of-band emissions from active services allocated in adjacent bands, the exclusive status of the allocation essentially guarantees the cleanliness of the passive band, thus preserving the potential improvement of this sensing technique.

1.5.2 Use of the band 23.6-24 GHz by EESS

The band 23.6-24 GHz is of primary interest by itself to measure water vapour and liquid water. The total water vapour content from the ground to the satellite is best measured in this frequency band which has no equivalent frequency band having this same characteristic in the whole electromagnetic spectrum.

Spaceborne microwave passive sensors are operated by the EESS for the purpose of weather forecast and climatology to measure geophysical data worldwide, which describe the status of the complex atmosphere/oceans/land surface machinery.

The exclusive status granted by RR No. 5.340 to most passive allocations recognizes:

– the extreme vulnerability to interference of microwave passive sensors which are designed to measure very faint natural emissions;

– and the catastrophic consequences that interference may have on operational and scientific applications which rely on microwave passive measurements.

This concerns in particular frequency bands which are used for 3 dimensional (3D) atmospheric measurements, to the exception of frequency bands where the natural atmospheric attenuation provides sufficient shielding to prevent interference (for instance, in the O_2 absorption spectrum around 60 GHz).

The 3D atmospheric temperature measurements of utmost importance for operational meteorology (numerical weather forecasting models) and climate studies and monitoring are performed in the oxygen absorption spectrum around 60 GHz. Temperature is also essential to retrieve passive measurements of other atmospheric gases which play a major role in energy transport (water vapour) and photo-chemistry processes (O_3, CH_4, NO_2).

Besides these primary measurements, auxiliary parameters are simultaneously measured because they are mandatory to decontaminate the primary measurements from unwanted effects due to atmospheric moisture (water vapour and liquid water).

Auxiliary parameters are obtained in three radiometric channels:

– Around 23.8 GHz for the total water vapour content.

– Around 90 GHz for the liquid water (precipitations).

– Around 31.5 GHz, which is the optimum "window" in the "valley" resulting from the combination of the oxygen and water-vapour absorption curves (see the channel 2 (A) on the Fig. 324), and which serves as a reference for all other measurements.

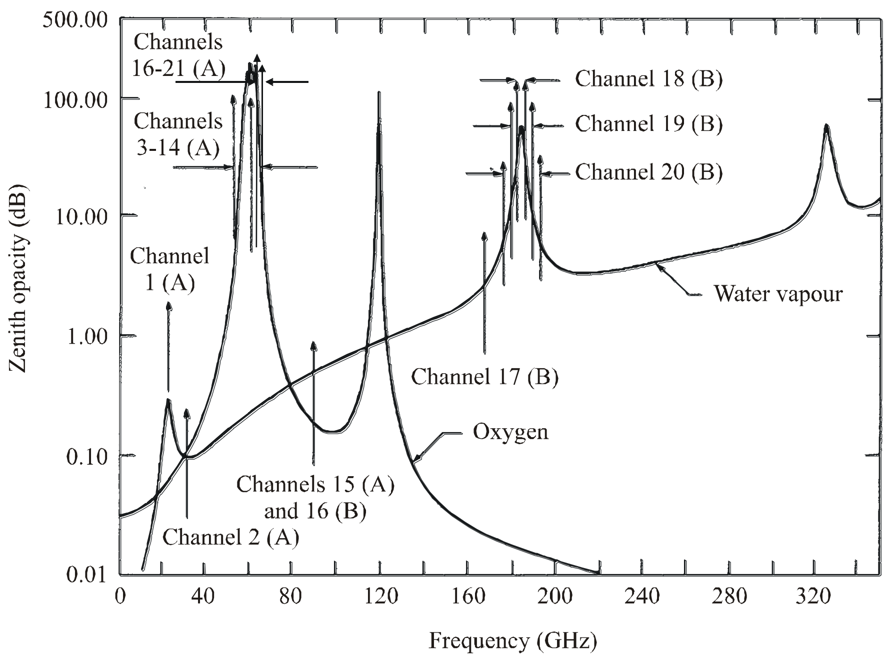
These auxiliary measurements must have radiometric and geometric performances consistent with those of the primary measurements, and must receive similar protection against interference. It is noted that the non-availability of only one auxiliary channel totally invalidates the complete data set.

These frequencies are indicated on the atmospheric O_2 and H_2O absorption curves presented on Fig. 324, where "channels 1(A) and (B), 2(A) and (B), 3(A) and (B)…" refer to the AMSU-A and B vertical sounders which are currently deployed on operational meteorological satellites.

FIGURE 324

Frequencies for 3D passive atmospheric sounding

Oxygen and water vapour absorption spectrum and position of AMSU-A and AMSU-B channels



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It must be emphasized that besides the numerical weather prediction, many applications relying on these measurements are strongly life and property-safety related. It was demonstrated that they can be severely hampered by any interference exceeding the internationally agreed threshold.

These applications are in particular:

– detection and signalization of potentially hazardous meteorological events. The augmentation of these hazardous events, even at mid latitudes, raise serious concerns in the scientific community;

– air and sea traffic routing and safety in the vicinity of airports;

– off-shore activities and in general out-door industrial activities.

The fulfilment of these tasks requires:

– the most accurate models of the atmosphere/oceans/land surface system;

– routinely acquired worldwide data which describe the status of the atmosphere/oceans/land surface system;

– the most powerful computers able to run the models and to assimilate the increasing volume of data.

Because the atmosphere/oceans/land surface system is extremely complex, the operational tasks must be supported by important background scientific activities aiming at a better understanding and the consequential better modelling of this system.

In addition to that, concerning the band 23.6-24 GHz, it is important to note that this is the unique band in the whole electromagnetic spectrum where it is possible to retrieve with a good quality the total vertical water vapour content.

Therefore, it is essential to preserve such a frequency band for undisturbed EESS observations.

The EESS (passive) currently operates two types of passive sensors in the 23.6-24 GHz band:

– Conically scanned sensors around the nadir direction, which are designed to measure two-dimensional surface (land and ocean) parameters as MEGHA-TROPIC, AMSR-E and CMIS instruments.
– Cross-track nadir sensors, which are designed to measure three-dimensional atmospheric parameters: Push-Broom, ATMS and AMSU-A instruments.

1.5.3 Protection criteria for EESS (passive)

Performance and interference criteria are provided in the following Recommendations ITU-R:

– Recommendation ITU-R SA.1028 – Performance criteria for satellite passive remote sensing.
– Recommendation ITU-R SA.1029 – Interference criteria for satellite remote sensing.

The current requirement for protection of EESS is as follows:

– The interference threshold of the passive sensor is –166 dBW in a reference bandwidth of 200 MHz. This is a maximum interference level from all sources. Such a threshold corresponds to a measurement sensitivity of 0.05 K.
– The number of measurement cells where the interference threshold can be exceeded must not be more than 0.01% of pixels in all service areas for any kind of instrument.

Acknowledging that the current study is assumed to represent a long-term scenario, it should also been emphasized that these criteria are more than likely to become even more stringent in the future while passive sensors will improve, taking advantage of the technological advances, to better meet accuracy and sensitivity requirements.

In addition, the above criterion from Recommendation ITU-R SA.1029 represents the maximum level of aggregate interference from all sources and therefore needs to be apportioned for UWB devices.

Radiocommunication WP 7C has provided information regarding apportionment of interference criteria to apply to interference from UWB devices that would be necessary to protect the EESS (passive): the interference criteria to be used for in band emissions in purely passive bands protected by RR No. 5.340 is based on an apportionment of 1% to 5% of the total interference criteria, that is to say –186 dBW for a bandwidth of 200 MHz for a 1% apportionment factor. This information was not derived from an ITU-R Recommendation and was provided through a liaison, the reason for this is that no Recommendation can be developed on apportionment for active in band emissions in band listed in RR No. 5.340.

1.5.4 24 GHz automotive short-range radars (SRR) characteristics

a) SRR car density

Car density information representative of peak hours during week days are needed to assess the maximum expected interference to EESS sensors from a deployment of SRR.

Based on estimations provided by the car industry to the United States and European countries during their regulatory process, the expected density of vehicles used in the calculations are given in Table 254.

TABLE 254

Expected car density

Type of deployment	Car density (vehicles/km²)
Highway scenario (outside urban/suburban areas)	123
Urban/suburban areas	330
Urban areas	453

It is to be noted that additional studies based on traffic statistics confirmed the adequacy of such figures and provide level of confidence that they indeed represent typical and relevant car density for peak hours traffic.

b) SRR activity factor, mitigation factors

An average number of four active SRRs per car is used in the interference analysis, taking into account a maximum number of eight SRR per car.

This activity factor reduction has taken into account the following mitigation elements:

– luxury car market shared factor (6% of the total);

– reduced number of sensors active in specific car scenarios (highway fluent traffic, highway low traffic, city driving, city parking).

For the specific case of the conical scan instruments, because of their specific geometry, a mitigation factor of 25% (i.e. only 1 SRR per car) is considered due to random car directions was assumed. However, this mitigation factor only applies to the direct interference from the SRR to the satellite but is not relevant to scattered interference (see § 1.5.5.2).

c) e.i.r.p. density

The maximum e.i.r.p. density of the 24 GHz SRR considered in the calculations is −41.3 dBm/MHz or –71.3 dBW/MHz.

d) Limitation of vertical antenna characteristics

The vertical antenna attenuation used in the calculation is based on the United States rules for the frequency band between 23.6 GHz to 24.0 GHz that gives the following limitations of vertical antenna pattern for the car radars at angles greater than 30º elevation above the horizontal plane:

25 dB attenuation by 1 January, 2005

30 dB attenuation by 1 January, 2010

35 dB attenuation by 1 January, 2014

For this analysis, only the third pattern (35 dB, more stringent) has been used, since it corresponds to the situation that would develop in the long term.

It should be noted that the two other patterns that are specified for dates prior to 2014 would result in a higher interference potential from SRR to EESS.

e) Bumper loss

It is likely that SRR would be mounted behind bumpers which could add attenuation on the SRR signal. Therefore, a loss of 3 dB due to bumper attenuation at 24 GHz has been considered.

1.5.5 Interference assessment

1.5.5.1 Introduction

The UWB emissions from vehicular radar systems deployed over the surface of an EESS cell pixel aggregate into EESS sensors.

EESS sensors encompass two different types of instruments:

– Conically scanned instruments, MEGHA-TROPIC, AMSR and CMIS

– Cross-track nadir instruments, Push-Broom, AMSU-A and ATMS

The interference mechanism includes a direct interference component (direct path from the SRR side lobes to the EESS pixel) and a scattered power component (reflections of the SRR main lobe on preceding cars or road).

Two complementary methodologies have been considered.

– A specific methodology that calculates, based on each EESS system characteristics, the maximum car density to reach the EESS interference threshold and the resulting margin (positive or negative).

– A generic methodology that is assumed to be independent from the EESS system characteristics.

1.5.5.2 Scattering effects and coupling factor

One of the most probable scattering mechanisms between mobile vehicle radar and a satellite radiometer is a reflection of the main lobe of the radar by another directly-illuminated vehicle toward the main lobe of the radiometer. The United States meteorological administration (NOAA) has made a study that analyses the impact of the radar signal scattering. This study has shown that the reflection generated by the rear part of the car in front of the transmitting radar would create a coupling ranging from –10 to –30 dB with respect to the EESS radiometers within the range of look angles.

It considers reflections from other cars only and takes into account the reflections due to the curvature of the window (characterized by an effective radius of curvature), the glass thickness and the distance between the two cars. Both cases of vertical and horizontal polarization have been considered.

The corresponding figures for a glass thickness of 0.5 cm and for a radius of curvature of 10 m are the following:

– Cars with a separation distance of less than 10 m: about 5% of cars and a scatter gain of –15 dB.

– Cars with a separation distance of less than 30 m and more than 10 m: about 45% of cars and a scatter gain of –18 dB.

– Cars with a separation distance of more than 30 m: about 50% of cars and a scatter gain of –25 dB.

On this basis, the averaged car scattering gain becomes:

$$car\_scattering\_gain = 10 * \log 10\left[0.05 * 10^{-1.5} + 0.45 * 10^{-1.8} + 0.5 * 10^{-2.5}\right] = -19.8\,\text{dB}$$

The resulting scattered power is: PSRR – car_cattering_gain – bumper_attenuation

= –71.3 −19.8 −3 = −94.1 dBW/MHz

Field tests performed to measure the scattering effects at 24 GHz further indicate that a 4.7 dB factor should be deducted from the above scattered power to take into account the hemispherical distribution of the scattering. The resulting total scattered power per transmitter is therefore:

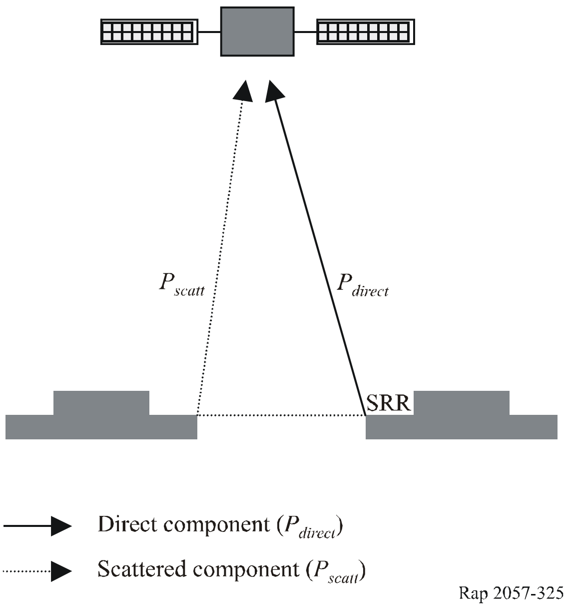
$$\text{scattered\_power} = P_{scatt} = –94.1 –4.7 = −98.8 \text{ dBW/MHz}$$

It must be noted that the above analysis does not include considerations about the ground scattering and any additional power scattered by secondary reflections. This could increase the interference level, in particular in the urban scenario. At this stage, given the margin levels calculated in the interference assessment below, it was not felt that the additional study effort is required. In case it is needed, the work of Radiocommunication SG 3 could provide some guidance for the part relevant to the secondary reflections contribution.

As a summary, Fig. 325 describes the interference mechanism and coupling between 24 GHz SRR and EESS sensors.

FIGURE 325

Interference mechanism and coupling between SRR and EESS



The resulting coupling between SRR and EESS sensors is hence, at the surface of the Earth (i.e. without free-space losses):

$$P_{coupling} = 10 \log(10^{(P_{direct}/10)} + 10^{(P_{scatt}/10)})$$

where:

P_{scatt}: scattered power = −98.8 dBW/MHz

P_{direct}: direct path power = SRR e.i.r.p. density – vertical attenuation − bumper loss = −71.3 −35 − 3 = −109.3 dBW/MHz

If the scattered power and the direct path power are both combined, then it hence results that

$$P_{coupling} = -98.4 \text{ dBW/MHz}$$

In that case, compared to the SRR emission (SRR e.i.r.p. density – bumper loss), the total coupling factor between 24 GHz SRR and EESS sensors is:

$$C = \text{SRR e.i.r.p. density} - \text{bumper loss} - P_{coupling} = 24.1 \text{ dB}$$

It has to be noted that this coupling factor relates to the cross-track nadir EESS systems for which the same number of SRR per car (4 as given in § 1.5.4 b)) is considered either for the direct component or for the scattered component.

In the case of conical scan instruments, only one SRR is considered for the direct path, due to random car directions, but the 4 SRR per car are to be considered for the scattered component since the scattered power is treated as a "hemispherical distribution".

1.5.5.3 Interference calculations for specific conically scanned EESS instruments with apportionment of the interference criteria

TABLE 255

Interference analysis between 24 GHz SRR and conically scanned EESS instruments with apportionment of interference criteria

Parameter	Megha-tropic	AMSR-E	CMIS
Maximum e.i.r.p. (power spectral density) (dBm/MHz)	–41.3	–41.3	–41.3
Bumper attenuation (dB)	3	3	3
Gating effect (dB)	0	0	0
Radar antenna gain to be substracted (2 014 mask) (dBi)	35	35	35
Direct power component (dBW/MHz)	–109.3	–109.3	–109.3
Adjustment factor due to random car directions applicable for the direct power component only (%)	25	25	25
Total direct power component (dBW/MHz)	–115.3	–115.3	–115.3
Total scattered power component (dBW/MHz)	–98.8	–98.8	–98.8
Total power (dBW/MHz)	–98.7	–98.7	–98.7
Distance radar – EESS sensor (km)	1 336	1 229	1 336
Space attenuation (dB)	182.5	181.8	182.5
EESS antenna gain (dBi)	40	46	52
Atmospherical loss (Rec. ITU–R P.676) (dB)	1.6	1.7	1.7
Received power at the EESS in a 1 MHz bandwidth (dBW)	–242.8	–236.2	–230.9
Corresponding received power at the EESS in a bandwidth of 200 MHz for one single radar (dBW)	–219.8	–213.2	–207.9
EESS interference threshold in a reference bandwidth of 200 MHz: application of Rec. ITU-R SA.1029 with 5% apportionment (dBW)	–179	–179	–179
EESS interference threshold in a reference bandwidth of 200 MHz: application of Rec. ITU-R SA.1029 with 1% apportionment (dBW)	–186	–186	–186

TABLE 255 (*end*)

Parameter	Megha-tropic	AMSR-E	CMIS
Number of radars in order to reach the EESS threshold for 1% apport	2 390	520	154
Number of radars in order to reach the EESS threshold for 1% apport (dB)	33.8	27.2	21.9
Number of active radars per car	4	4	4
Pixel surface (km^2)	1 926	425	264
Maximum car density/km^2 corresponding to the above number of cars in the EESS pixel for 1% apport	0.31	0.31	0.15
Maximum car density/km^2 corresponding to the above number of cars in the EESS pixel for 1% apport (dB)	–5.1	–5.1	–8.4
Expected car density/km²: highway scenario (car/km^2)	123	123	123
Expected car density/km^2: urban/suburban scenario (car/km^2)	330	330	330
Expected car density/km^2: urban scenario (car/km^2)	453	453	453
Margin in highway scenario (dB, 1% apportionment)	–26.0	–26.0	–29.3
(dB, 5% apportionment)	–19.0	–19.1	–22.3
Margin in urban/suburban scenario (dB, 1% apportionment)	–30.3	–30.3	–33.5
(dB, 5% apportionment)	–23.3	–23.3	–26.5
Margin in urban scenario (dB, 1% apportionment)	–31.6	–31.7	–34.9
(dB, 5% apportionment)	–24.7	–24.7	–27.9

Based on a 100% deployment of SRR, the margins for all instruments are heavily negative for all scenarios down to –35 dB. Taking into account other aspects not considered in the interference analysis (see § 1.5.6), some elements such as operation modes or market penetration could decrease the negative margin whereas other elements such second reflection effects and future developments of EESS sensors could further degrade these margins. These factors are expected to offset each other to a significant degree.

It is to be noted that the analysis is based on the United States emission mask that will be in operation by the year 2014. Taking into account the earlier, less stringent masks would increase the negative margin.

1.5.5.4 Interference calculations for specific cross-track nadir EESS sensors

TABLE 256

Interference analysis between 24 GHz SRR and nadir sensors with apportionment of the interference criteria

Parameter	Push broom	AMSU-A	ATMS
Maximum e.i.r.p. (power spectral density) (dBm/MHz)	–41.3	–41.3	–41.3
Bumper attenuation (dB)	3	3	3
Direction of interfering path	Zenith	Zenith	Zenith
Radar antenna gain to be substracted (2 014 mask) (dBi)	35	35	35

TABLE 256 (*end*)

Parameter	Push broom	AMSU-A	ATMS
Direct power component (dBW/MHz)	–109.3	–109.3	–109.3
Total scattered power component (dBm/MHz)	–98.8	–98.8	–98.8
Total power (dBW/MHz)	–98.4	–98.4	–98.4
Resulting coupling (dB)	24.1	24.1	24.1
Distance radar – EESS sensor (km)	850	850	850
Space attenuation (dB)	178.6	178.6	178.6
EESS antenna gain (dBi)	45	36	31
Atmospherical loss (Rec. ITU–R P.676) (dB)	1	1	1
Received power at the EESS in a 1 MHz bandwidth (dBW)	–233.0	–242.0	–247.0
Corresponding received power at the EESS in a bandwidth of 200 MHz for one single radar (dBW)	–210.0	–219.0	–224.0
EESS interference threshold in a reference bandwidth of 200 MHz: application of Rec. ITU-R SA.1029 with 5% apportionment (dBW)	–179	–179	–179
EESS interference threshold in a reference bandwidth of 200 MHz: application of Rec. ITU-R SA.1029 with 1% apportionment (dBW)	–186	–186	–186
Number of radars in order to reach the EESS threshold for 1% apportment	250	1 986	6 281
Number of radars in order to reach the EESS threshold for 1% apportment (dB)	24.0	33.0	38.0
Number of active radars per car	4	4	4
Pixel surface (km^2)	206	1 842	4 542
Maximum car density/km^2 corresponding to the above number of cars in the EESS pixel for 1% apportionment	0.30	0.27	0.35
Maximum car density/km^2 corresponding to the above number of cars in the EESS pixel for 1% apportionment (dB)	–5.2	–5.7	–4.6
Expected car density/km^2: highway scenario (car/km^2)	123	123	123
Expected car density/km^2: urban/suburban scenario (car/km^2)	330	330	330
Expected car density/km^2: urban scenario (car/km^2)	453	453	453
Margin in highway scenario (dB, 1% apportionment)	–26.1	–26.6	–25.5
(dB, 5% apportionment)	–19.1	–19.6	–18.5
Margin in urban/suburban scenario (dB, 1% apportionment)	–30.4	–30.9	–29.8
(dB, 5% apportionment)	–23.4	–23.9	–22.8
Margin in urban scenario (dB, 1% apportionment)	–31.7	–32.3	–31.2
(dB, 5% apportionment)	–24.7	–25.3	–24.2

Based on a 100% deployment of SRR, the margins for all instruments and all car densities scenarios are also all heavily negative down to –32 dB. Taking into account other aspects not considered in the interference analysis (see § 1.5.6), some elements such as operation modes or market penetration could decrease the negative margin whereas other elements such second reflection effects and future developments of EESS sensors could further degrade these margins. These factors are expected to offset each other to a significant degree.

It is to be noted that the analysis is based on the United States emission mask that will be in operation by the year 2014. Taking into account the earlier less stringent masks would increase the negative margin.

1.5.5.5 Interference calculations with a generic methodology

The generic methodology assumes that the interference assessment from SRR to EESS sensors is independent from the satellites characteristics and can be generalized to the case of an isotropic EESS sensor antenna, using the following equation:

$$n = \frac{4\pi}{PC} \frac{\alpha k \delta T_{th}}{\lambda^2} \cos(\theta) e^{\frac{\tau}{\cos(\theta)}}$$

where:

- n: number of SRR per unit area (km^2)
- P: e.i.r.p. density of a SRR (including bumper loss and gating)
- δTh: allowable interference threshold (K)
- C: Coupling factor (direct path and scattering effect) on a polarized basis
- τ: atmospheric opacity from the surface to the satellite
- θ: incidence angle of the satellite beam from nadir
- λ: wavelength (m)
- k: Boltzmann's constant (1.38×10^{-23} J/K)
- α: incidental coefficient to account for other factors.

On this basis, it is hence possible to calculate the maximum number of cars per unit area (km^2) to reach the EESS threshold as a function of the maximum power density. Such calculations were performed on this basis and confirmed the above results based on specific EESS systems.

1.5.6 Other aspects not considered in the interference analysis

Although the above interference analysis can be used to draw conclusions on the sharing feasibility, the following factors have not been considered.

1.5.6.1 Other mitigation factors

1.5.6.1.1 Additional mitigation factors

The following additional mitigation factors may be used to improve the interference analysis.

SRR device operation modes leading to an average emission power reduction needs to be considered in the derivation of SRR device activity factors. These modes are listed below:

– *SRR switched off*: Depending upon the control device in a vehicle, SRR devices may be turned off automatically when the vehicle is stopped for a duration longer than some preset interval. For example at a stoplight or a railroad crossing; in some vehicles both the engine and the SRR devices may be turned off while in other vehicles the engine may remain on but some or all SRR devices may be turned off[62].

[62] Some low fuel consumption car models already use this technique.

– *Reduced pulse repetition frequency (PRF)*: The parking aid and stop-and-go application can run at a reduced PRF rate because of low vehicle motion and traffic scenario. This resulting PRF reduction linearly reduces the average emission power of the SRR device ensemble. The nominal PRF in this context is then the frequency where the SRR device achieves the maximum allowed mean power. Depending on the traffic scenario dynamics some applications will run on a lower PRF or with longer quiescent periods. Both effects reduce the maximum allowed mean power. This mean power reduction can be expressed by an activity factor.

– *Non-UWB Mode*: Beside the UWB mode the sensors are being designed to operate in certain driving situations in a non-UWB mode within the ISM band 24.00 to 24.25 GHz. The non-UWB mode can be either a narrow band mode in this frequency range or a Doppler mode (CW mode).

  The reason for a non-UWB mode of SRRs is that some vehicular applications or driving situations need either less object separation capability (which results in a much smaller occupied bandwidth) or a longer detection range (which requires higher emission power as permitted solely in this band). Due to hardware limitations SRR devices may switch either in a wideband mode or in a narrowband mode. So if a SRR device operates for a given time instance in a non-UWB mode, UWB emissions are completely switched off.

– *Partial frequency range and multiband UWB operation*: A further reduction of the aggregated mean power within the SRR ensemble is possible when the SRR devices use the available frequency range in a sharing manner. Five SRR with an occupied bandwidth of 1 GHz each may use, when arranged one beside another in the spectrum domain, the same spectrum as one SRR with 5 GHz bandwidth[63]. Furthermore, similar to multiband operation interference risk with radio communication services can be mitigated by change to another sub-frequency range.

1.5.6.1.2 Potential effect of those additional mitigation factors

The combined potential effect of the mitigation factors described in § 1.5.6.1.1 is expected to provide a maximum additional mitigation factor of 3 dB.

1.5.6.1.3 SRR device penetration factor

There will be alternative technologies for some of the functionality supplied by 24 GHz UWB SRR devices including 79 GHz UWB SRR devices[64], as well as infrared, ultrasonic and closed circuit video devices. A 100% technology penetration of 24 GHz UWB SRR is unrealistic. Studies may assume a theoretical penetration of 100%, which might be not even conceivable if mandatory regulated by administrations due to technological neutral policies. It is more likely that any administration regulations would require a capability that may be satisfied by various technologies rather than specifying a particular single technology, so that the eventual technology penetration will stabilize at a smaller percentage. On a long term basis (2030) it is assumed that the UWB SRR technology would represent a market penetration of about 55%. Depending on national regulations the portion of 24 GHz SRR is assumed to be around 40% if no mandatory limitations are applied. It has to be noted that the regulation in Europe authorizes the placing into the market of 24 GHz SRR until 2013 and limits the penetration to 7% of the car fleet. A penetration of 7% or 40% corresponds to a mitigation factor of 11.5 dB and 4 dB respectively.

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[63] Actually a blind spot monitoring SRR system is under development with an occupied bandwidth below 1 GHz.

[64] To be considered only if this band has been allocated by the administration for this purpose.

1.5.6.2 Aggravating factors

It is worth noting that each of the following effects is able to create additional negative margins in the interference analysis.

1.5.6.2.1 Scattering effects (secondary reflections and ground scattering) and other effects

It must be noted that the scattering analysis in this section does not include considerations about the additional power scattered by secondary reflections (from asphalt for example). This could add a significant interference level, in particular in the urban scenario. At this stage, given the margin levels calculated in the interference analysis, it is felt that the additional study effort is not required. In case it is needed, the work of Radiocommunication SG 3 could provide some guidance.

Also the ground scattering effect has not been evaluated at this stage, since the car scattering appears to be dominant (see § 1.5.5.2). Nevertheless the ground scattering contribution can be calculated in the future if required.

Finally, other aspects such as SRR misalignments, unwanted emissions from the high power carrier signal have been not taken into consideration.

1.5.6.2.2 Future possible developments of EESS sensors

As already stated in § 1.5.3 above, in line with other Recommendations providing equipment characteristics to be used in interference studies, Recommendations ITU-R SA.1028 and ITU-R SA.1029 are expected to be under continuous review. It is therefore to be expected that a future revision of Recommendation ITU-R SA.1029 will have a lower threshold value for this band, as a consequence of an improved sensitivity as in Recommendation ITU-R SA.1028.

It is assumed that both accuracy and sensitivity of passive sensors will improve, taking advantage of technological advances and a 6/7 dB tightening of the performance criteria of EESS sensors that would operate at around 2020 represents a reasonable assumption.

1.5.7 Summary of interference studies between EESS and 24 GHz SRR, conclusion

The result of interference analysis using specific EESS systems characteristics or generic methodology, concludes that a 100% deployment of SRR operating at 24 GHz results in interference exceeding the EESS threshold up to 35 dB with a 1% apportionment of the interference criteria.

According to the analysis, data derived from measurements performed in the band 23.6-24 GHz, where vehicular radars are in operation, will be corrupted in corresponding EESS observations (cities, roads or motorways).

TABLE 257

Summary of interference analysis between 24 GHz SRR and EESS sensors

Car density/km^2	Resulting margin with 5% apportionment	Resulting margin with 1% apportionment
123 (highway scenario)	−22.3	−29.3
330 (suburban scenario)	−26.5	−33.5
453 (urban scenario)	−27.9	−34.9

This study accounts for mitigation techniques such as improved SRR antenna side lobes above 30° of the horizontal plane (35 dB attenuation by 2014 in the United States rules) as well as four active SRR per car over the eight SRR implemented.

It has to be noted that other aspects were not considered in the interference analysis. Some elements such as operation modes or market penetration could decrease the negative margin whereas other elements such second reflection effects and future developments of EESS sensors could further degrade these margins. These factors are expected to offset each other to a significant degree.

Considering the current level of negative margin, it appears unlikely that, at 100% deployment, other possible mitigation techniques could provide efficiency in achieving the protection to EESS from the 24 GHz SRR.

NOTE 1 – It has to be noted that one administration has already established its domestic rules allowing vehicular anti-collision short range radars (SRR) to operate in the 23.6 to 24.0 GHz, based on a previous analysis using different parameters and assumptions:

– Scattering or reflection of SRR signals was not used in this analysis. Later studies, as described in § 1.5.5.2, found that scattered energy added to the direct energy could substantially increase the total energy directed toward the sensor.
– The interference threshold used in this administration's analysis was based on Recommendation ITU-R SA.1029 which contains an interference threshold value for sensors in this band that is 6 dB higher than the corresponding value in the current Recommendation ITU-R SA.1029.
– This analysis apportions 100% of this interference threshold to the UWB SRR devices. A 1% apportionment would decrease the margins by 20 dB.

2 Space research service (including deep space) and space operation service

2.1 Interference analysis in the 2 025-2 110 MHz band

The band 2 025-2 110 MHz is allocated to the following services: Earth exploration-satellite (Earth-to-space), space research (Earth-to-space) and space operation (Earth-to-space). Space research communications are required for several kinds of several functions: telecommand, maintenance telemetering, stored scientific data and real-time scientific data. According to Recommendation ITU-R SA.609, the protection criterion for the above services is −177 dBW/kHz at the input terminal of the spaceborne receiver. The average gain of a quasi omnidirectional antenna for this frequency band is around 0 dBi. Therefore, with a 0 dBi antenna, the acceptable interference at the antenna input is −207 dBW/Hz or −117 dBm/MHz.

Radiocommunication WP 7B has studied the apportionment of degradation for space research and space operation service systems for the following categories of emissions:

– emissions from other SRS and SOS networks sharing the same band;
– emissions from networks of other services with equal status sharing the same band;
– emissions from all other sources.

It is noted that interference from the emissions of devices using UWB technology falls within the third category. It is considered that the aggregate interference from the third category of sources of interference should constitute on the order of 1% of the total degradation.

Therefore, the acceptable interference at the antenna input is −137 dBm/MHz.

Typical altitudes of those kinds of satellites are around 700 km.

In Table 258, two cases are considered: indoor use and outdoor use. For the case of indoor use, an average building attenuation of 12 dB is used in the aggregate model only.

TABLE 258

Interference analysis between UWB and SRS in the band 2 025-2 110 MHz

Frequency	2 025	MHz (2 025-2 110 MHz band)
Wavelength	0.15	m
Protection criteria (Rec. ITU-R SA.609-1)	–177	dBW/kHz at the spaceborne receiver
Satellite antenna gain	0	dBi
Minimum elevation angle at the ground station	5	(degrees)
Maximum interference level at the antenna level of the spacebornereceiver including 1% apportionment	–137.0	dBm/MHz

Parameter	**United States mask (outdoor)**	**United States mask (indoor)**	**United States mask (indoor and outdoor)**
Maximum e.i.r.p. (power spectral density) of a single UWB device (dBm/MHz)	–59	–49	–35
Distance UWB – Satellite receiver at the nadir (km)	700	700	700
Space attenuation (dB)	155	155	155
Satellite antenna gain (dBi)	0	0	0
Received power at the SRS in 1 MHz bandwidth (dBm/MHz)	–214	–204	-190
Threshold (dBm/MHz)	–137.0	–137.0	-137.0
Margin with a single UWB device (dB)	77.4	67.4	53.4
Activity factor (%)	5	5	5
% Outdoor	20	20	20
% Indoor	80	80	80
Indoor/outdoor attenuation (dB)	0	12	12
Half geocentric angle (degrees)	21.15	21.15	21.15
Size of the satellite footprint: radius (km) for a minimum ground station elevation angle of 5° assuming a flat Earth (km)	2 354	2 354	2 354
Maximum UWB density/km^2 corresponding to the above SRS footprint (UWB/km^2)	64	101	4
Received power of a single UWB device at the SRS receiver in 1 MHz bandwidth (dBm) for both indoor and outdoor usage (dBm/MHz)	–215.95		–196.44279
Maximum UWB density/km^2 corresponding to the above SRS footprint for both indoor and outdoor usage (UWB/km^2)	90		1

Table 259 summarizes the above results as a function of the UWB density.

TABLE 259

Summary of interference analysis between UWB and SRS in the band 2 025-2 110 MHz

Density of UWB transmitters/km^2	Required UWB e.i.r.p. density (dBm/MHz)		Required UWB e.i.r.p. density (dBm/MHz)
	Indoor	Outdoor	Both outdoor and indoor
1	−29	−39	−35
10	−39	−49	−45
100	−49	−59	−55
1 000	−59	−69	−65
10 000	−69	−79	−75

2.2 2 200-2 290 MHz band

The band 2 200-2 290 MHz is allocated to the following services: Earth exploration-satellite (space-to-Earth), space research (space-to-Earth) and space operation (space-to-Earth). Space research communications are required for several kinds of several functions: telecommand, maintenance telemetering, stored scientific data and real-time scientific data. According to Recommendation ITU-R SA.609, the protection criterion for SRS is −216 dBW/Hz at the input of the earth station receiver. Typical antenna gain for SRS earth station is 62 dBi (diameter of 70 m). For this case, in order to take into account more realistic situations, the fixed gain of the antenna gain of the earth station which is directional because the ground station is tracking a LEO satellite in azimuth and in elevation, is decreased by 40 dB in order to reach the antenna side lobes.

Therefore, with a 62 – 40 = 22 dBi antenna, the acceptable interference at the antenna input is –238 dBW/Hz or –148 dBm/MHz. Due do the 1% apportionment factor, the acceptable interference at the antenna input is –168 dBm/MHz.

Typical altitudes of science satellites are around 700 km.

Table 260 summarize the above results as a function of the UWB density.

TABLE 260

Computation of the protection distance for a maximum radius of 10 km for the band 2 200-2 290 MHz

UWB density (UWB/km^2)	UWB spectrum mask e.i.r.p. limit (dBm/MHz)	United States outdoor mask –62	United States indoor mask –52	Mask outdoor and indoor –60	Mask outdoor and indoor –70
1	Protection distance, maximum radius of 10 km	5 km	3.5 km	2 km	10 m
10	Protection distance, maximum radius of 10 km	9.4 km	9 km	8.5 km	2 km
100	Protection distance, maximum radius of 10 km	9.95 km	9.9 km	9.85 km	8.5 km
1 000	Protection distance, maximum radius of 10 km	Not available	Not available	Not available	9.9 km

TABLE 261

Computation of the protection distance for a maximum radius of 30 km for the band 2 200-2 290 MHz

UWB density (UWB/km^2)	UWB spectrum mask e.i.r.p. limit (dBm/MHz)	United States outdoor mask –62	United States indoor mask –52	Mask outdoor and indoor –60	Mask outdoor and indoor –70
1	Protection distance, maximum radius of 30 km	15 km	10 km	5 km	10 km
10	Protection distance, maximum radius of 30 km	28 km	27 km	25 km	6 km
100	Protection distance, maximum radius of 30 km	29.8 km	29.7 km	29.5 km	26 km
1 000	Protection distance, maximum radius of 30 km	29.98 km	29.97 km	29.95 km	29.5 km

2.3 Preliminary conclusion about the bands 2 025-2 110 and 2 200-2 290 MHz

The above calculations have shown that quite a coordination distance is required around each earth station. Therefore, due to the fact the characteristics of the UWB deployment are not correctly known, it is recommended that a specific attention must be paid to the band 2 200-2 290 MHz and that the analysis tends to show that UWB devices must avoid such band in order not to cause any interference to the earth stations.

2.4 8 400-8 450 MHz band, SRS (deep space)

The band 8 400-8 450 MHz is allocated to space research (space-to-Earth, deep space only). According to Recommendation ITU-R SA.1157, the protection criterion for SRS is −220 dBW/Hz at the input of the earth station receiver. Typical antenna gain for SRS earth station is 73 dBi (diameter of 70 m). For this case, in order to take into account more realistic situations, the fixed gain of the antenna gain of the earth station which is directional because the ground station is tracking a LEO satellite in azimuth and in elevation, is decreased by 60 dB in order to reach the antenna side lobes.

Therefore, with a 73 – 60 = 13 dBi antenna, the acceptable interference at the antenna input is –233 dBW/Hz or –143 dBm/MHz. Due do the 1% apportionment factor, the acceptable interference at the antenna input is –163 dBm/MHz.

Tables 262 and 263 summarize the above results as a function of the UWB density.

TABLE 262

Computation of the protection distance for a maximum radius of 10 km for the band 8 400-8 450 MHz

UWB density (UWB/km^2)	UWB spectrum mask e.i.r.p. limit (dBm/MHz)	Mask outdoor and indoor –40	Mask outdoor and indoor –50	Mask outdoor and indoor –60	Mask outdoor and indoor –70
1	Protection distance, maximum radius of 10 km	4 km	10 m	10 m	10 m
10	Protection distance, maximum radius of 10 km	9 km	4 km	10 m	10 km
100	Protection distance, maximum radius of 10 km	9.9 km	9 km	4 km	10 km
1 000	Protection distance, maximum radius of 10 km	Not available	9.9 km	9.1 km	4 km

Not available: Integral method breaks down for the above parameters.

TABLE 263

Computation of the protection distance for a maximum radius of 30 km for the band 8 400-8 450 MHz

UWB density (UWB/km^2)	UWB spectrum mask e.i.r.p. limit (dBm/MHz)	Mask outdoor and indoor –40	Mask outdoor and indoor –50	Mask outdoor and indoor –60	Mask outdoor and indoor –70
1	Protection distance, maximum radius of 30 km	11 km	10 m	10 m	10 m
10	Protection distance, maximum radius of 30 km	27 km	10 km	10 m	10 m
100	Protection distance, maximum radius of 30 km	29.9 km	27 km	14 km	10 m
1 000	Protection distance, maximum radius of 30 km	Not available	29.9 km	27 km	12 km

Not available: Integral method breaks down for the above parameters.

2.5 Conclusion about the SRS bands

The above calculations have shown the following.

For the band 2 025-2 100 MHz (Earth-to-space) and based on an outdoor mask of –62 dBm/MHz and an indoor mask of –52 dBm/MHz, a limited deployment of UWB devices may be possible.

For the bands 2 200-2 290 and 8 400-8 450 MHz (space-to-Earth), in each case, a protection distance is required around each Earth station. It is recommended that specific attention must be paid to those bands in order not to cause any interference to those earth stations.

3 Studies related to the impact of devices using UWB technology on systems operating within the radio astronomy service

3.1 Impact on the radio astronomy service

In this chapter the impact of devices using UWB technology on stations operating within the radio astronomy service (RAS) is examined for the following three cases: for devices using UWB technology operating in the frequency range 0.6-10.6 GHz in § 3.1.1, for automotive SRR operating around 24 GHz in § 3.1.2, and for automotive SRR operating around 79 GHz in § 3.1.3.

3.1.1 RAS and UWB in the range 0.6-10.6 GHz

In this sub-chapter, the possible impact of devices using UWB technology between 0.6 and 10.6 GHz on radio astronomy stations operating in radio astronomy bands between these frequencies is studied.

Recommendations ITU-R RA.769, ITU-R RA.1513 and ITU-R P.452 were taken as a basis for the performed interference studies.

3.1.1.1 Bands allocated to the RAS

Table 264 lists the frequency bands allocated to, and used by, the RAS in the range 0.6-10.6 GHz.

TABLE 264

Frequency bands used by the RAS in the range 0.6-10.6 GHz and their protection criteria

Frequency band (MHz)	Relevant RR footnote	Detrimental spfd (Rec. ITU-R RA.769) (dB(W/(m^2.Hz)))
608-614	RR No 5.149 (in Regions 1 and 3)	–253(2)
1 330.0-1 400.0	RR No. 5.149	–239(1), –255(2)
1 400.0-1 427.0	RR No. 5.340	–239(1), –255(2)
1 610.6-1 613.8	RR No. 5.149	–238(1)
1 660.0-1 670.0	RR No. 5.149	–237(1), –251(2)
1 718.8-1 722.2	RR No. 5.149	–237(1)
2 655.0-2 690.0	RR No. 5.149	–247(2)
2 690.0-2 700.0	RR No. 5.340	–247(2)
3 260.0-3 267.0	RR No. 5.149	–230(1)
3 332.0-3 339.0	RR No. 5.149	–230(1)
3 345.8-3 352.5	RR No. 5.149	–230(1)
4 800.0-4 990.0	RR No. 5.149	–230(1), –241(2)
4 990.0-5 000.0	RR No. 5.149	–241(2)
6 650.0-6 675.2	RR No. 5.149	–230(1)

(1) Spectral line observations (narrow band).

(2) Continuum observations (broadband).

RR No. 5.149 states that "...administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. Emissions from spaceborne or airborne stations can be particularly serious sources of interference to the radio astronomy service (see Nos. 4.5 and 4.6 and Article 29)" in given frequency bands.

RR No. 5.340 states that "All emissions are prohibited..." in given frequency bands.

3.1.1.2 Required protection criteria for the RAS

The protection criteria for the RAS frequency bands in the 0.6-10.6 GHz range are given in Table 264 in terms of spfd at receiver input detrimental to radio astronomy, for both spectral line (narrow band) and continuum (broadband) observations made in single-dish mode, as all radio telescopes operational in this range are used for this kind of observations – the most stringent levels should always be used. These threshold levels have been determined using the methodology of Recommendation ITU-R RA.769.

Recommendation ITU-R RA.769 assumes that the chance of the interference being received by the main lobe of the antenna is low, and that interference is received in a side lobe of the antenna pattern, i.e. at a level of 0 dBi at 19º from boresight (see also Recommendation ITU-R SA.509). For the assumptions considered in Recommendation ITU-R RA.769, it is irrelevant whether the interferer is in the near field or in the far field of a radio telescope.

Above the threshold levels of interference detrimental to radio astronomy observations given in Recommendation ITU-R RA.769, radio astronomical data are degraded and may be eventually obliterated. In principle, under rather idealized circumstances, if these levels are very slightly exceeded, it may be possible to compensate at the radio astronomy observatory by increased observing time. In doing so, the channel capacity of the telescope is reduced, with a corresponding reduction in scientific throughput. If the interference exceeds the detrimental interference threshold levels given in Recommendation ITU-R RA.769 by 10 dB or more, then increased observing time will no longer be effective in ensuring that valid scientific data are provided to the scientist. The radio astronomy station will be unable to operate in the affected frequency band, and its ability to provide service will have been lost if no appropriate mitigation techniques can be applied.

3.1.1.3 Operational characteristics of the RAS

The RAS bands in the 0.6-10.6 GHz range are used for a wide variety of scientific programs, using both spectral line (narrow-band) and continuum (broadband) observations, with radio telescopes used in single-dish or very long baseline interferometry (VLBI) mode. In general, observations are made differentially. In the case of continuum emissions, a map may be made of the area of sky containing the source, and the background emission subtracted; measurements are made of the power coming from the direction from the source (on-source) and at one or more nearby positions in the sky (off-source).

In the case of spectral line observations, spectra are recorded in frequency ranges including the line emissions of interest (the line spectra), and then at a frequency that is offset from the line emissions, or at the same frequency but at a nearby position in the sky (the reference spectra). Multichannel spectrometers are used that can integrate simultaneously the power in many (typically 256 to 4 096) frequency channels distributed across the band.

VLBI observations are made by digitizing the data without rectification, recording them along with precise timing signals, and synchronizing and correlating them later in a VLBI data processing centre. Consequently, the full impact of interference might not be known until the observing period is over and the data has been processed.

3.1.1.4 Interference assessment

3.1.1.4.1 Methodology used to assess the maximum tolerable e.i.r.p. per device using UWB technology

To estimate the tolerable transmission power of a device using UWB technology received at a RAS antenna, the mathematical summation methodology described in § A2.3.3 of Recommendation ITU-R SM.1757 was used, for a given separation distance, protection criterion and some additional necessary parameters as given in Table 265. The path loss is assumed to be the same for all emitters on a specific ring. The spfd was then calculated for all the emitters per ring and the total spfd is the summation of the spfd contributed by each ring.

TABLE 265

Input parameters used for the summation methodology

R_I	30 m(1)
R_0	500 km
Δ	0.01 km

(1) The assumed inner ring radius of 30 m is in practice the shortest distance between the edge of a radio telescope and the boundary of the terrain over which the radio astronomy site has enforcement authority.

Δ = Ring separation distance.

Radio astronomy observations must be protected from all devices using UWB technology anywhere outside the extent of the radio astronomy station territory. Results are given for a inner ring radius, R_I, of 30 m, and a maximum distance of 500 km was adopted in order to sample a sufficiently large geographic area and to reduce the influence of local fluctuations in the density of devices using UWB technology.

For the evaluation of the atmospheric attenuation of UWB transmissions towards a radio telescope Recommendation ITU-R P.452 was used.

3.1.1.4.2 Calculation of the maximum tolerable e.i.r.p. per device using UWB technology

For the calculations presented here it is considered that the interference received at the radio telescope antenna shall not exceed the levels of detrimental interference given in Recommendation ITU-R RA.769. The radio telescope antenna gain was taken as 0 dBi, following Recommendation ITU-R RA.769. For impact studies generically applicable to all radio telescopes, it must be assumed that a radio telescope can point to all directions in the sky, i.e. that its azimuth can vary between 0º and 360º and its elevation angle between 0º and 90º.

In the application of Recommendation ITU-R P.452, attenuation due to anomalous propagation, terrain shielding and clutter loss were not taken into account. The sea level refractivity values used taken from the Recommendation are representative for the latitudes of most radio telescopes in the world. A 10% loss due to tropospheric fluctuations was used, in accordance with Recommendation ITU-R RA.1031 and the ITU-R Handbook for Radio astronomy. Water vapour density values of 3 to 7.5 g/cm^3 were used, depending on the distance domain, following the Recommendation ITU-R P.452.

A path angular distance θ of 0° was assumed, which implies a transmit horizon elevation angle (device using UWB technology) of $\theta_t = 0°$ and a receive horizon elevation angle (radio telescope) of $\theta_r = 0°$, respectively. This does not mean, however, that the attenuation calculations shown here represent a worse-case scenario, which would concern observations made with the radio telescope pointing towards the horizon ($\theta_r = 0°$) – since it is assumed that all UWB transmissions are received through the 0 dBi side lobes of the radio telescope, these calculations are actually valid for any pointing direction of the telescope.

With the input parameters given in Table 266 the maximum tolerable e.i.r.p. per device using UWB technology has been estimated, as a function of the density of devices using UWB technology/km^2, the building attenuation for the frequency considered and the fraction of devices using UWB technology used outdoor. The 2% value used for the fraction of data-loss due to interference is in compliance with Recommendation ITU-R RA.1513. It is assumed that all devices using UWB technology have the same transmitting power.

TABLE 266

Input parameters used for the maximum tolerable e.i.r.p. calculations

Maximum permissible spfd	From Table 264
Frequency	From Table 264
Reference bandwidth	1 MHz
Path angular distance	0°
Sea level refractivity	320
Fraction of data-loss due to interference	2%

It should be noted that the results are rather insensitive to the height of either the radio telescope antenna or the device using UWB technology.

3.1.1.4.3 Values achieved

The following expression is found for the maximum permissible e.i.r.p. per device using UWB technology in the frequency range of 0.6 – 10.7 GHz that does not exceed the protection criteria for radio astronomy:

$$e.i.r.p._{max} = -10 * \log \rho + e.i.r.p._o(f) + \beta + 10 * \log (1-\Pi) \qquad \text{dBm/MHz}$$

where:

- ρ: number of devices using UWB technology/km^2 from which emission is received by a radio telescope
- $e.i.r.p._o(f)$: e.i.r.p. at frequency f for a density ρ of 1 device using UWB technology/km^2. The values for $e.i.r.p._o(f)$ are given in column 2 of Table 267.
- β : building attenuation (dB)
- Π : fraction of devices deployed outdoor.

TABLE 267

Maximum tolerable e.i.r.p.$_{max}$ per device using UWB technology for example values of the density ρ of devices using UWB technology/km^2 transmitting towards a radio telescope

Frequency band (MHz)	Required UWB e.i.r.p. limit (dBm/MHz)				
			Rural (1a)	Suburban (1b)	Dense urban (1c)
	Building attenuation (dB)	ρ = 1/km^2 100% outdoor	ρ = 5/km^2 20% outdoor	ρ = 50/km^2 20% outdoor	ρ = 500/km^2 20% outdoor
608-614(1)	5	–110.2(2)	–113.2(2)	–123.2(2)	–133.2(2)
1 330.0-1 400.0(1)	9	–96.4(3), 112.4(2)	–95.4(3), –111.4(2)	–105.4(3), –121.4(2)	–115.4(3), –131.4(2)
1 400.0-1 427.0(4)	9	–96.4(3), 112.4(2)	–95.4(3), –111.4(2)	–105.4(3), –121.4(2)	–115.4(3), –131.4(2)
1 610.6-1 613.8(1)	12	–94.6(3)	–90.6(3)	–100.6(3)	–110.6(3)
1 660.0-1 670.0(1)	12	–93.8(3), –108.8(2)	–89.8(3), –103.8(2)	–99.8(3), –113.8(2)	–109.8(3), –123.8(2)
1 718.8-1 722.2(1)	12	–94.2(3)	–90.2(3)	–100.2(3)	–110.2(3)
2 655.0-2 690.0(1)	12	–104.0(2)	–100.0(2)	–110.0(2)	–120.0(2)
2 690.0-2 700.0(4)	12	–104.0(2)	–100.0(2)	–110.0(2)	–120.0(2)
3 260.0-3 267.0(1)	12	–86.9(3)	–82.9(3)	–92.9(3)	–102.9(3)
3 332.0-3 339.0(1)	12	–86.9(3)	–82.9(3)	–92.9(3)	–102.9(3)
3 345.8-3 352.5(1)	12	–86.9(3)	–82.9(3)	–92.9(3)	–102.9(3)
4 800.0-4 990.0(1)	12	–86.4(3), 97.4(2)	–82.4(3), –93.4(2)	–92.4(3), –103.4(2)	–102.4(3), –113.4(2)
4 990.0-5 000.0(1)	12	–97.4(2)	–93.4(2)	–103.4(2)	–113.4(2)
6 650.0-6 675.2(1)	17	–86.9(3)	–77.9(3)	–87.9(3)	–97.9(3)

(1) RR No. 5.149 applies.

(2) Continuum observations (broadband).

(3) Spectral line observations (narrow-band).

(4) RR No. 5.340 applies.

Obviously, the results apply only for those devices using UWB technology transmitting towards a radio telescope.

At this moment no accurate estimate can be made of the density ρ of devices using UWB technology. The values retained in Table 267 correspond to a rural, suburban or dense urban deployment with an activity factor of 5%. 20% of devices using UWB technology are deployed outdoor. RAS stations are mainly deployed in rural environment.

3.1.1.4.4 Separation distances necessary to protect the radio astronomy service (single device using UWB technology case)

Estimated separation distances for a single device using UWB technology are given in Table 268 for continuum measurements and in Table 269 for spectral line measurements, for two different proposed spectrum masks: the slope spectrum mask (outdoor), and the United States spectrum mask (outdoor). The separation distances range from few hundred metres to about 100 km

Also given in these tables is the MCL, which is the difference between the UWB e.i.r.p. levels and the detrimental interference threshold levels for the RAS given in Recommendation ITU-R RA.769.

TABLE 268

Estimates of separation distances for a single device using UWB technology, for different spectrum masks (for continuum measurements)

RAS frequency bands (MHz)	Required MCL (dB) slope mask (outdoor)	Required MCL (dB) United States mask (outdoor)	Resulting separation distance (km) slope mask (outdoor)	Resulting separation distance (km) United States mask (outdoor)
608-614	58	138	–	–
1 400.0-1 427.0	98	114	1.37	9.6
1 660.0-1 670.0	102	124	1.86	27
2 690.0-2 700.0	120	126	10	21
4 990.0-5 000.0	144	145	86	96

TABLE 269

Estimates of separation distances for a single device using UWB technology, for different spectrum masks (for spectral-line measurements)

RAS frequency bands (MHz)	Required MCL (dB) slope mask (outdoor)	Required MCL (dB) United States mask (outdoor)	Resulting separation distance (km) slope mask (outdoor)	Resulting separation distance (km) United States mask (outdoor)
1 400.0-1 427.0	82	98	0.21	1.37
1 610.6-1 613.8	87	109	0.335	4.46
1 660.0-1 670.0	88	109	0.36	4.32
4 800.0-4 990.0	130	133	18.2	26.2

3.1.1.5 Mitigation techniques

3.1.1.5.1 RAS

There are various methods, including those described below, which might in principle be considered to reduce the UWB emissions transmitted towards a radio telescope. It will be particularly difficult to filter out UWB signals once they are have entered the radio telescope receiver, however, given the similarity between the generally noise-like cosmic radio emissions, receiver noise and UWB emissions.

Antenna side lobe performance: The aperture illumination of radio telescopes is usually optimized to maximize the signal-to-noise ratio for point sources. A key element of this approach is to reduce ground radiation, which would include transmissions from terrestrial UWB transmissions, entering through far side lobes. Inevitably this leads to some increase in the levels of near side lobes.

Blanking in time and/or frequency: This technique can only be applied in cases where interference can be fully and unambiguously identified in time and/or frequency. This will not be the case for UWB transmissions.

3.1.1.5.2 UWB application

Some methods could be considered to reduce the UWB transmissions towards a radio telescope, the most effective being the attenuation of the UWB emission to the level required to protect radio astronomy in a frequency band to which related regulatory provisions apply.

Terrain related methods: when the circumstances allow, use of terrain irregularities could add to this method. Usually the effectiveness of terrain related methods are site dependent. This method could well depend on season dependent conditions.

Separation distances: an effective method is the installation of exclusion zones within which devices using UWB technology must not operate. The area of such exclusion zones depends on different factors such as the nature of terrain.

As an example, one study provided by one Administration has shown that, for the specific RAS sites of this Administration, to afford protection from a single device using UWB technology located beyond the control of an observatory, at 500 m range, would require an e.i.r.p. limit of –65 dBm/MHz at around 5 GHz.

Moreover, in this Administration, the observations performed in this frequency band will generally be made as an element of a VLBI network. If it is assumed that the victim telescope is part of such a network, then the e.i.r.p. limit for this band increases to –45 dBm/MHz.

It has also been shown that an e.i.r.p. limit of –85 dBm/MHz would offer full protection to the RAS bands below 3 GHz and above 10.7 GHz for the specific RAS site of this Administration.

3.1.1.5.3 Potential impact on the RAS

UWB transmissions received at a radio telescope will increase the environmental noise floor for radio astronomy observations, which includes both a natural component and man-made emissions. Since the objective of radio astronomy is to investigate the cosmic component of this natural component, UWB transmissions reduce the effective sensitivity with which an observation can be done.

3.1.1.6 Results of studies

3.1.1.6.1 Summary

The calculated maximum tolerable e.i.r.p. per device using UWB technology in the frequency range 0.6-10.6 GHz is significantly below the currently considered e.i.r.p. per device using UWB technology of –41.3 dBm/MHz. It is noted that this difference depends strongly on the aggregated impact of devices using UWB technology emitting towards a radio telescope operating in the frequency range 0.6-10.6 GHz. At this moment no accurate estimate can be made of a realistic density of devices using UWB technology. For any significant deployment of devices using UWB technology it is shown that substantial separation distances must be respected for the protection of radio astronomy stations.

3.1.1.6.2 Conclusions

It can be seen from the initial results that for UWB transmissions a spectrum mask that offers protection to the radio astronomy service is required. It is also noted that the geographic separation distances required to meet the RAS protection criteria are substantial and clearly highlight the sharing difficulties between UWB and radio astronomy. The separation distance depends on site specific factors and needs to be calculated on a case by case basis (see an example in § 3.1.1.5.2).

3.1.2 RAS and automotive SRR around 24 GHz

In this sub-chapter, the possible impact is studied of UWB transmissions from automotive SRR devices operating around 24 GHz on radio astronomy operations at these frequencies.

The ITU-R Recommendations that were taken as the basis for the performed interference study are those listed in § 3.1.1.

3.1.2.1 Bands allocated to the RAS

Table 270 lists the frequency bands allocated to, and used by, the RAS in the range 22-24 GHz.

TABLE 270

Frequency bands used by the RAS in the range 22-24 GHz, and their protection criteria

Frequency band (MHz)	Relevant RR footnote	Detrimental spfd (Rec. ITU-R RA.769) (dB(W/(m^2.Hz)))
22 010-22 210	RR No. 5.149	–216[(1)]
22 210-22 500	RR No. 5.149	–216[(1)]
22 810-22 860	RR No. 5.149	–216[(1)]
23 070-23 120	RR No. 5.149	–215[(1)]
23 600-24 000	RR No. 5.340	–215[(1)], –233[(2)]

(1) Spectral line observations (narrow band).

(2) Continuum observations (broadband).

3.1.2.2 Required protection criteria for the RAS

The protection criteria for the RAS frequency bands in the 22-24 GHz range are given in Table 270 in terms of spectral power flux density levels at receiver input detrimental to radio astronomy, for both spectral line (narrow band) and continuum (broadband) observations made in single-dish mode, as all radio telescopes operational around 24 GHz are used for this kind of observations – the most stringent levels should always be used. These threshold levels have been determined using the methodology of Recommendation ITU-R RA.769 – see § 3.1.1.2 for further details on this Recommendation. This table shows that the protection criteria between 22 and 24 GHz are rather frequency independent.

3.1.2.3 Operational characteristics of the RAS

The generic operational characteristics of the RAS in the frequency range around 24 GHz are described in § 3.1.1.3. Most observations in the 22-24 GHz frequency range are made in single-dish mode. VLBI observations are made in the 22.195-22.26 GHz range. The observations made in the 22-24 GHz range mainly involve spectral line (narrow-band) observations, and continuum (broadband) observations in the 23.6-24.0 GHz band.

3.1.2.4 Interference assessment

3.1.2.4.1 Methodology used to assess the maximum tolerable e.i.r.p. per SRR device

The summation methodology used here is described in § 3.1.1.4.1, and the basic input parameters used are those listed in Table 265.

3.1.2.4.2 Calculation of the maximum tolerable e.i.r.p. per SRR device

For the calculations presented here, the same scenario is used as outlined in § 3.1.1.4.2. With the input parameters given in Table 271 the maximum tolerable e.i.r.p. per device using UWB technology as a function of the density ρ of SRR devices/km^2 emitting towards a radio telescope has been estimated.

TABLE 271

Input parameters used for the maximum tolerable e.i.r.p. calculations

Maximum permissible spectral power flux density (for radio astronomy spectral line observations)	–215 (dB(W/(m^2 · Hz)))
Frequency	22 GHz
Reference bandwidth	1 MHz
Path angular distance	0°
Sea level refractivity	320
Fraction of data-loss due to interference	2%

3.1.2.4.3 Values achieved

The calculations lead to the following expression for the maximum permissible e.i.r.p. per SRR device at frequencies ~22 GHz that will not exceed the protection criteria for spectral line radio astronomy observations:

$$e.i.r.p._{max} = -10 * \log \rho - 71.3 \qquad \text{dBm/MHz}$$

where ρ is the number of SRR devices/km^2 operating at ~24 GHz from which emission is received by a radio telescope.

For continuum observations, the constant in the formula should be changed to 89.2 instead of 71.3.

Obviously, the results apply only for those SRR devices transmitting towards a radio telescope.

At this moment no accurate estimate can be made of the actual density ρ of devices using UWB technology. For a density of 100 SRR devices/km^2 corresponding to a rural scenario and an activity factor of 100%, $e.i.r.p._{max}$ = –91.3 dBm/MHz for spectral line radio astronomy observations and –109.2 dBm/MHz for continuum observations.

Section 3.1 of Annex C of Recommendation ITU-R SM.1757 considers additional activity factors for SRR. Applying those activity factors in the calculation would increase the maximum permissible e.i.r.p.

3.1.2.5 Mitigation techniques

3.1.2.5.1 RAS

See § 3.1.1.5.1.

3.1.2.5.2 SRR application

See § 3.1.1.5.2.

3.1.2.5.3 Potential impact on the RAS

See § 3.1.1.5.3.

3.1.2.6 Results of studies

3.1.2.6.1 Summary

The calculated maximum tolerable e.i.r.p. per SRR device at ~24 GHz is several orders of magnitude below the currently considered e.i.r.p. per SRR device of –41.3 dBm/MHz. It is noted that this difference depends strongly on the aggregated impact of SRR devices emitting towards a radio telescope; for densities that could be considered as realistic in areas with a radio observatory site (e.g. 100 devices/km^2) the difference between the currently considered and the maximum tolerable e.i.r.p. per SRR device emitting to a radio telescope would be in the order of 50 dB for spectral line observations and about 70 dB for continuum observations.

It shows that, in the absence of mitigation factors adequate to enable the protection of the RAS, co-existence is not feasible

In practical scenarios, a number of mitigation factors may be taken into account, such as local terrain and car density. These elements could be included in the determination of separation distances required to protect a specified radio astronomy site. These distances could result in determining exclusion zones where the operation of the SRR must be switched off.

3.1.2.6.2 Conclusions

These results show the impact, with a large margin, between automotive SRR devices transmitting at ~24 GHz with a mean e.i.r.p. of –41.3 dBm/MHz per device and radio astronomy facilities operating between 22 and 24 GHz, in the absence of mitigation factors.

If all possible mitigation factors, including sufficiently large exclusion zones around radio astronomy antennas, can be applied then sharing between automotive SRR at ~24 GHz and radio astronomy could be possible. Site specific studies have indicated exclusion zone radii of up to 35 km for a uniform density of 100 SRR devices/km^2 from which emission is received by a radio telescope.

3.1.3 RAS and automotive SRR around 79 GHz

In this sub-chapter, the possible impact is studied of UWB transmissions from automotive SRR devices operating in the range 77-81 GHz on radio astronomy operations at these frequencies.

The calculations presented here do not include the consideration of the Doppler mode of the automotive SRR UWB application. The ITU-R Recommendations that were taken as the basis for the performed interference study are those listed in § 3.1.1.

3.1.3.1 Bands allocated to the RAS

Table 272 lists the frequency bands allocated to, and used by, the RAS in the range 76-84 GHz.

TABLE 272

Frequency bands allocated to the RAS in the range 76-84 GHz and their protection criteria

Frequency band (GHz)	Relevant RR footnote	Protection level(1) (dB(W/(m^2 · Hz)))
76-77.5	RR No. 5.149	–205(2), -221(3)
77.5-78	RR No.5.149	–205(2), -218(3)
78-79	RR No. 5.149	–205(2), -220(3)
79-81	RR No. 5.149	–205(2), -221(3)
81-84	RR No. 5.149	–204(2), -222(3)

(1) Calculated according to Recommendation ITU-R RA.769 using a minimum antenna noise temperature of 30 K and receiver noise temperature of 150 K.

(2) Spectral line observations (narrow band).

(3) Continuum observations (broadband).

3.1.3.2 Required protection criteria for the RAS

The protection criteria for the RAS frequency bands in the 76-84 GHz range, taken from Recommendation ITU-R RA.769**,** are given in Table 272 in terms of spectral power flux density at receiver input detrimental to radio astronomy, for both spectral line (narrow band) and continuum (broadband) observations made in single-dish mode, as all radio telescopes operational in this range are used for this kind of observations – the most stringent levels should always be used. For further remarks on Recommendation ITU-R RA.769, see § 3.1.1.3.

Since the protection criteria between 76 and 84 GHz are rather frequency independent, for the purpose of the calculations presented in this report it is assumed that in this frequency range the threshold level for interference detrimental to radio astronomy observations is –222 dB(W/(m^2.Hz)).

3.1.3.3 Operational characteristics of the RAS

The generic operational characteristics of the RAS in the frequency range 76-84 GHz are described in § 3.1.1.3. Observations in this frequency range are all made in single-dish mode, and involve both spectral line (narrow-band) and continuum (broadband) observations.

3.1.3.4 Interference assessment

3.1.3.4.1 Methodology used to determine the maximum tolerable e.i.r.p. per SRR device

The summation methodology used here is described in § 3.1.1.4.1, and the basic input parameters used are those listed in Table 265.

3.1.3.4.2 Calculation of the maximum tolerable e.i.r.p. per SRR device

For the calculations presented here, the same scenario is used as outlined in § 3.1.1.4.2. With the input parameters given in Table 273 the maximum tolerable e.i.r.p. per SRR device as a function of the density ρ of SRR devices/km^2 emitting towards a radio telescope has been estimated at a frequency of 79 GHz only, since it is not expected that significantly different results would be found for other frequencies in the range 76-84 GHz. The Doppler mode of the SRR application was not taken into account.

TABLE 273

Input parameters used for the maximum tolerable e.i.r.p. calculations

Maximum permissible spectral power flux density (for spectral line observations)	–205 dB(W/(m2 · Hz))
Frequency	79 GHz
Reference bandwidth	1 MHz
Path angular distance	0°
Sea level refractivity	320
Fraction of data-loss due to interference	2%

3.1.3.4.3 Values achieved

The following expression is found for the maximum permissible e.i.r.p. per SRR device at frequencies ~79 GHz that will not exceed the protection criteria for spectral line radio astronomy observations:

$$e.i.r.p._{max} = -10 * \log \rho - 60.4 \qquad \text{dBm/MHz}$$

where ρ is the number of SRR devices/km^2 operating at ~79 GHz from which emission is received by a radio telescope.

For continuum observations, the constant in the formula should be changed to 77.4 instead of 60.4.

It should be noted that these results are similar to those found for SRR devices around 24 GHz.

Obviously, the results apply only for those SRR devices transmitting towards a radio telescope.

At this moment no accurate estimate can be made of the actual density ρ of devices using UWB technology. For a density of 100 SRR devices/km^2 corresponding to a rural scenario and an activity factor of 100%, $e.i.r.p._{max}$ = –80.4 dBm/MHz for spectral line radio astronomy observations and –97.4 dBm/MHz for continuum observations.

Section 3.1 of Annex C of Recommendation ITU-R SM.1757 considers additional activity factors for SRR. Applying those activity factors in the calculation would increase the maximum permissible e.i.r.p.

3.1.3.5 Mitigation techniques

3.1.3.5.1 RAS

See § 3.1.1.5.1.

3.1.3.5.2 SRR application

See § 3.1.1.5.2.

3.1.3.5.3 Potential impact on the RAS

See § 3.1.1.5.3.

3.1.3.6 Results of studies

3.1.3.6.1 Summary

The calculated maximum tolerable e.i.r.p. per SRR device at ~79 GHz is several orders of magnitude below the currently considered e.i.r.p. per SRR device of –3 dBm/MHz for the wide-band component. It is noted that this difference depends strongly on the aggregated impact of SRR devices emitting towards a radio telescope; for densities that could be considered as realistic in areas with a radio observatory site (e.g. 100 devices/km^2) the difference between the currently considered and the maximum tolerable e.i.r.p. per SRR device emitting to a radio telescope would be in the order of 77 dB for spectral line observations and about 94 dB for continuum observations, i.e. 11 dB higher than found for SRR devices at ~24 GHz.

It shows that, in the absence of mitigation factors adequate to enable the protection of the RAS, co-existence is not feasible. In practical scenarios, a number of mitigation factors may be taken into account (see § 3.1.1.5).

3.1.3.6.2 Conclusions

These results show the impact, with a large margin, between automotive SRR devices transmitting at ~79 GHz with a mean e.i.r.p. of –3 dBm/MHz per device and radio astronomy facilities operating at ~79 GHz, in the absence of mitigation factors.

If all possible mitigation factors (see § 3.1.1.5) can be applied then sharing between automotive SRR at ~79 GHz and radio astronomy could be possible.

Annex 7

Test measurements related to the impact of devices using ultra-wideband technology on systems operating within radiocommunication services

1 Test measurements related to the impact on systems operating within the land mobile services except IMT-2000

1.1 Laboratory test measurements: GSM-based land mobile

1.1.1 Approach

The first part of this study is a series of controlled lab experiments to determine the C/I_{UWB} ratio required for protection of a GSM/GPRS handset from a device using UWB technology. In other words, we wanted to see, relative to the UWB signal, how much stronger the intended GSM/GPRS signal had to be at the handset receiver in order that the handset be still capable of meeting its minimum performance requirements.

1.1.2 UWB transmitter set-up

The UWB transmitter used in this study is the TFP1001 UWB impulse source from Multispectral Solutions (MSSI). Each transmitter is controlled by two triggering signals generated by a Tektronix DG2030 data pattern generator. A mini-circuits VHP-16 high-pass filter was placed at the output of the TFP1001 to attenuate the UWB signal below 1.6 GHz so as to minimize the possibility of non-linear effects arising from OoB interference. The UWB signal types considered in this study are listed in Table 274.

TABLE 274

MSSI UWB transmitter settings

Type	PRF (MHz)	PPM	Polarity
1	0.1	1	Mono-phase
2	0.1	1	Bi-phase
3	0.1	4	Mono-phase
4	0.1	4	Bi-phase
5	0.1	8	Mono-phase
6	0.1	8	Bi-phase
7	0.5	1	Bi-phase
8	0.5	4	Mono-phase
9	0.5	4	Bi-phase
10	0.5	8	Mono-phase
11	0.5	8	Bi-phase
12	1	1	Bi-phase
13	1	4	Mono-phase
14	1	4	Bi-phase
15	1	8	Mono-phase
16	1	8	Bi-phase
17	5	1	Bi-phase
18	5	4	Mono-phase
19	5	4	Bi-phase
20	5	8	Mono-phase
21	5	8	Bi-phase
22	10	1	Bi-phase
23	10	4	Mono-phase
24	10	4	Bi-phase
25	10	8	Mono-phase
26	10	8	Bi-phase
27	50	1	Bi-phase
28	50	2	Mono-phase
29	50	2	Bi-phase
30	100	1	Bi-phase

1.1.3 Test set-up

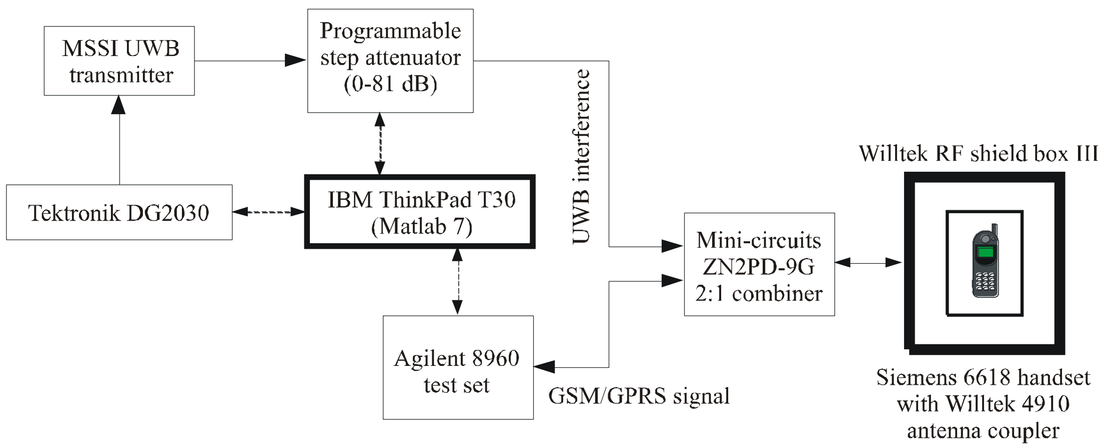
The set-up used for the GSM and GPRS laboratory experiments is shown in Fig. 326. The victim handset used in this experiment was an ordinary, commercially available GSM/GPRS mobile phone. The base station signal was generated by an Agilent 8960 Series 10 wireless communications test set running the E1968A GSM/GPRS Mobile Test Application (version A.03.32). The step attenuator connected to the output of the UWB transmitter enabled us to vary the UWB signal power in 1 dB steps. The step attenuator, the DG 2030 and the Agilent test set were controlled remotely via GPIB from the IBM laptop, which ran an automation script developed using Matlab for this study.

This set-up allowed us to determine how the BER (for GSM) or BLER (for GPRS) of the radio downlink varies with the C/I_{UWB} ratio for 30 different impulse-based UWB signal types. C is the handset's received signal level and I_{UWB} is the amount of UWB power within the 3 dB bandwidth (81.25 KHz) of the handset's receiver. Note that we measured I_{UWB} within a bandwidth of 81.25 KHz instead of 200 KHz to obtain a smaller value for I_{UWB}, which will yield a more conservative value for C/I_{UWB}.

We relied on the RXLEV value reported by the handset to determine the total path loss between the test set and the handset receiver. According to 3GPP TS 45.008 V6.8.0 (§ 8.1.2), RXLEV is accurate only to ±4 dB at best. Fortunately, this large margin of error does not affect our ability to calculate C/I_{UWB} because C and I_{UWB} can be measured accurately at the input of the combiner with a spectrum analyser.

FIGURE 326

GSM/GPRS test set-up



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1.1.4 GSM (1 800 MHz)

1.1.4.1 Test procedure

We measured the residual bit-error rate (RBER) of the GSM 1 800 MHz downlink in the presence of UWB interference. For every one of the 30 UWB signal types, we brought the UWB power level down to a very low level and increased it gradually in 1 dB steps until the RBER exceeded around 7%. We carried out this experiment at four different received signal levels (–102 dBm, –96 dBm, –90 dBm and –84 dBm). –102 dBm corresponds to the reference sensitivity level of the handset (as specified in 3GPP TS 05.05/45.005).

The key test parameters are given in Table 275.

TABLE 275

GSM test parameters

BCH and TCH channel	883
Downlink frequency	1 879.4 MHz
Uplink frequency	1 784.4 MHz
Received signal level at handset	–102 dBm, –96 dBm, –90 dBm, –84 dBm
BER type	Residual Type II (with Loopback Type A)
No. of bits for BER test	50 000
Payload pattern type	PRBS-15
Degradation criterion	RBER < 2%
Test reference	3GPP TS 05.05 V8.16.0, Table 1 3GPP TS 45.005 V6.6.0, Table 1 See under DCS 1 800, TCH/FS class II (RBER), static propagation conditions.

1.1.4.2 Results and findings

Figure 327 shows all four sets of 30 BER curves (a total of 120 BER curves) obtained in this part of the study. The curves are continuous and smooth because the GSM Residual Type II test measures the error rate of bits that are not protected by forward error correction. Note that the curves are clustered into four neat bundles. The spread of each bundle, notwithstanding the rightmost curve, is quite small (about 2 dB). The leftmost bundle corresponds to a received signal level of –102 dBm, while the rightmost bundle corresponds to a received signal level of –84 dBm.

The criterion for degradation in this experiment is a RBER not exceeding 2%. Indicated by an arrow on each bundle of curves in the diagram is the approximate in-band UWB signal power level at which the 2% threshold is breached. The threshold UWB power levels for the four bundles are then used to calculate C/I_{UWB} in Table 276. In Table 276, we see that, once we take the noise floor of the GSM receiver into consideration, we obtain a consistent C/I_{UWB} value of 11 dB[65], regardless of the received signal level.

The unusual position of the rightmost curve of each bundle, which corresponds to the 0.1 MHz, PPM = 1 (i.e. no time dithering), mono-phase UWB signal type, requires further explanation. The far-right position of the curve, which corresponds to a markedly lower C/I_{UWB} ratio, indicates that this particular UWB signal type is considerably less harmful to the GSM receiver compared to the other signal types. We believe that this deviation arises from the fact that the nature of the interference produced by this UWB signal type and the other UWB signal types is different. In the frequency domain, the 0.1 MHz, PPM = 1, mono-phase UWB signal consists of a comb of spectral lines spaced 0.1 MHz apart. A GSM receiver with a 3-dB bandwidth of only 81.25 KHz sees at most one spectral line, which to the narrowband receiver appears like a CW signal. By contrast, the other UWB signal types have spectra that are much more noise-like and therefore appear almost like white noise to the GSM receiver.

[65] This figure is slightly more conservative than the 10 dB figure reported in our previous submission. The difference arises from the fact that we now calculate I_{UWB} within a smaller bandwidth of 81.25 KHz, whereas previously the bandwidth used was 200 kHz, which gave a higher value for I_{UWB}.

TABLE 276

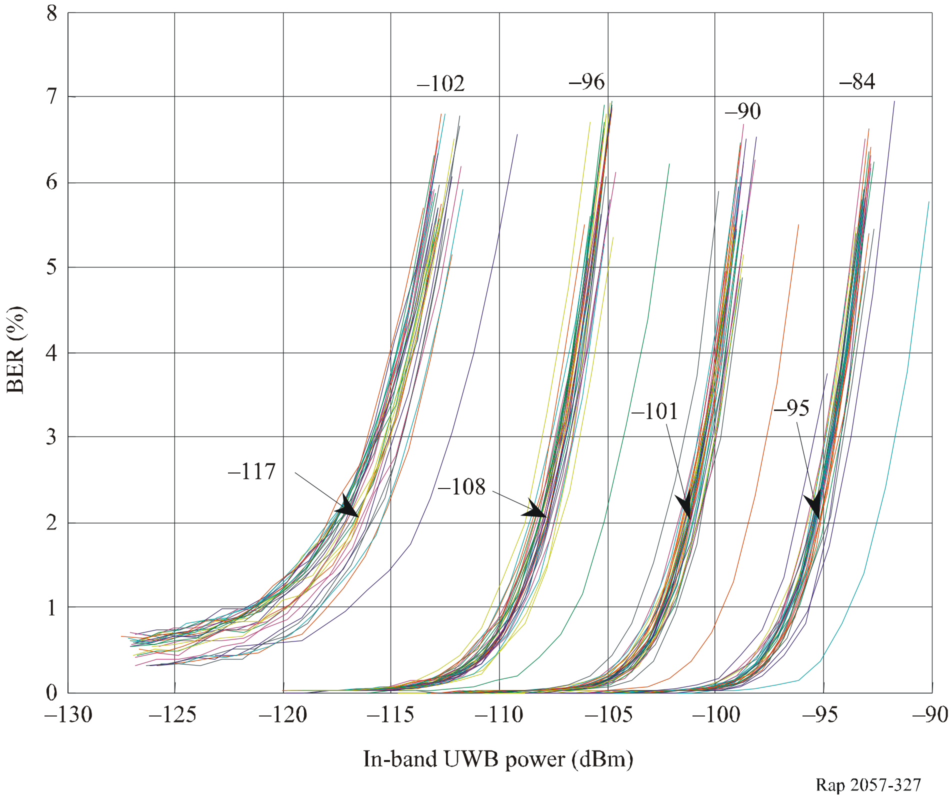
Calculation of *C/I* for GSM-UWB impact

Received signal level C (dBm)	I_{UWB} (dBm)	C/I_{UWB}	$C/(I_{UWB} + N_{Receiver})$(1)
–102	–117	15	11
–96	–108	12	11
–90	–101	11	11
–84	–95	11	11

(1) Assuming a receiver noise figure of 6 dB, we estimate the receiver noise floor to be $N_{Receiver}$ = -174 + 10 $\log_{10}$ (200 kHz) + Noise figure = –115 dBm.

FIGURE 327

BER vs. in-band UWB signal power



1.1.5 GPRS (1 800 MHz)

1.1.5.1 Test procedure

We measured the block error rate (BLER) of the GPRS 1 800 MHz PDTCH downlink in the presence of UWB interference. For every one of the 30 UWB signal types, we brought the UWB power level down to a very low level and increased it gradually in 1 dB steps until the BLER exceeded around 10% or when the GPRS link was dropped. We carried out this experiment with two different coding schemes (CS-1, CS-2) and at four different received signal levels (–100 dBm, –95 dBm, –90 dBm and –85 dBm). One uplink and two downlink time slots were used throughout. –100 dBm corresponds to the minimum input level specified in 3GPP TS 51.010-1 V5.9.0 Section 14.16.1.2 for a class 1 DCS 1 800 handset.

The key test parameters are given in Table 277.

TABLE 277

GPRS test parameters

BCH and TCH channel	883
Downlink frequency	1 879.4 MHz
Uplink frequency	1 784.4 MHz
Received signal level at handset	–100 dBm, –95 dBm, –90 dBm, –85 dBm
PDTCH coding scheme	CS-1, CS-2[66]
PDTCH timeslot configuration	2 downlink timeslots, 1 uplink timeslot
BLER type	ETSI B acknowledged (loopback) mode
No. of blocks for BLER test	2 000
Payload pattern type	PRBS-15
Degradation criterion	BLER < 10%
Test reference	3GPP TS 51.010-1 V5.9.0 Section 14.16.1.2

1.1.5.2 Results and findings

Figures 328 and 329 show the four sets of 30 BLER curves (a total of 120 BER curves in each figure) obtained in this part of the study for the CS-1 and CS-2 coding schemes respectively. Unlike in the GSM case, the GPRS BLER curves rise sharply and terminate suddenly. In most of the test cases, the GPRS link broke even before the BLER reached 10%, our threshold criterion. This behaviour is due to the fact that the bits used to compute the BLER are protected by FEC, which reduces the minimum SNR required to achieve a given error rate but causes the link to degrade very quickly once the minimum S/N cannot be met. Because of this phenomenon, we cannot use BLER < 2% as the criterion for determining the C/I_{UWB} ratio. Instead, we define I_{UWB} as the UWB power level beyond which either the GPRS link will break or the BLER will exceed 10%.

We calculated the log average (i.e. by taking the arithmetic mean of the dBm levels) of the I_{UWB} values obtained for each received signal level and each coding scheme, which we then used to calculate the C/I_{UWB} ratio (see Table 278). We found that, after correcting for the contribution from the GPRS receiver's noise floor, C/I_{UWB} for GPRS is consistently 10 dB for both the CS-1 and CS-2 coding schemes.

Not surprisingly, the curves corresponding to the same received signal level are clustered together. As in the GSM case, the rightmost curve of each bundle of curves corresponds to the 0.1 MHz, PPM = 1, mono-phase UWB signal type, which we know is more benign than the other UWB signal types. To err on the conservative side, we did not include the C/I_{UWB} corresponding to this signal type in the computation of the log average C/I_{UWB} values in Table 278. Note that we were unable to generate a 0.1 MHz, PPM = 1, mono-phase UWB signal that is strong enough to cause either the GPRS link to break or the BLER to exceed 10%. This is why the rightmost bundle of curves in Figs. 328 and 329 is missing the "outlier" curve.

[66] CS-1 and CS-2 are the most common coding schemes used in commercial GPRS networks. CS-1 and CS-2 provide a maximum data rate of 8 kbit/s and 12 kbit/s per time slot respectively.

FIGURE 328

BLER vs. in-band UWB signal power (CS-1)

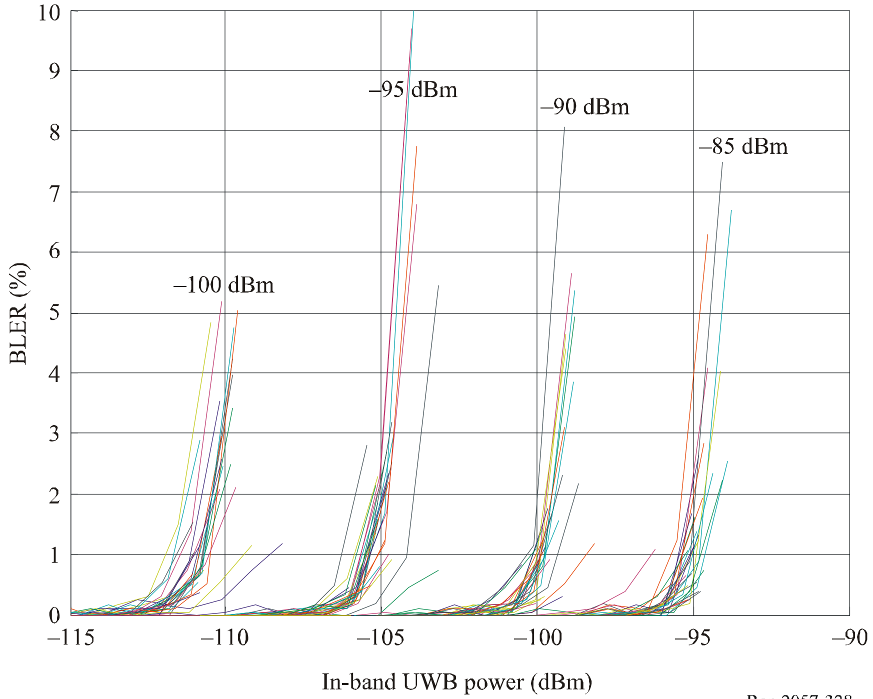


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FIGURE 329

BLER vs. in-band UWB signal power (CS-2)

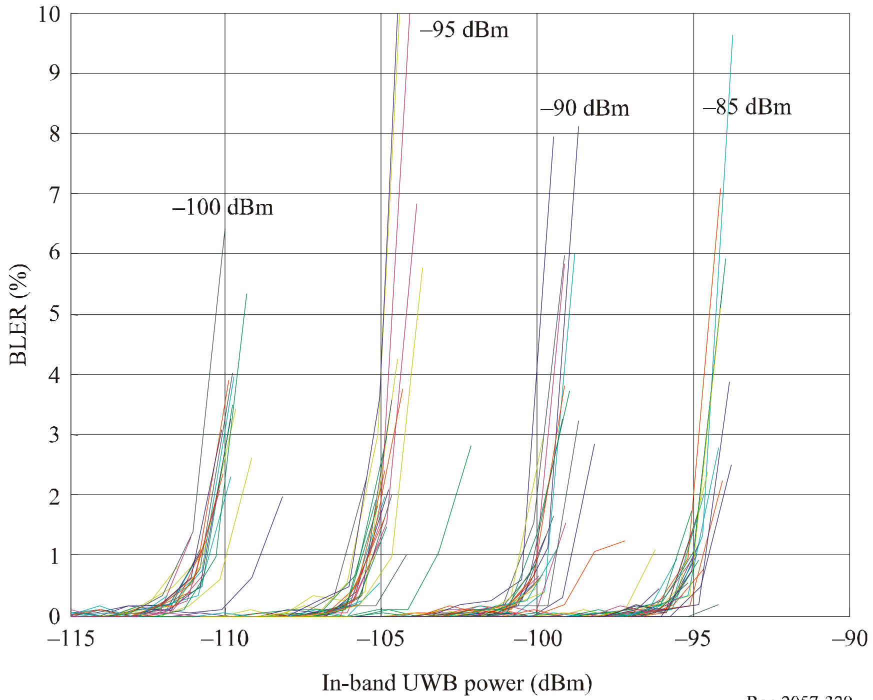

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TABLE 278

Calculation of *C*/*I* for GPRS-UWB impact

Coding scheme	Received signal level C (dBm)	Log average I_{UWB} (dBm)(1)	C/I_{UWB}	$C/(I_{UWB} + N_{Receiver})$(2)
CS-1	–100	–111	11	10
	–95	–105	10	10
	–90	–100	10	10
	–85	–95	10	10
CS-2	–100	–111	11	10
	–95	–105	10	10
	–90	–100	10	10
	–85	–95	10	10

(1) Not including I_{UWB} for the 0.1 MHz, PPM = 1, mono-phase signal type.

(2) Assuming a receiver noise floor $N_{Receiver}$ of –115 dBm.

1.1.6 OFDM transmitter test

In response to some concerns raised at the 3rd Radiocommunication TG 1/8 meeting, we carried out a lab test to see if the OoB (i.e. below 3.1 GHz) spectral energy of the multi-band OFDM alliance (MBOA) transmitter's output would cause harmful interference to a GSM 1 800 MHz handset. Using the same set-up as described in § 1.1.3, we replaced the MSSI UWB transmitter (and the high-pass filter attached to it) with a Staccato SC1000D UWB physical-layer transmitter, which is designed to version 0.7 of the MBOA specifications. There is nothing to configure on the SC1000D; once turned on, it generates a test MBOA signal in three 528 MHz bands centred on 3.432 GHz, 3.960 GHz and 4.488 GHz.

Using a spectrum analyser, we found that the MBOA UWB power spectral density at the output of the SC1000D transmitter was very low at around –99 dBm/81.25 kHz at 1 879.4 MHz. Taking into account the path loss of about 18 dB between the handset receiver and the SC1000D's output, the amount of UWB power at the handset receiver was only –117 dBm/81.25 kHz.

As expected, even with the GSM received signal level lowered to –102 dBm, the MBOA signal did not produce any measurable change in the BER of the GSM downlink signal even when the step attenuator connected to the output of the UWB transmitter was set to 0 dB. Neither did the MBOA UWB signal affect the BLER of the GPRS downlink with a GPRS received signal level of –100 dBm and with both the CS-1 and CS-2 coding schemes. In both cases, the C/I_{UWB} threshold was not crossed. Nevertheless, we should point out that the MBOA signal's power spectral density level at 1 879.4 MHz is much lower than what is permitted by the hand held UWB mask in the United States rules (–63.3 dBm/MHz, or –74.2 dBm/81.25 kHz).

Indeed, if the OoB emission of an OFDM-based device using UWB technology operating primarily above 3.1 GHz is a genuine concern to mobile cellular users, one should also look at imposing stringent limits on the OoB emission of other OFDM systems operating below 3.1 GHz, e.g. IEEE 802.16a/HIPERMAN in the 2.5 GHz MMDS band, IEEE 802.11g wireless LAN, and possibly even emerging 4G systems.

1.2 Field test for 1 device using UWB technology

1.2.1 Approach

For this part of the study, we worked very closely with MobileOne, a major mobile cellular operator in Singapore, to determine how the presence of UWB interference affects the GSM base station's (BTS) use of power control. Although a BTS can use power control to compensate for a handset's loss of SNR caused by UWB interference, doing so may cause the surrounding BTSes to experience more adjacent and co-channel interference, thereby leading to an overall loss of network coverage and capacity. For this reason, several parties we have spoken to believe that UWB interference is no longer acceptable if it brings about a downlink power control response. Therefore, the focus of this study is to determine an appropriate e.i.r.p. limit for the GSM 1 800 MHz band that will ensure that, under our test conditions, the presence of a device using UWB technology in the vicinity of a handset will not trigger the power control mechanism of the BTS serving the handset.

Note that the UWB transmitter used in the field test was the same as that used in the laboratory test. As before, we connected a VHP-16 high-pass filter and a step attenuator to the output of the transmitter. However, because this is a radiated experiment, we also needed a UWB antenna at the output of the step attenuator. Here, we used a Skycross SMT-8TO25-MA UWB antenna, which has a frequency range of 824-2 500 MHz.

1.2.2 Test procedure

The test was carried out in MobileOne's indoor GSM test bed. This test bed provides a test environment that is nearly indistinguishable from an actual indoor GSM deployment. We configured the BTS serving the test bed to use the same TCH (channel 883) for the field test as for the laboratory test. The power control settings on the BTS are described in the next section.

We placed a Sagem OT 96M GSM/GPRS handset in an area where the received signal level of the TCH was about –83 dBm and established a continuous voice call. We then placed an MSSI UWB transmitter 30 cm away from the handset. It is important to note that, while –83 dBm may be considered low by some operators, it does not represent the worst possible scenario, as the sensitivity of the GSM terminal is defined as –102 dBm by the specifications.

The received signal level measured by the Sagem handset was monitored on a laptop running Agilent's E6474A Nitro software. Note that the absolute value of the received signal level was unimportant and could not be accurately measured under such conditions. What we were looking for was a sudden, sharp increase in the received signal level, which indicated that the BTS had begun to use power control to compensate for the UWB interference (see the following section). Starting with a high attenuator setting, we gradually decreased the amount of attenuation applied to the UWB transmitter in 1 dB steps until we noticed this sharp jump. To determine the threshold UWB e.i.r.p. density (dBm/MHz) that triggered the BTS power control mechanism, we subtracted the attenuator setting from the maximum e.i.r.p. density of the UWB transmitter within a 10 MHz span centred on 1 879.4 MHz, which had previously been measured in an anechoic chamber at PSB Corp, an accredited test lab.

1.2.3 Overview of power control mechanism

MobileOne's power control settings for its indoor test bed BTS are typical of the settings used in many live GSM networks. The base station responds primarily to the RxQual value reported by the handset. If RxQual is greater than 2, the BTS will increase its power. The power increment step size is 4 dB; the actual power control step size is the product of increment step size and the amount by which RxQual exceeds 2 (e.g. if RxQual is 4, the power control step size is $(4 - 2) \times 4$ dB = 8 dB). Therefore, when the quality of the GSM signal becomes unacceptably poor, the BTS increases its transmission power with an increment large enough to be easily detected by monitoring the received signal level reported by the handset.

1.2.4 Results and findings

The threshold UWB e.i.r.p. density values for a device using UWB technology located 30 cm away from a victim GSM handset are given in Table 279. We carried out this experiment with only 19 of the 30 UWB signal types (types 12-30) identified in Table 274.

The threshold e.i.r.p. values obtained in this experiment ranged from –53 dBm/MHz to –46 dBm/MHz. Assuming a free-space path loss of 27 dB over 30 cm and a bandwidth scaling factor of 7 dB, it can be calculated that the C/I_{UWB} observed in this experiment ranges from –3 dB to 4 dB, which is much lower than the 11 dB obtained in the previous section. There are many possible factors that helped mitigate the impact of UWB interference here. First, multipath could have led to a path loss exponent greater than two. Second, the antenna of the GSM handset could have been lower than 0 dBi, or the polarization of the GSM antenna and the UWB antenna might not have been perfectly matched. Finally, and most importantly, it must be noted that I_{UWB} here is not the actual in-band UWB PSD but the maximum e.i.r.p. density within a 10 MHz span centred on the carrier frequency, which is almost certain to be higher because of the unevenness of the power spectrum of the UWB signal. That means that the actual UWB PSD e.i.r.p. in the measured GSM channel can be smaller than what is given in Table 279.

Three UWB signal types (types 18, 20 and 23) were much less harmful than the others. For types 18 and 20, we were unable to generate a UWB signal strong enough to trigger the BTS power control response. The reason for these three signal types' unusual behaviour becomes clear when we examine the spectral plot of these signals. The centre frequency of the downlink signal, 1 879.4 MHz actually falls within a spectral null to the left of the spectral line at 1 800 MHz in these signals' frequency domain representation (see Fig. 330 for a detailed spectral plot of the type 20 signal). Thus, very little UWB energy was actually picked up by the handset in these three test cases, although the e.i.r.p. density of the UWB signal, which is measured with a resolution bandwidth of 1 MHz, can be quite high.

TABLE 279

Threshold e.i.r.p. density for UWB-GSM impact

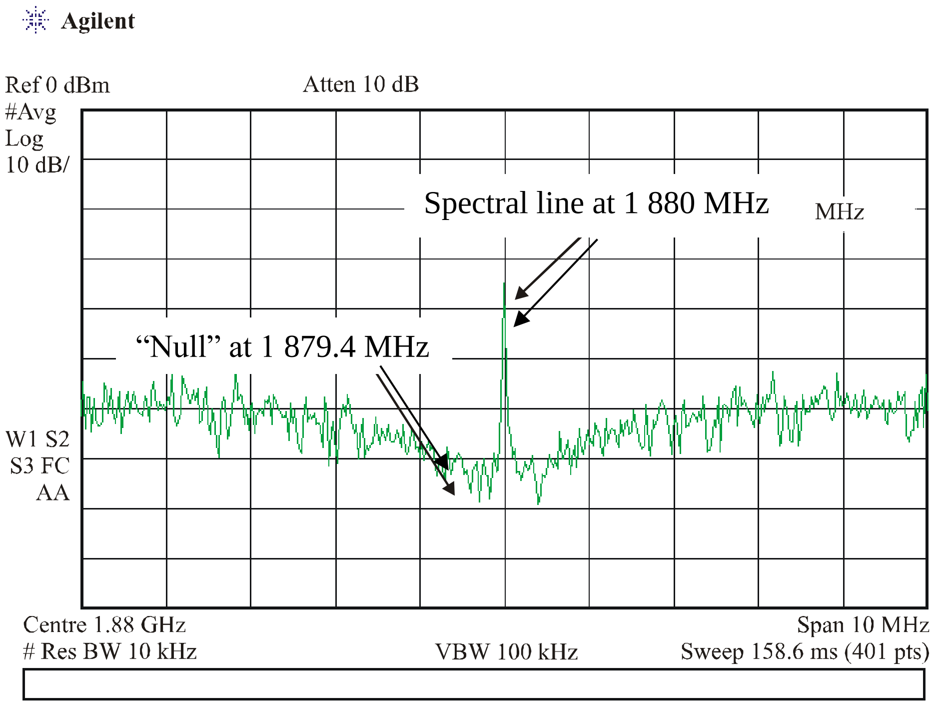
Type	PRF (MHz)	PPM	Polarity	Threshold e.i.r.p. (dBm/MHz)
12	1	1	Bi-phase	–53
13	1	4	Mono-phase	–50
14	1	4	Bi-phase	–51
15	1	8	Mono-phase	–49
16	1	8	Bi-phase	–52
17	5	1	Bi-phase	–49
18	5	4	Mono-phase	Not available
19	5	4	Bi-phase	–49
20	5	8	Mono-phase	Not available
21	5	8	Bi-phase	–48
22	10	1	Bi-phase	–47
23	10	4	Mono-phase	–33

TABLE 279 (*end*)

Type	**PRF (MHz)**	**PPM**	**Polarity**	**Threshold e.i.r.p. (dBm/MHz)**
24	10	4	Bi-phase	–48
25	10	8	Mono-phase	–50
26	10	8	Bi-phase	–52
27	50	1	Bi-phase	–46
28	50	2	Mono-phase	–50
29	50	2	Bi-phase	–44
30	100	1	Bi-phase	–44

FIGURE 330

Spectral detail of PRF = 5 MHz, PPM = 8, mono-phase signal (Centre frequency = 1 880 MHz, span = 10 MHz)



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1.3 Field tests for 1, 2 and 4 devices using UWB technology

1.3.1 Overview

The second half of this study looks at the impact of UWB interference on a victim receiver operating in a live, commercial GSM 1 800/GPRS network. The UWB transmitters were placed at a distance of 0.3 m and 0.5 m from a victim receiver. Experiments were carried out both indoors and outdoors at –63 dBm/MHz for Type 3, 5 and 12 UWB signals (viz. Tables 280 and 282).

Four test scenarios were carried out once for GSM 1 800 (continuous voice call) and repeated for GPRS (download of a large file). In each scenario, the measurement system recorded RxQual for GSM1800 (Table 281) and BLER and LLC downlink throughput for GPRS.

TABLE 280

Field test scenarios

Scenario	Location	Location within cell	Rx level (dBm)	UWB PSD (dBm/MHz)	Calculated *C*/*I* (single UWB)
1	Indoors	Near base station	≥ –47(1)	–63	≥ 53
2	Indoors	Near cell boundary	–86	–63	14
3	Outdoors	Near base station	–53	–63	47
4	Outdoors	Near cell boundary	–80	–63	20

(1) –47 dBm is the maximum Rx level the handset can report.

TABLE 281

GSM1800 – Relationship between RxQual and BER

RxQual	BER
0	< 0.2%
1	0.2% – 0.4%
2	0.4% – 0.8%
3	0.8% – 1.6%
4	1.6% – 3.2%
5	3.2% – 6.4%
6	6.4% – 12.8%
7	>12.8%

1.3.2 Results and analysis

1.3.2.1 Indoor measurements

1.3.2.1.1 GSM 1 800

Near the base station (Scenario 1 in Table 280), no degradation in the RxQual was observed regardless of the UWB signal type, PSD level or number of UWB transmitters. This is completely in line with our expectations because *C*/*I* under those conditions was well above the 10 dB required to sustain a BER lower than 2%.

The impact of the UWB transmitters became visible when moving the victim receiver towards the boundary of the coverage cell (Scenarios 3 and 4 in Table 280). Table 282 shows the measured average RxQual values.

For an UWB PSD of –63 dBm/MHz (Scenario 2), RxQual was not as severely affected. With only one UWB transmitter present, RxQual was almost always three or better. However, with its *C*/*I* at around 14 dB, the victim receiver was not far from dropping below the threshold *C*/*I* value of 10 dB. Indeed, when more than one transmitter was turned on, there were several instances where RxQual exceeded three. The impact of four Type 3 UWB transmitters operating concurrently was particularly severe, with RxQual occasionally hitting seven (corresponding to a BER higher than 12.8%). Nevertheless, the average RxQual was still below three in every one of the test cases in Scenario 2. In general, the relationship between RxQual and the number of active UWB transmitters is not clear, partly because of environmental factors that cannot be controlled. Even in the absence of UWB transmission, there were instances where RxQual was as high as four.

When the distance between the UWB transmitters and the victim receiver was increased to 0.5 m, the impact of the UWB transmitters became negligible for all four test scenarios.

TABLE 282

RxQual (indoors, cell boundary)

UWB signal type	UWB PSD (dBm)	Average RxQual			
		No UWB	1 UWB	2 UWB	4 UWB
3	–63	0	0	1.67	2.72
5	–63	0	0.15	0	0.05
12	–63	0	0.07	0.32	0.17

1.3.2.1.2 GPRS

At a UWB PSD of –63 dBm/MHz, a constant LLC downlink throughput of around 35 kbit/s was observed regardless of the UWB signal type or number of UWB transmitters for all four test scenarios; BLER was mostly 0%. However, there were a few very brief, isolated instances where the BLER momentarily increased beyond 10%.

As before, when increasing the distance between the UWB transmitters and the victim receiver to 0.5 m, the UWB transmitters did not have any measurable impact on the performance of the victim receiver.

1.3.2.2 Outdoor measurements

1.3.2.2.1 GSM1800

As in the indoor test scenarios, the UWB transmitters caused virtually no measurable degradation in the victim receiver’s performance when near the base station.

For all combinations of UWB signal types and number of transmitters at PSD level –63 dBm/MHz, the interference experienced by the victim receiver was negligible.

The UWB transmitters did not have any measurable impact on the performance of the victim receiver when the distance between the UWB transmitters and the victim receiver was increased to 0.5 m.

1.3.2.2.2 GPRS

With the victim receiver at 0.3 m from the UWB sources a constant LLC downlink throughput of around 35 kbit/s was observed, regardless of the UWB signal type or number of UWB transmitters for all test scenarios. For the most part, the BLER did not appear to be affected by the presence of the UWB transmitters. However, there were a few very brief, isolated instances where the BLER momentarily increased beyond 10%.

The UWB transmitters did not have any measurable impact on the performance of the victim receiver when the distance between the UWB transmitters and the handset was increased to 0.5 m.

2 Test measurements related to the impact on systems operating within IMT-2000 and systems beyond IMT-2000

2.1 Experimental data on IMT-DS and UWB impact

2.1.1 Laboratory test

2.1.1.1 Approach

The first part of this study is a series of controlled lab experiments to determine the $\hat{I}_{or}/I_{UWB}$ ratio required for protection of an IMT-DS UE from a device using UWB technology. In other words, we wanted to see, relative to the UWB signal, how much stronger the intended IMT-DS signal had to be at the UE receiver in order that the UE be still capable of meeting its minimum performance requirements.

2.1.1.2 UWB transmitter set-up

The UWB transmitter used in this study is the TFP1001 UWB impulse source from Multispectral Solutions (MSSI). Each transmitter is controlled by two triggering signals generated by a Tektronix DG2030 data pattern generator. A Mini-Circuits VHP-16 high-pass filter was placed at the output of the TFP1001 to attenuate the UWB signal below 1.6 GHz so as to minimize the possibility of non-linear effects arising from OoB interference.

2.1.1.3 Test set-up

The set-up used for the IMT-DS laboratory tests is shown in Fig. 331. The victim handset used in this experiment was an ordinary, commercially available IMT-DS mobile phone. The base station signal was generated by an Agilent 8960 Series 10 wireless communications test set running the E1963A IMT-DS Mobile Test Application (version A.05.16). The step attenuator connected to the output of the UWB transmitter enabled us to vary the UWB signal power in 1 dB steps. The step attenuator, the DG2030 and the Agilent test set were controlled remotely via GPIB from the IBM laptop, which ran an automation script developed using Matlab for this study.

This set-up allowed us to determine how the loopback BER of the IMT-DS downlink varies with the $\hat{I}_{or}/I_{UWB}$ ratio for 44 different impulse-based UWB signal types (see Table 283). $\hat{I}_{or}$ is the UE's received signal level and I_{UWB} is the amount of UWB power within the 3 dB bandwidth (3.84 MHz) of the UE's receiver. Note that we relied on the CPICH RSCP value reported by the handset to determine the total path loss between the test set and the UE receiver. We know from 3GPP TS 34.121 V5.3.1 (Table E.3.2.1) that, for the physical channels used in these tests, $\hat{I}_{or}$ = CPICH RSCP + 3.32 dB.

We are aware that, according to 3GPP TS 45.008 V6.8.0 (§ 8.1.2), CPICH RSCP is accurate only to ± 6 dB at best. Fortunately, this large margin of error does not affect our ability to calculate $\hat{I}_{or}/I_{UWB}$ because $\hat{I}_{or}$ and I_{UWB} can be measured accurately at the input of the combiner with a spectrum analyser.

Finally, note that the BER reported by the Agilent 8960 was the BER of the downlink signal only, even though both the uplink and downlink would contain some amount of UWB interference. The uplink would not be affected by UWB interference because the signal generated by the UE was many orders of magnitude stronger than the UWB signal, and uplink power control had been enabled to ensure the integrity of the uplink.

FIGURE 331

IMT-DS test set-up

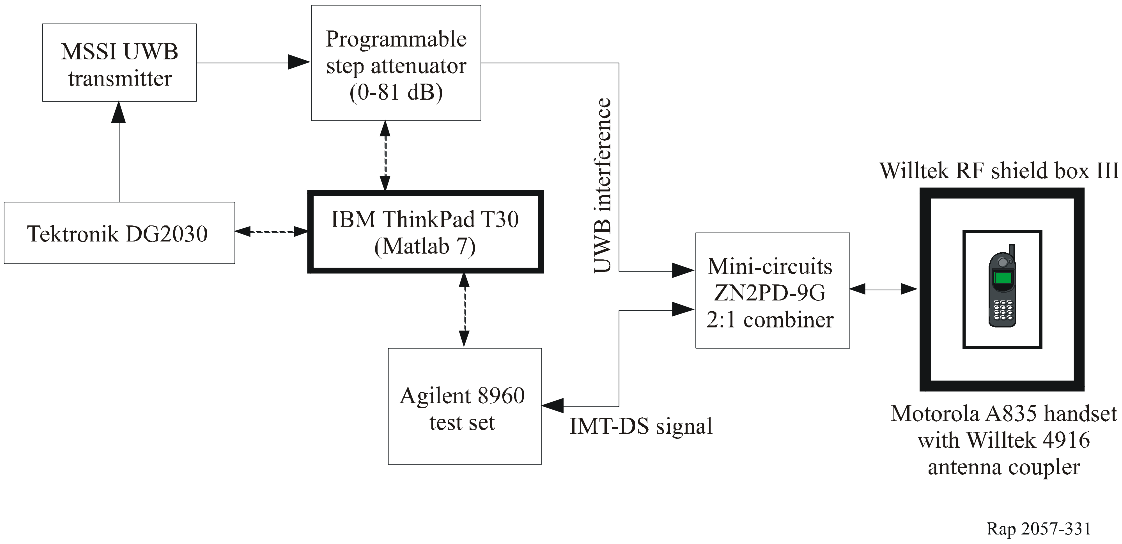


TABLE 283

MSSI UWB transmitter settings

Type	PRF (MHz)	PPM	Polarity
1	0.1	1	Mono-phase
2	0.1	1	Bi-phase
3	0.1	4	Mono-phase
4	0.1	4	Bi-phase
5	0.1	8	Mono-phase
6	0.1	8	Bi-phase
7	0.2	1	Mono-phase
8	0.2	1	Bi-phase
9	0.2	4	Mono-phase
10	0.2	4	Bi-phase
11	0.2	8	Mono-phase
12	0.2	8	Bi-phase
13	0.3	1	Mono-phase
14	0.3	1	Bi-phase
15	0.3	4	Mono-phase
16	0.3	4	Bi-phase
17	0.3	8	Mono-phase
18	0.3	8	Bi-phase
19	0.5	1	Mono-phase
20	0.5	1	Bi-phase
21	0.5	4	Mono-phase

TABLE 283 (*end*)

Type	PRF (MHz)	PPM	Polarity
22	0.5	4	Bi-phase
23	0.5	8	Mono-phase
24	0.5	8	Bi-phase
25	1	1	Mono-phase
26	1	1	Bi-phase
27	1	4	Mono-phase
28	1	4	Bi-phase
29	1	8	Mono-phase
30	1	8	Bi-phase
31	5	1	Bi-phase
32	5	4	Mono-phase
33	5	4	Bi-phase
34	5	8	Mono-phase
35	5	8	Bi-phase
36	10	1	Bi-phase
37	10	4	Mono-phase
38	10	4	Bi-phase
39	10	8	Mono-phase
40	10	8	Bi-phase
41	50	1	Bi-phase
42	50	2	Mono-phase
43	50	2	Bi-phase
44	100	1	Bi-phase

2.1.1.4 Test procedure

We measured the loopback BER of the IMT-DS downlink in the presence of UWB interference. For every one of the 44 UWB signal types, we brought the UWB power level down to a very low level and increased it gradually in 1 dB steps until communication failure. We carried out this experiment with two different channel types (12.2k RMC, 64k RMC) and at four different received signal levels (–106 dBm, –101 dBm, –96 dBm and –91 dBm). –106 dBm corresponds to the reference $\hat{I}_{or}$ specified in Table 6.2.2 of 3GPP TS 34.121. 64 k is the highest rate RMC at which a loopback BER can be carried out using the agilent test set. Although both the UE and agilent test set support up to the 384 k RMC on the downlink, loopback BER measurement is not possible at such high data rates because the throughput of the loopback connection is limited by the much lower data rate of the uplink.

The key test parameters are given in Table 284. Note that, with the 64 k RMC, we could not carry out the test at $\hat{I}_{or}$ = –106 dBm. It appeared that the UE was unable to support 64 k communication at such a low received signal level, even in the absence of UWB interference.

TABLE 284

IMT-DS test parameters

Downlink frequency	2 167.4 MHz (channel 10 837)
Uplink frequency	1 977.4 MHz (channel 9 887)
Îor at UE	–106 dBm (for 12.2 k RMC only), –101 dBm, –96 dBm, –91 dBm
Channel type	12.2 k RMC, 64 k RMC
Downlink physical channels	Established according to 3GPP TS 34.121 V5.3.1 Table E.3.2.1
BER type	Loopback BER (loopback Mode 1)
No. of bits for BER test	50 000
Payload pattern type	PRBS-15
Degradation criterion	BER < 0.1%
Test reference	3GPP TS 34.121 V5.3.1 § 6.2

2.1.1.5 Results and findings

Beyond a certain threshold UWB power level, the BER would increase rapidly until the agilent test set issued a "Signal lost of uplink DCH" error, indicating that the UE was unable to receive the downlink signal and loop it back. In Tables 285 and 286 we report, for each $\hat{I}_{or}$, the logarithmic average of the amount of in-band UWB signal power I_{UWB} beyond which the BER of the downlink would exceed 0.1%. Note that the granularity of the results is limited by the 1 dB step size of the programmable step attenuator that was used to control the UWB signal power.

Table 285 shows the results for the 12.2 k RMC, while Table 286 shows the results for the 64 k RMC. For PRFs 0.1 MHz through to 10 MHz, we gave an I_{UWB} value for each PRF, the log average of the results obtained from 5 or 6 signal types. The results from the remaining four UWB signal types, (PRF = 50 MHz and 100 MHz) were averaged together to yield a single average I_{UWB}. There is no I_{UWB} value for most of the test cases involving the PRF = 0.1 MHz signal types. Even with the step attenuator at the output of the transmitter set at 0 dB, the UWB signal was too weak to have any measurable impact on the IMT-DS downlink. This does not mean that the low-PRF UWB signals are completely harmless. Rather it means that a more powerful UWB transmitter would be needed for the PRF = 0.1 MHz test cases.

If we take into consideration the noise contribution from the receiver noise when I_{UWB} is comparable to the noise floor of the UE receiver (see the last column of Tables 285 and 286), we find that $\hat{I}_{or}/I_{UWB}$ is consistently about –8 dB for the 12.2 k RMC and –4 dB for the 64 k RMC for PRFs greater than 0.3 MHz, regardless of the $\hat{I}_{or}$ level. The 4 dB increase going from 12.2 k to 64 k can be traced to Table 8.6 of 3GPP TS 25.101 V6.4.0, which shows that the difference in DPCH_Ec/Ior required to achieve a BLER lower than 10^{-2} for a 12.2 k and 64 k DCH is 3.8 dB.

The fact that any UWB interference at all was tolerable even in the case the $\hat{I}_{or}$ level was at the reference sensitivity indicates that the actual sensitivity of the terminal is better then the reference sensitivity. Had a terminal be used that just meets the reference sensitivity requirement, no UWB interference at all would have been tolerable for the case of $\hat{I}_{or}$ level being equal to the reference sensitivity, so that $\hat{I}_{or}/I_{UWB} \rightarrow -\infty$ in this case.

When the PRF of the UWB signal was very low (i.e. less than 0.3 MHz), we found that $\hat{I}_{or}/I_{UWB}$ was much lower than expected. This could be because, at low PRFs, the UWB interference appears as impulsive noise instead of white Gaussian noise to the UE receiver. This is consistent with the findings of the time domain analysis as presented by Radiocommunication SG 8. Impulsive noise may be less harmful to the UE receiver because forward error correction and bit scrambling, which handle bursty data loss well, can help to mitigate its impact.

TABLE 285

Calculation of $\hat{I}_{or}$ /I_{UWB} for IMT-DS impact (12.2 k RMC)

$\hat{I}_{or}$ (dBm)	PRF (MHz)	I_{UWB} range (dBm)	Log average I_{UWB} (dBm)	$\hat{I}_{or}/I_{UWB}$	$\hat{I}_{or}$/ (I_{UWB} + $N_{Receiver}$)(1)
–106	0.1	–100 to –94	–98	–8	–10
	0.2	–103 to –102	–102	–4	–8
	0.3	–106 to –100	–103	–3	–8
	0.5	–104 to –101	–102	–4	–8
	1	–107 to –101	–104	–2	–7
	5	–103 to –102	–102	–4	–8
	10	–103 to –99	–101	–5	–9
	50, 100	–106 to –100	–102	–4	–8
–101	0.1	UWB transmitter is too weak to have any impact			
	0.2	–90 to –89	–89	–12	–12
	0.3	–93 to –92	–93	–8	–8
	0.5	–94 to –93	–93	–8	–8
	1	–94 to –94	–94	–7	–7
	5	–95 to –93	–94	–7	–7
	10	–94 to –92	–93	–8	–8
	50, 100	–96 to –93	–94	–7	–7
–96	0.1	UWB transmitter is too weak to have any impact			
	0.2	–81 to –80	–80	–16	–16
	0.3	–87 to –85	–86	–10	–10
	0.5	–88 to –87	–87	–9	–9
	1	–89 to –88	–88	–8	–8
	5	–89 to –88	–88	–8	–8
	10	–88 to –87	–88	–8	–8
	50, 100	–90 to –87	–88	–8	–8
–91	0.1	UWB transmitter is too weak to have any impact			
	0.2	–75 to –74	–74	–17	–17
	0.3	–81 to –79	–80	–11	–11
	0.5	–83 to –81	–82	–9	–9
	1	–83	–83	–8	–8
	5	–84 to –83	–83	–8	–8
	10	–83 to –81	–82	–9	–9
	50, 100	–85 to –82	–83	–8	–8

(1) Assuming a receiver noise floor $N_{Receiver}$ of –100 dBm.

TABLE 286

Calculation of $\hat{I}_{or}$ /I_{UWB} for IMT-DS impact (64 k RMC)

$\hat{I}_{or}$ (dBm)	PRF (MHz)	I_{UWB} range (dBm)	Log average I_{UWB} (dBm)	$\hat{I}_{or}/I_{UWB}$	$\hat{I}_{or}$/ $(I_{UWB} + N_{Receiver})$(1)
–101	0.1	–98 to –92	–95	–6	–7
	0.2	–101 to –98	–99	–2	–5
	0.3	–102 to –100	–101	0	–4
	0.5	–102 to –99	–100	–1	–4
	1	–103 to –100	–101	0	–4
	5	–101 to –100	–101	0	–4
	10	–100 to –98	–99	–2	–5
	50, 100	–105 to –99	–102	1	–3
–96	0.1	UWB transmitter is too weak to have any impact			
	0.2	–90 to –89	–89	–7	–7
	0.3	–93 to –92	–92	–4	–4
	0.5	–93 to –92	–92	–4	–4
	1	–93	–93	–3	–3
	5	–93	–93	–3	–3
	10	–93 to –91	–92	–4	–4
	50, 100	–95 to –92	–93	–3	–3
–91	0.1	UWB transmitter is too weak to have any impact			
	0.2	–83 to –82	–82	–9	–9
	0.3	–86 to –85	–86	–5	–5
	0.5	–87 to –86	–87	–4	–4
	1	–88 to –87	–87	–4	–4
	5	–88 to –87	–88	–3	–3
	10	–87 to –86	–87	–4	–4
	50, 100	–89 to –87	–87	–4	–4

(1) Assuming a receiver noise floor $N_{Receiver}$ of –100 dBm.

2.1.1.6 OFDM transmitter test

We carried out a lab test to see if the OoB (i.e. below 3.1 GHz) spectral energy of the multi-band OFDM Alliance (MBOA) transmitter's output would cause harmful interference to a IMT-DS UE. Using the same set-up as described in § 2.1.1.3, we replaced the MSSI UWB transmitter (and the high-pass filter attached to it) with a Staccato SC1000D UWB physical-layer transmitter, which is designed to version 0.7 of the MBOA specifications. There is nothing to configure on the SC1000D; once turned on, it generates a test MBOA signal in three 528 MHz bands centred on 3.432 GHz, 3.960 GHz and 4.488 GHz.

Using a spectrum analyser, we found that the MBOA UWB power spectral density at the output of the SC1000D transmitter was very low at around –74 dBm/3.84 MHz at 2 167.4 MHz. Nevertheless, even with the path loss between the UWB transmitter and the UE receiver, it was still able to affect the IMT-DS downlink at the lowest $\hat{I}_{or}$ settings (–106 dBm for the 12.2 k RMC and –101 dBm for the

64 k RMC). Using the same criterion for degradation as before (loopback BER < 0.1%), we obtained the results in Table 287. Note that these results are perfectly consistent with the results presented in Tables 285 and 286 for the impulse-based UWB signal types, suggesting that both MBOA UWB and high-PRF impulse-based UWB signals affect the UE receiver in similar ways.

At this juncture, it is important for us to point out that, if the out-of-band emission of an OFDM-based device using UWB technology operating primarily above 3.1 GHz is a genuine concern to mobile cellular users, we should also look at imposing stringent limits on the out-of-band emission of other OFDM systems operating below 3.1 GHz, e.g. IEEE 802.16a/HIPERMAN in the 2.5 GHz MMDS band, IEEE 802.11g wireless LAN, and possibly even emerging 4G systems.

TABLE 287

$\hat{I}_{or}/I_{UWB}$ for MBOA UWB and IMT-DS impact

Channel Type	$\hat{I}_{or}$ (dBm)	$\hat{I}_{or}/I_{UWB}$	$\hat{I}_{or}/(I_{UWB} + N_{Receiver})$ (1)
12.2 RMC	–106	–4	–8
64 RMC	–101	–1	–4

(1) Assuming a receiver noise floor $N_{Receiver}$ of –100 dBm.

2.1.2 Field test

2.1.2.1 Approach

For this part of the study, we worked very closely with MobileOne, a major mobile cellular operator in Singapore, to determine how the presence of UWB interference affects the IMT-DS base station's (Node B) use of power control. In general, if a UE's downlink reception is affected by interference, the Node B will attempt to increase the power of the DPCH serving that UE. By doing so, the Node B actually uses up more of its power budget to serve the affected UE, and consequently the capacity of the cell served by the Node B suffers. On the other hand, if the presence of a device using UWB technology in the vicinity of a UE has no impact on the way the Node B communicates with the UE, then any response to the UWB interference is entirely localized at the UE and will have no effect on the capacity of the Node B. Therefore, the focus of this study is to determine an appropriate e.i.r.p. limit for the IMT-DS downlink band (2 100 MHz) that will ensure that, under our test conditions, the presence of a device using UWB technology in the vicinity of a UE will not result in an increase in the downlink DPCH power serving the UE.

Note that the UWB transmitter used in the field test was the same as that used in the laboratory test. As before, we connected a VHP-16 high-pass filter and a step attenuator to the output of the transmitter. However, because this is a radiated experiment, we also needed a UWB antenna at the output of the step attenuator. Here, we used a Skycross SMT-8TO25-MA UWB antenna, which has a frequency range of 824-2 500 MHz.

2.1.2.2 Test procedure

The test, which comprises two usage scenarios – one for adaptive multi rate (AMR) voice and another for high-speed data – was carried out in MobileOne's indoor IMT-DS test bed. This test bed provides a test environment that is nearly indistinguishable from an actual indoor, single-cell IMT-DS deployment. We configured the Node B serving the test bed to use the same uplink and downlink frequencies (channels 9 887 and 10 837 respectively) for the field test as for the laboratory test. MobileOne's power control settings for the test bed Node B were the same as those it uses for its live network and are typical of the settings used by IMT-DS operators in general. The power control step size of 0.5 dB.

We placed a Nokia 7600 UE in an area where the CPICH RSCP level was about –90 dBm and established a continuous voice call. It is important to note that, while –90 dBm may be considered low by some operators, it does not represent the worst possible scenario, because the level according to the sensitivity test specification is with –110 dBm much lower. Accordingly, the tolerable UWB e.i.r.p. PSD that would be found in an environment where the useful signal level is at the reference sensitivity level would be 20 dB lower than what is reported below. We then placed an MSSI UWB transmitter 30 cm away from the handset. To monitor the UE's downlink DPCH, we relied on MobileOne's network monitoring system, which was able to report the total power transmitted by the Node B. Starting with a high attenuator setting, we gradually decreased the amount of attenuation applied to the UWB transmitter until we noticed an increase in the Node B's transmission power. Since the test bed's Node B was serving only the UE used in the experiment, any increase in the Node B's transmission power had to be due to the use of power control to manage the interference caused by the UWB transmitter to the UE.

To determine the threshold UWB e.i.r.p. density (dBm/MHz) that caused the Node B to increase its DPCH power to the UE, we subtracted the attenuator setting from the maximum e.i.r.p. density of the UWB transmitter around 2 167.4 MHz, which had previously been measured in an anechoic chamber at PSB Corp, an accredited test lab.

After carrying out the steps above with various UWB signal types, we repeated the test in a slightly different location where the CPICH received signal level was higher, at about –75 dBm. Again, –75 dBm does not represent the worst possible scenario. Here, we established a continuous 384 kbit/s data connection by repeatedly downloading very high-quality streaming videos from a web server.

2.1.2.3 Results and findings

The calculated threshold UWB e.i.r.p. density values (i.e. the e.i.r.p. above which the Node B will employ downlink power control to compensate for the UWB interference) for a device using UWB technology located 30 cm away from a victim IMT-DS UE handset are given in Tables 288 and 289 for a 12.2 k voice call (CPICH RSCP = –90 dBm) and a 384 kbit/s data connection (CPICH RSCP = –75 dBm) respectively. We carried out this experiment with only 12 of the 44 UWB signal types identified in Table 283.

The threshold e.i.r.p. values obtained in this experiment ranged from –55 dBm/MHz to –47 dBm/MHz. Assuming a free-space path loss of 29 dB over 30 cm, a bandwidth scaling factor of –6 dB, and a total received signal power of –87 dBm (estimated from the base station transmitted power level reported by the network monitoring system), it can be estimated that the $\hat{I}_{or}/I_{UWB}$ observed in this experiment ranges from –17 dB to –9 dB for the 12.2 k voice call, which is lower than the –8 dB obtained in the previous section. There are many possible factors responsible for the discrepancy. First, multipath could have led to a path loss exponent greater than 2. Second, the antenna of the UE could have been lower than 0 dBi, or the polarization of the UE antenna and the UWB antenna might not have been perfectly matched. Third, it must be noted that I_{UWB} here is not the actual in-band UWB PSD but the maximum e.i.r.p. density within a 10 MHz span centred on the carrier frequency, which is almost certain to be higher because of the unevenness of the power spectrum of the UWB signal. Fourth, the relative power levels of the different physical channels in the IMT-DS signal were not identical to the relative levels specified by 3GPP for compliance testing. Finally, it is important to note that the field measurement did not assess the exact value of the increase of IMT-2000 BER due to UWB interference, but was only considering the resulting IMT-2000 base station power increase.

TABLE 288

Threshold e.i.r.p. density for UWB-IMT-DS impact (12.2 k voice)

Type	PRF (MHz)	PPM	Polarity	Threshold e.i.r.p. (dBm/MHz)
25	1	1	Mono-phase	–55
26	1	1	Bi-phase	–55
29	1	8	Mono-phase	–50
30	1	8	Bi-phase	–52
31	5	1	Bi-phase	–52
34	5	8	Mono-phase	–50
35	5	8	Bi-phase	–52
36	10	1	Bi-phase	–50
39	10	8	Mono-phase	–50
40	10	8	Bi-phase	–50
41	50	1	Bi-phase	–47
44	100	1	Bi-phase	–53

TABLE 289

Threshold e.i.r.p. density for UWB-IMT-DS impact (384 kbit/s data)

Type	PRF (MHz)	PPM	Polarity	Threshold e.i.r.p. (dBm/MHz)
25	1	1	Mono-phase	–57
26	1	1	Bi-phase	–57
29	1	8	Mono-phase	–54
30	1	8	Bi-phase	–54
31	5	1	Bi-phase	–54
34	5	8	Mono-phase	–51
35	5	8	Bi-phase	–49
36	10	1	Bi-phase	–50
39	10	8	Mono-phase	–53
40	10	8	Bi-phase	–54
41	50	1	Bi-phase	–50
44	100	1	Bi-phase	–55

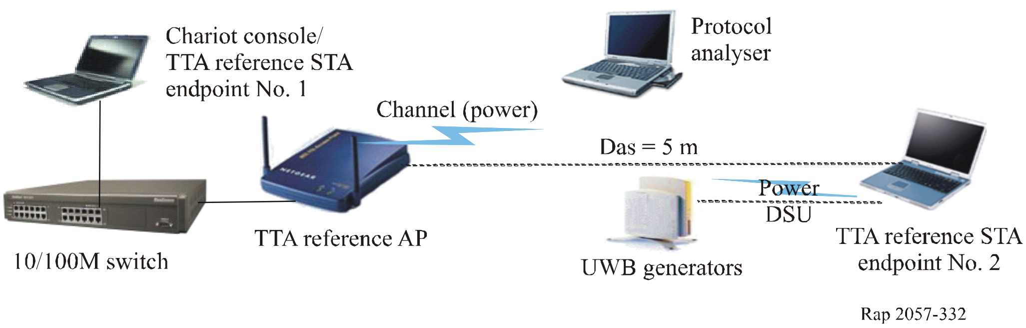
3 Test measurements related to the impact on systems operating within wireless access including RLAN

3.1 Field measurement of interference to IEEE 802.11a from device using UWB technology

This section represents the interference measurement between IEEE 802.11a, WLAN and available UWB systems such as PulsON200TM impulse UWB transmitter from Time Domain, XSUWBWDK DS-CDMA transmitter from Motorola, and MB-OFDM EVT transmitter from Wisair for each type of modulation, respectively. The test determine the impact of certain devices using UWB technology on 5.18 GHz WiFi systems.Test measurement setup is represented in Fig. 332.

FIGURE 332

Test measurement setup



The characteristics of UWB test source are shown in Table 290.

TABLE 290

Characteristics of UWB test source

Specifications	Pulsed UWB	DS-CDMA UWB	MB-OFDM UWB
Pulse repetition frequency (PRF)	9.6 MHz	–	–
Center frequency (radiated)	4.7 GHz	4.15 GHz	Variable (3 channel)
10 dB – bandwidth	3.2 GHz	2.05 GHz	528 MHz
PSD (e.i.r.p.)	–41.25 dBm/MHz	–41.25 dBm/MHz	–41.25 dBm/MHz

For WLAN AP and STA, Proxim AP-600 v 2.1.1 and Client card were used. The measurement frequency was 5.18 GHz and emission power of WLAN transmitter was 40 mW/16 MHz in average. The test data rate was 23 Mbit/s and the measured receiving power with the distance of 5 m from the WiFi test source was –50.1 dBm/16 MHz, which represents average operating conditions.

For the traffic generator, Chariot 4.2 FilesndL (10 Mbytes, 10 Transaction per each run) was used and repeatedly generated traffic three times.

The average emission level of Impulse, DS-CDMA and OFDM UWB test sources at the frequency of 5.18 GHz were −51.3 dBm/MHz, −75.2 dBm/MHz and −95 dBm/MHz, respectively.

WLAN throughput was measured according to the distance. The test results are shown in Table 291 and Fig. 333.

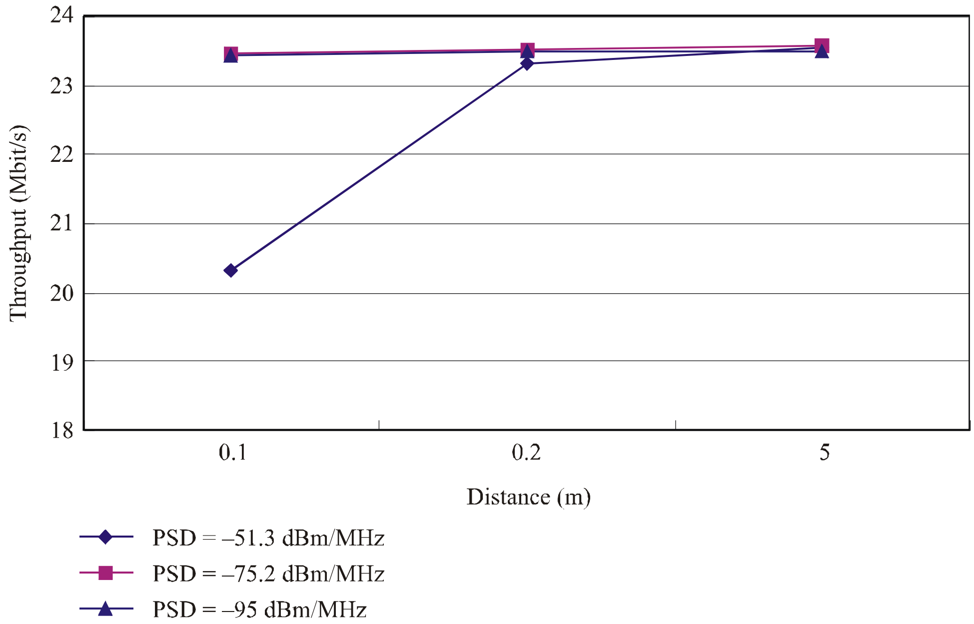
TABLE 291

Throughput of WiFi according to distance from UWB

UWB PSD / Distance (m)	Impulse –51.3 dBm/MHz	DS-CDMA –75.2 dBm/MHz	MB-OFDM –95 dBm/MHz
0.1	20.320	23.447	23.426
0.2	23.322	23.498	23.472
5.0	23.540	23.57	23.483

FIGURE 333

Throughput vs. distance



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The UWB PSD of –51.3 dBm/MHz (impulse UWB) causes 13% throughput degradation (3 Mbit/s degradation of 23 Mbit/s data rate) at the distance of 0.1 m, while UWB PSD of 75.2 dBm/MHz (DS-CDMA UWB) and –95 dBm/MHz (MB-OFDM UWB) cause ignorable degradation. When the UWB sources are located at the distance of over 0.2 m, and assuming average WiFi operating conditions, the effects can be disregarded as shown in Table 276.

TABLE 292

Throughput degradation of WiFi according to distance from UWB

UWB PSD / Distance(m)	Impulse –51.3 dBm/MHz	DS-CDMA –75.2 dBm/MHz	MB-OFDM –95 dBm/MHz
0.1	13.67%	0.52%	0.24%
0.2	0.93%	0.31%	0.05%
5.0	< 0.01%	< 0.01%	< 0.01%

3.2 Lab measurements of the impact of short-pulse ultra-wideband emissions on IEEE 802.11a systems

In response to Question ITU-R 227/1 and Resolution 952 (WRC-03), this section presents experimental data that shows that the existing United States emission limits for devices using UWB technology are adequate for ensuring co-existence between short-pulse UWB and IEEE 802.11a systems.

3.2.1 Introduction

This section presents some experimental results showing how the throughput of an IEEE 802.11a communication link is affected by the presence of a short-pulse UWB interferer in one typical indoor scenario. Although 802.11a radios are licence-exempt and must accept interference from other users sharing that band, it is still useful to examine the extent to which 802.11a systems can co-exist with a UWB radio that conforms to the United States rules (FCC Part 15 Subpart F).

3.2.2 Description of setup

We established a wireless link between a Proxim Harmony 802.11a access point and an IBM T30 Thinkpad equipped with a Proxim 802.11a Cardbus WLAN card as shown in Fig. 334. The access point, type-approved for use in Singapore based on the IDA's earlier rules for the licence-exempt 5 GHz band, operated with an e.i.r.p. of 100 mW in a 20 MHz channel centred on 5 180 MHz (channel 36). The access point and the laptop were placed 4.92 m apart with unobstructed LoS to each other.

The access point was connected to an Ethernet switch, to which an IBM T22 Thinkpad and another T30 laptop were also connected. The former served as the console for Net IQ's Chariot, a test and measurement program capable of measuring application throughput between any two nodes in a computer network. The latter would be instructed by the Chariot console to send network data to the victim T30 laptop (i.e. the laptop with the WLAN card) over the 802.11a link and measure the throughput of that connection.

We then placed a UWB transmitter 0.3 m away from the victim T30 laptop and pointed the UWB transmitter's antenna directly at the WLAN card. The UWB antenna was placed perpendicularly to the table to match the polarization angle of the WLAN card's antenna. Figure 335 shows a photo of this setup. We initially tried to perform the experiment with a separation distance of 0.5 m between the UWB transmitter and the WLAN card, but we found that the UWB interference generated by the transmitter was too weak to cause any impact on the WLAN throughput under these conditions.

Finally, we varied the parameters of the signal generated by the UWB transmitter and measured the throughput between the two T30 laptops.

FIGURE 334

Equipment setup

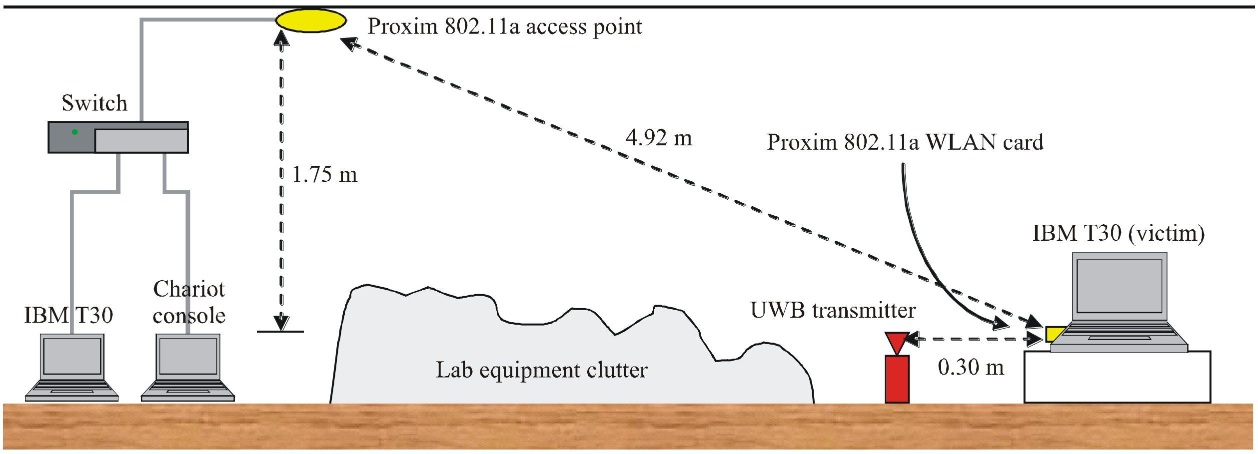

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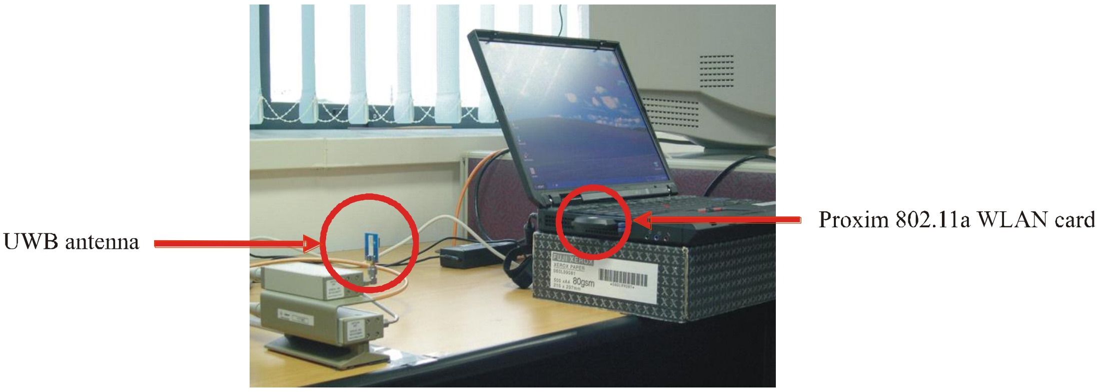
FIGURE 335

Photo of UWB transmitter and victim WLAN card



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3.2.3 UWB transmitter description

We used two different types of short-pulse UWB sources in our experiments: a Cellonics UWB TX Module boosted by one of two Miteq LNAs (AFS3-04000800-10-ULN for 32.5 dB of gain at 5 GHz, and AFS5-00101000-20-10P-5 for 40 dB of gain at 5 GHz), and a Multispectral TFP1001 Impulse Source. The UWB pulses produced by these two transmitters are quite different. The Cellonics unit generates 2.5 ns pulses of time-gated sine waves centred at 5.12 GHz. The 10 dB bandwidth of the signal is just a little below 500 MHz. The Multispectral unit, on the other hand, generates a series of monopulses with a typical pulse width of 250 ns and a very sharp rising edge containing spectral energies well beyond 10 GHz.

Thanks to the gain provided by the Miteq LNA, the Cellonics unit was able to generate spectral energy well above the −41.3 dBm/MHz United States mask (FCC Part 15) level within the 5.18 GHz channel used by the 802.11a system under test. On the other hand, the very strong low frequency components of the Multispectral unit made its output unsuitable for amplification in the absence of a band-pass filter. Therefore, with the Multispectral unit, we were only able to generate UWB signals with power spectral densities of around −50 dBm/MHz (depending on the pulse repetition frequency) in the 5.18 GHz channel. The Multispectral unit, however, can generate both positive and negative pulses, a feature that enabled us to produce bi-phase UWB signals.

Both UWB sources were triggered by a Tektronix DG2030 data pattern generator, which was operated remotely using Matlab scripts developed in-house to control the PRF, the number of PPM steps, and the polarity (either mono-phase or bi-phase, if applicable) of the UWB signal. PPM refers to the number of possible positions a single pulse can occupy within any time interval *T*, the reciprocal of the PRF. There is always one and only pulse within every *T*, but the polarity and/or position of the pulse can change from interval to interval. Bi-phase, high-PPM UWB signals are almost noise-like, while mono-phase, PPM = 1 UWB signals consist of distinct, evenly-spaced spectral lines in the frequency domain.

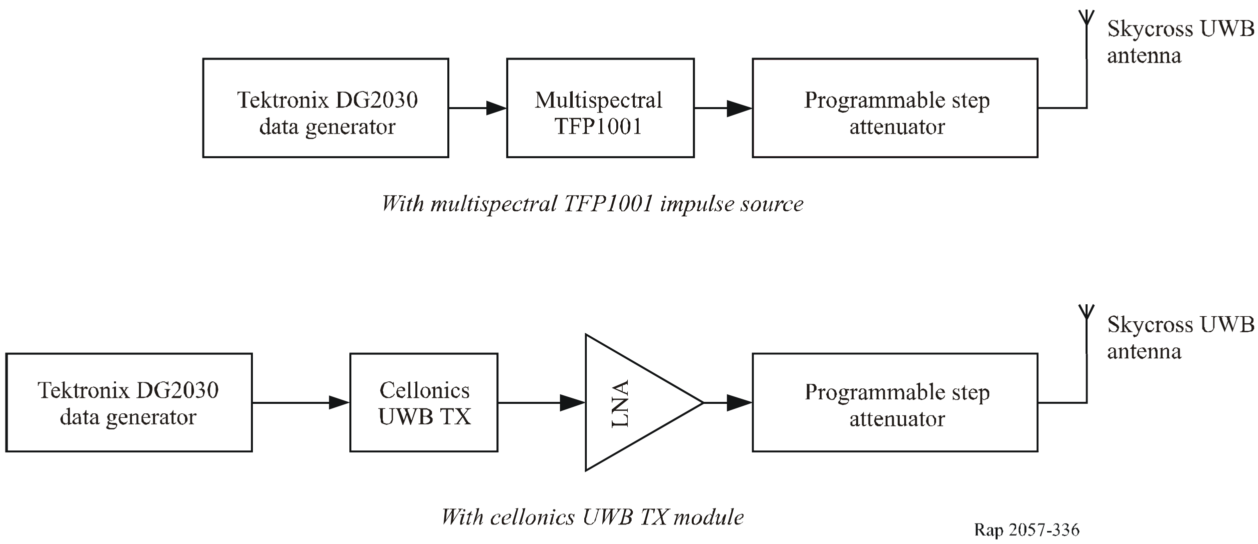
The output of the UWB sources was connected to an Agilent 8494H 1 dB programmable step attenuator and an Agilent 8495H 10 dB programmable step attenuator. Together, both attenuators enabled us to reduce the UWB signal level in 1 dB steps. Finally, the UWB signal was radiated from a Skycross UWB antenna, which has a gain of −3 dBi at 5.18 GHz in the direction of the WLAN card installed on the victim laptop.

To estimate the e.i.r.p. of the UWB transmitter, we first made a *conducted* measurement of the maximum average power density between 5.17 and 5.19 GHz in accordance with the United States' procedures described in Appendix F of the United States rules, FCC First Report and Order for UWB, (i.e. 1 MHz resolution bandwidth, 3 MHz video bandwidth, RMS detector). Then, we added the gain of the antenna (obtained from the antenna's specification sheet) to our readings to obtain the e.i.r.p. spectral density within the bandwidth of the 802.11a receiver.

Figure 336 shows a block diagram of the UWB transmitter setup.

FIGURE 336

UWB transmitter setup



3.2.4 Chariot configuration

We configured the laptop connected to the Ethernet switch as Endpoint 1 and the laptop equipped with the Proxim 802.11a WLAN card as Endpoint 2. The Large Throughput endpoint script, which simulates an FTP-like transaction in which data is sent from Endpoint 1 to Endpoint 2, was used to measure the throughput between the two endpoints. We increased the number of bytes sent per transaction to 10 000 000 bytes and set the duration of each test run to 1 min. In the absence of any performance degradation, about 10 transactions would complete successfully in each run. We recorded only the overall throughput reported by Chariot, which is the average throughput for all the transactions. Note that this is not the raw throughput of the 802.11a physical layer but the effective, usable throughput at the application layer.

3.2.5 Measurement results (Cellonics)

Figure 337 shows a scatter plot of the throughput reported by Chariot against the maximum average e.i.r.p. (within 5.17-5.19 GHz) of the UWB signals generated by the Cellonics module. Approximately half of the data points were obtained with the 32.5 dB gain LNA, while the rest were obtained with the 40 dB gain LNA. The dark grey line is the worst-case lower envelope of the data points, while the light grey line provides a more representative picture of the throughout vs. e.i.r.p. relationship. The light grey line suggests that the throughput of an 802.11a link will fall from around 22 Mbit/s to 19 Mbit/s when a device using UWB technology transmitting at the −41.3 dBm/MHz e.i.r.p. limit is placed 0.3 m in front of the victim receiver.

Although there is no clear relationship between PRF/PPM and throughput, certain PRF/PPM combinations did cause more interference than others. In particular, (PRF = 5 MHz, PPM = 2), (PRF = 5 MHz, PPM = 4) and (PRF = 25 MHz, PPM = 2) appear to have the greatest impact on throughput. However, because of the limited gain of the transmitter system, we were unable to produce UWB signals that exceeded the maximum limit in the United States mask −41.3 dBm/MHz when the PRF was lower than 10 MHz. Had we been able to boost the (PRF = 5 MHz, PPM = 2) and (PRF = 5 MHz, PPM = 4) signals above the United States limit, we would surely have seen them cause measurable degradation to the throughput of the 802.11a link.

Interestingly, contrary to popular thinking, our results show that time-dithered UWB signals are not necessarily less harmful than non-dithered signals. In fact, time-dithering a mono-phase signal (e.g. through pulse position modulation) actually increases the amount of UWB energy seen by the victim receiver without increasing the signal's maximum average e.i.r.p., since the UWB spectral energy is no longer confined solely to spectral lines occurring at multiples of the PRF but is allowed fill out the emission mask efficiently.

Figure 338, which shows how the number of PPM steps at PRF = 25 MHz affected the throughput of the 802.11a link, indicates that, on the whole, the non-dithered UWB signal (represented by the little black squares on Fig. 338) is actually the most benign. At PRF = 25 MHz with no dithering, the WLAN receiver only saw one strong spectral component at 5.175 MHz. When PPM was increased to 2, the receiver's throughput dropped noticeably. When PPM was further increased from 2 to 4, and then from 4 to 8, there was almost no change in the amount of throughput degradation relative to the PPM = 2 case.

Please see Appendix 1 to this Annex for the spectral plots of these four UWB signals.

3.2.6 Measurement results (multispectral)

Figure 339 shows the scatter plot of the throughput reported by chariot against the maximum average e.i.r.p. (within 5.17-5.19 GHz) of the UWB signals generated by the Multispectral TFP1001. Since the power spectral density of the Multispectral unit is quite low at 5.18 GHz, we did not manage to obtain many data points near the maximum limit in the United States mask −41.3 dBm/MHz. Nevertheless, we can see from Fig. 339 that the typical Multispectral throughput-e.i.r.p. curve agrees fairly well with the cellonics-e.i.r.p. curve, suggesting that pulse shape does not affect the interference potential of a short-pulse UWB transmitter significantly.

With the Multispectral unit, we could generate both mono-phase and bi-phase UWB pulses, whereas with the cellonics unit, only mono-phase signals were possible. Figure 340 plots all the data points obtained with a mono-phase Multispectral signal as blue dots and those obtained with a bi-phase signal as red crosses. The jumbled distribution of the dots and crosses suggests that there may be no significant difference in interference potential between mono-phase and bi-phase short-pulse UWB signals with the same e.i.r.p.

FIGURE 337

Throughput vs. maximum average UWB e.i.r.p. (cellonics)

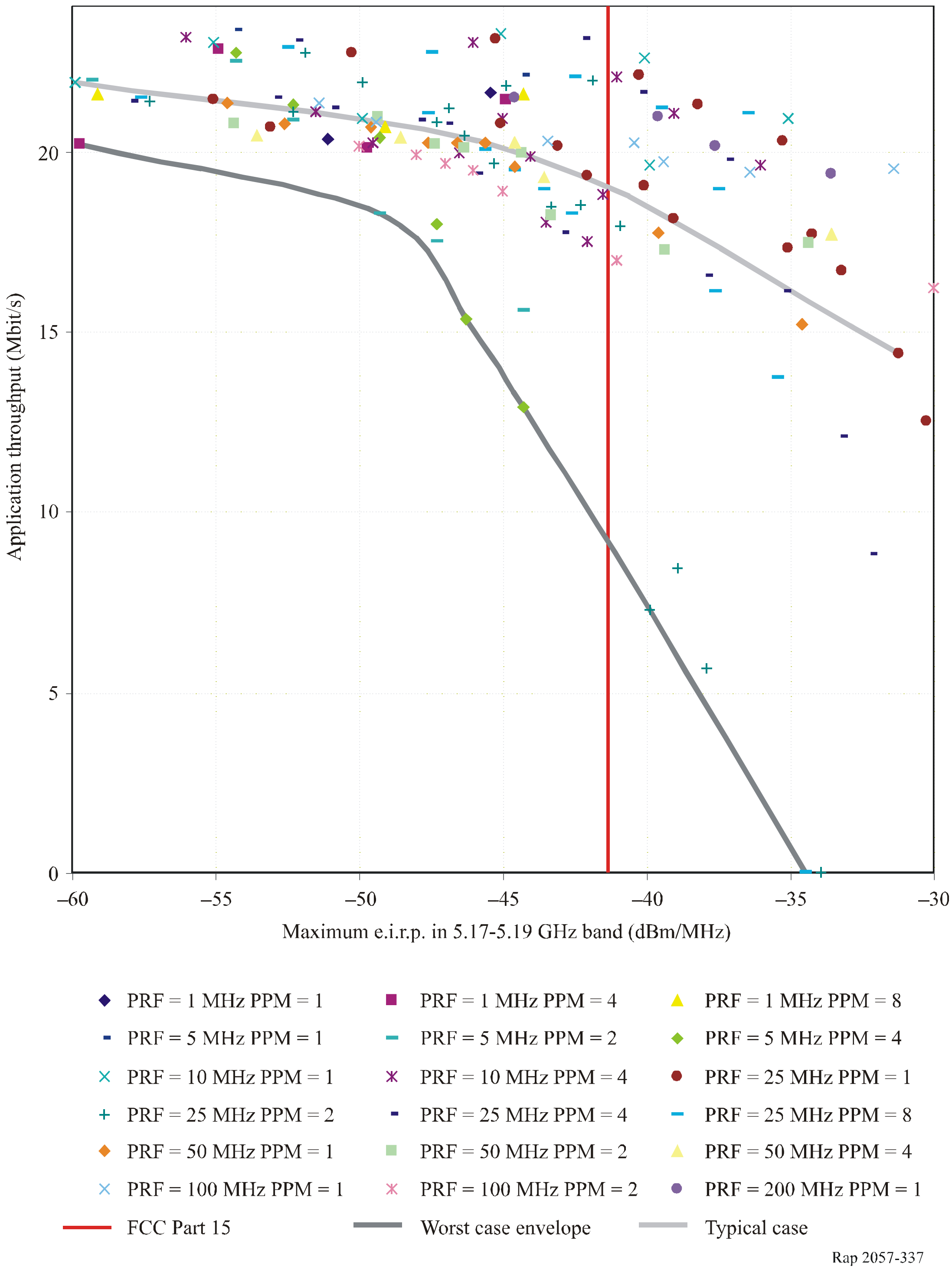


FIGURE 338

Throughput vs. e.i.r.p. For PRF = 25 MHz, PPM = 1 to 4 (cellonics)

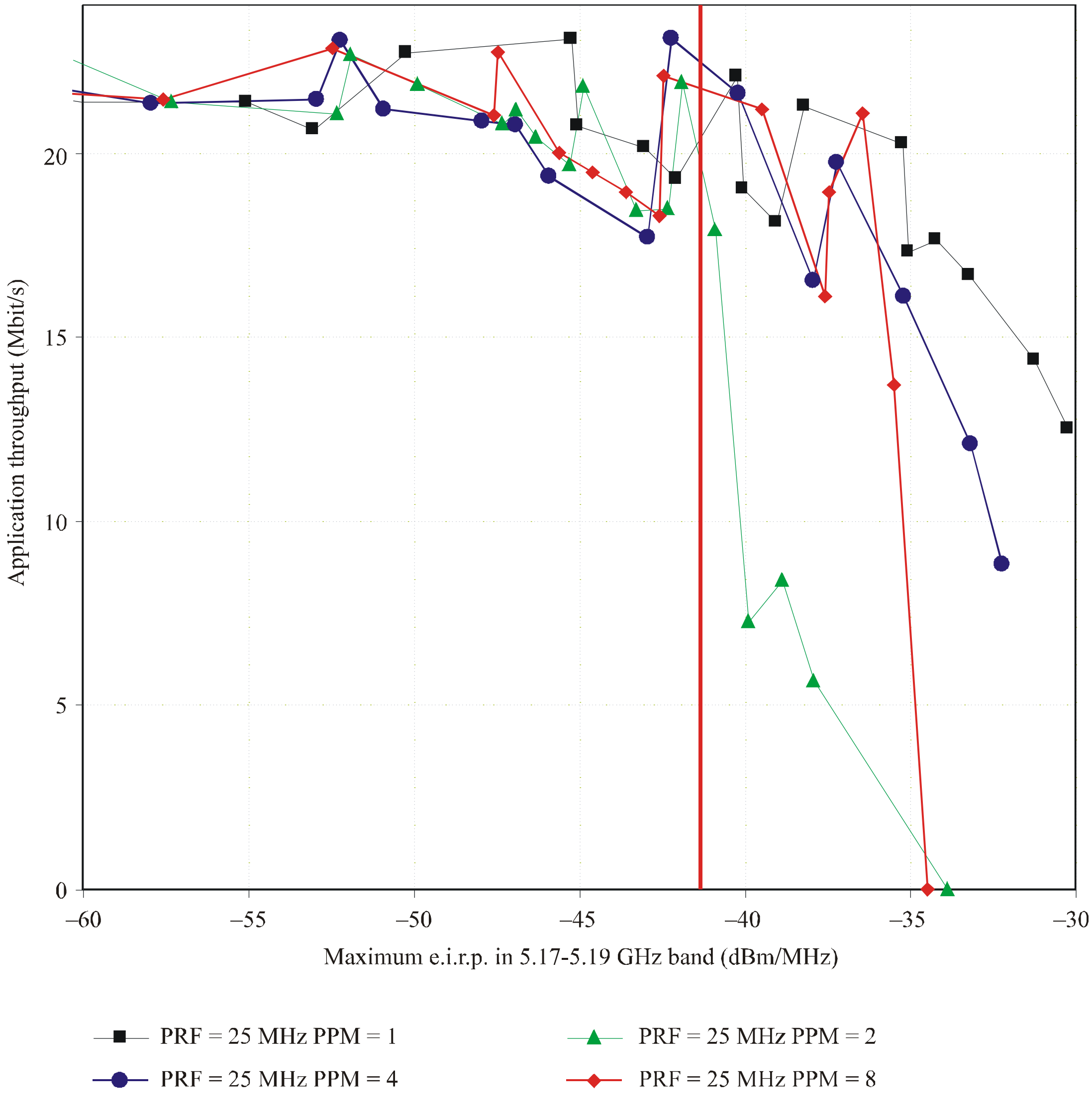


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FIGURE 339

Throughput vs. maximum average UWB e.i.r.p. (multispectral)

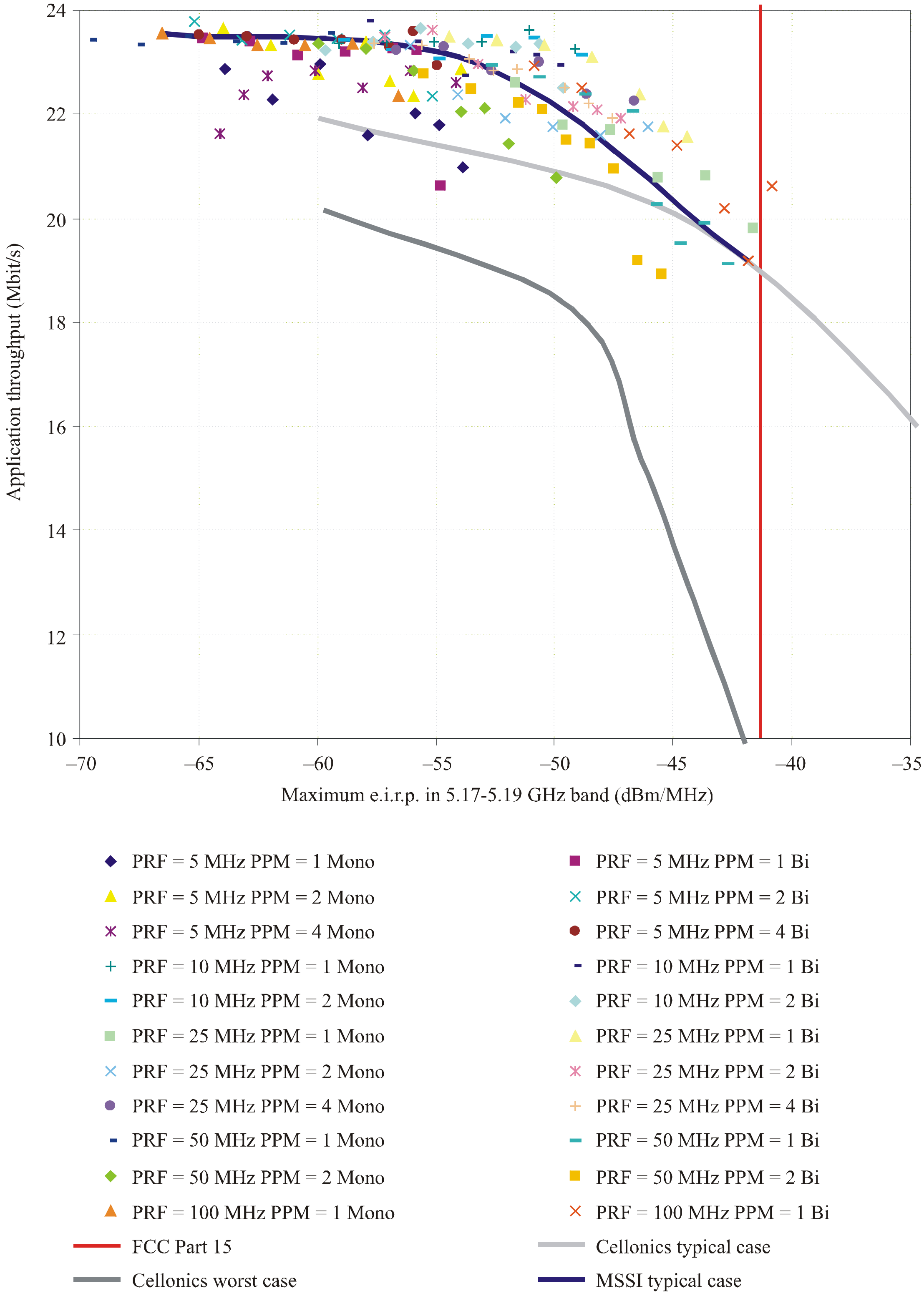

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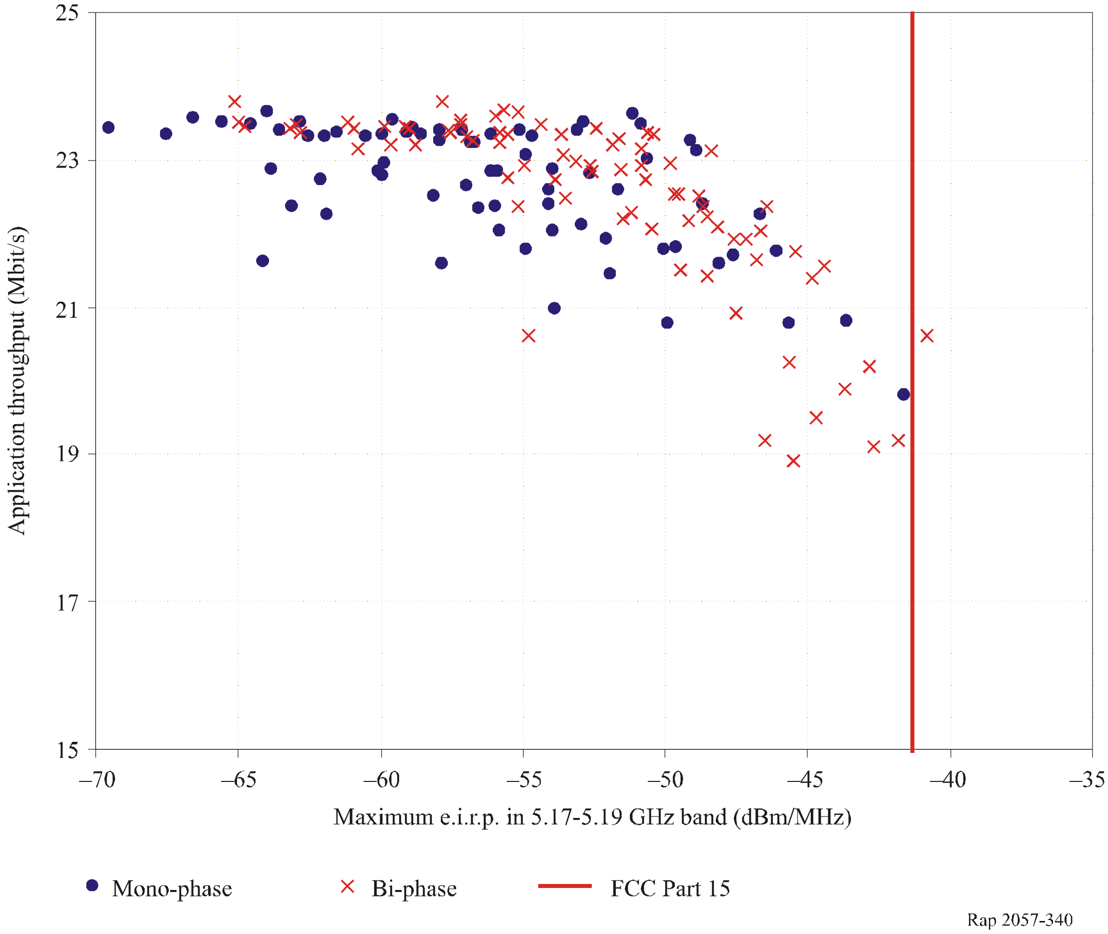
FIGURE 340

Interference potential of mono-phase and bi-phase UWB signals (multispectral)



3.2.7 Conclusions

Our results with the cellonics and the Multispectral UWB transmitters show that, on average, a short-pulse UWB transmitter with a PSD of −41.3 dBm/MHz placed 30 cm from an 802.11a WLAN card, with the transmitter's antenna pointing directly at the WLAN card, caused the throughput of the WLAN connection to drop by about 14% under the usage conditions considered in this study. If the e.i.r.p. of the WLAN access point is higher (e.g. 200 mW), the impact of UWB interference on the wireless link should be even less severe. When we increased the distance between the UWB transmitter and the WLAN card to 0.5 m, the UWB transmitter produced no measurable degradation to the throughput of the WLAN link.

Furthermore, we noted that time-dithered UWB signals were not necessarily more benign than undithered signals. The shape of the UWB pulse also did not appear to have an impact on the amount of interference observed.

In practice, we do not expect devices using UWB technology conforming to United States rules (FCC Part 15 Subpart F) to cause harmful interference to 802.11a devices, taking into account the fact that: (1) the distance between the device using UWB technology and the 802.11a device is probably larger than 30 cm if the two devices are not on the same piece of equipment; (2) the antennas of the 802.11a and the device using UWB technology are unlikely to be pointing directly at each other; and (3) the e.i.r.p. of the 802.11a device is much higher than that of the device using UWB technology. In fact, the presence of 802.11a devices actually makes the 5 GHz unlicensed band fairly hostile to UWB operation. For this reason, UWB system proposals currently being considered by the IEEE 802.15.3a task group avoid the 5 GHz U-NII band altogether. Indeed, given the information we have at hand, we believe that the existing United States rules for UWB are adequate for ensuring co-existence between short-pulse UWB and 802.11a devices.

4 Test measurements related to fixed service degradation due to UWB interference

4.1 Introduction

Under a CEPT/ECC WG-SE work item specifically dealing with studies on impact of 24 GHz ultra-wide band short range radars (SRR-UWB), intended for automotive applications, on FS and other services allocated in the bands around 24 GHz a test session has been agreed for finalizing those studies.

Provided that SRR-UWB available implementations cover a number of typical UWB applications (e.g. of pulsed, continuous and frequency hopping emission types) and being the wide-band FS receiver characteristics very similar in all bands, these tests are considered representative of the expected physical behaviour of the potential FS victim receiver in presence of pulsed UWB interference.

Tests were performed at R&D Labs of MW Dept. of a major FS systems manufacturer in Europe and were attended, besides the representative of four different SRR manufacturers[67] also by representatives of some Administrations as independent witnesses.

4.1.2 Test background

4.1.2.1 Scope

The main target of the tests was to determine and specify the relevant SRR parameters (e.g. maximum peak and/or mean interference level) which lead to impact consistent with the protection objective regarding the FS link budget.

Being the spectral characteristics of SRR quite different from thermal receiver noise it has been considered important to compare actual FS BER threshold degradation caused by a CW co-channel interference (on which preliminary assumption were based) and by the various kind of SRR signals presently foreseen in ETSI proposal. This would give more confidence to both SRR and FS parties on the objectives to be considered for defining final ECC regulations.

In particular the FS system selected was of “wide-band” kind (i.e. receiver Bw~41 MHz) being expected that peak SRR contribution to FS degradation is more affecting as far as the receiver Bw increases. Due to the kind of coded modulation (error correction) of the FS system used for the test, the results may be assumed as representative of current wide-band FS technology for presently deployed systems. The band is close to the 50 MHz assumed in United States regulations (difference from 50 MHz wide-band peak to r.m.s. ratio is less than 1 dB).

Representative characteristics of FS receiver under test are reported in Appendix 2 to this Annex.

The four types of SRR, presented to the test, were representative of all those described in ETSI System Reference Document TR 101 892, where detailed characteristics may be found.

It should be noted that the actual e.i.r.p. limit for SRR devices was beyond the scope of the test; it should be set comparing the objectives derived from the test results with the aggregate interference values coming from numerical evaluation of the representative scenarios. However this is a necessary step forward in the comprehension of the physical phenomena in order to set more technically sound and fair objectives for FS protection.

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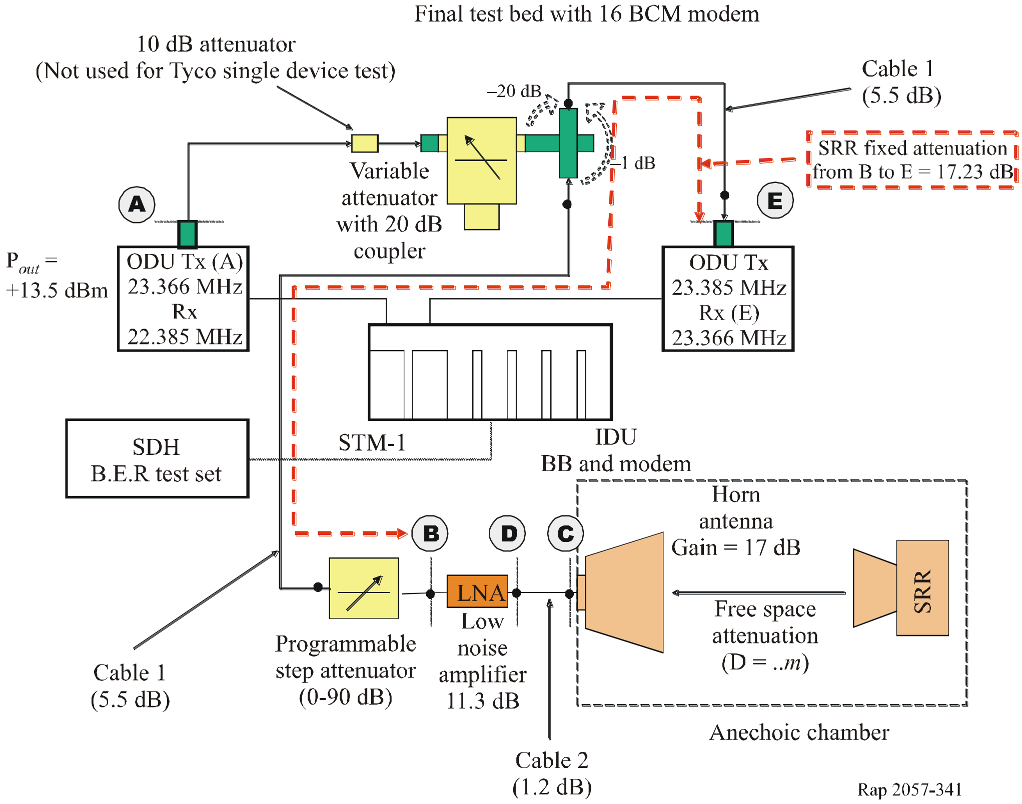
[67] Their prototypes will be identified as Devices 1, 2, 3 and 4.

Tentative practical objectives for both r.m.s. and peak *I*/*N* objectives are derived from the tests.

4.1.2.2 Test setup

FIGURE 341

Final set-up for SRR tests for improved sensitivity



A CW signal generator was also used for a reference *I*/*N* degradation test.

4.1.3 Test results

4.1.3.1 General

Data of FS RSL degradations for BER thresholds 10^{-6} and 10^{-8} versus SRR r.m.s. and peak power has been carried on and data recorded on Excel file and SA readings for further elaboration.

It should be noted that some tests (in particular for Device 1 and Device 3 devices and also for Device 4 aggregate), while still giving evident degradation to the FS receiver, the reference levels of SRR devices at Section B were very close to the SA noise floor ($S/N < 3$ dB). In those cases it is expected that the actual SRR levels would be quite lower than the reading.

For reducing the possible errors the SA noise floor was taken into account and correction of the actual SRR spectrum readings, nevertheless a potential error of few dBs has been considered and errors bars appears in the final graphs.

The following SRR devices/mode of operations have been tested for BER10^{-6} and 10^{-8} threshold degradation:

TABLE 293

Interfering signal
(CW or SRR type and mode of operation)

CW interference
Device 1 – Dithered mode no FM(1)
Device 1 – Undithered mode no FM(1)
Device 1 – Undithered mode + slow FM(1)
Device 2 – Undithered mode(1)
Device 2 – Dithered mode(1)
Device 3 – Single mode, (continuous pseudorandom phase shift)
Device 4 – Mode 1 (PRF 200 kHz – DC = 20 dB + fast frequency hopping)
Device 4 – Mode 2 (PRF 2 MHz – DC = 10 dB + fast frequency hopping)
Aggregate of up to 3 Device 1 devices dithered
Aggregate of up to 3 Device 4 devices (Mode 1)

(1) These SRR types have PRF ~3 MHz DC ~25 dB.

We should consider that data and conclusions are affected by:

– errors due to somehow insufficient sensitivity of the spectrum analyser used for defining the reference levels of interfering sources;

– tests made on a single FS receiver kind and therefore different behaviour might be expected from other receivers. However we are of the opinion that, when limited to very low interference degradation (as given by the interference objective considered), those differences should be quite limited.

In particular the peak objective is proposed being clear from the test that a r.m.s. limit only would not be technically sufficient for guaranteeing suitable and balanced criteria.

From the set of tests produced, the following considerations are relevant.

4.1.3.2 Aggregation of multiple devices

Tests have been made with up to three Device 1 (dithered mode) and up to three Device 4 (Mode 1) in order to have more confidence on the assumed 10 log$N$ adding law provisionally assumed in the interference study.

Results are not enough conclusive due to the far insufficient sensitivity in the tests however qualitative results might be summarized as:

– Device 1 aggregate tests seems to fit the 10 log adding law (aggregate devices behaviour is close to a single device with the same aggregate power).

– Device 4 Mode 1 results are inconclusive, due to the discovered power drop of one device that do not allows actual levels comparisons. However there is no evidence or feeling that might contradict Device 1 results.

4.1.3.3 FS thresholds degradations at different BER

Tests have been made for both BER 10^{-6} and 10^{-8} FS thresholds degradations in order to evaluate possible non-linear behaviour of the interference impact.

No significant difference have been found between BER 10^{-6} and BER = 10^{-8}.

Therefore only BER 10^{-6} data are here considered.

4.1.3.4 Measured BER threshold degradation versus *I*/*N*

4.1.3.4.1 Numerical results

Figures 342 and 343 are directly derived from the data of the tests and show the FS BER 10^{-6} threshold degradation as function of *I*/*N* r.m.s. ratio in 1 MHz bandwidth and Ipeak/Nrms ratio in the FS signal bandwidth of 41 MHz. Figure 344 shows the measured $I_{peak@41}/I_{rms@1}$ ratio of the SRR devices; the theoretical noise graph is shown for reference.

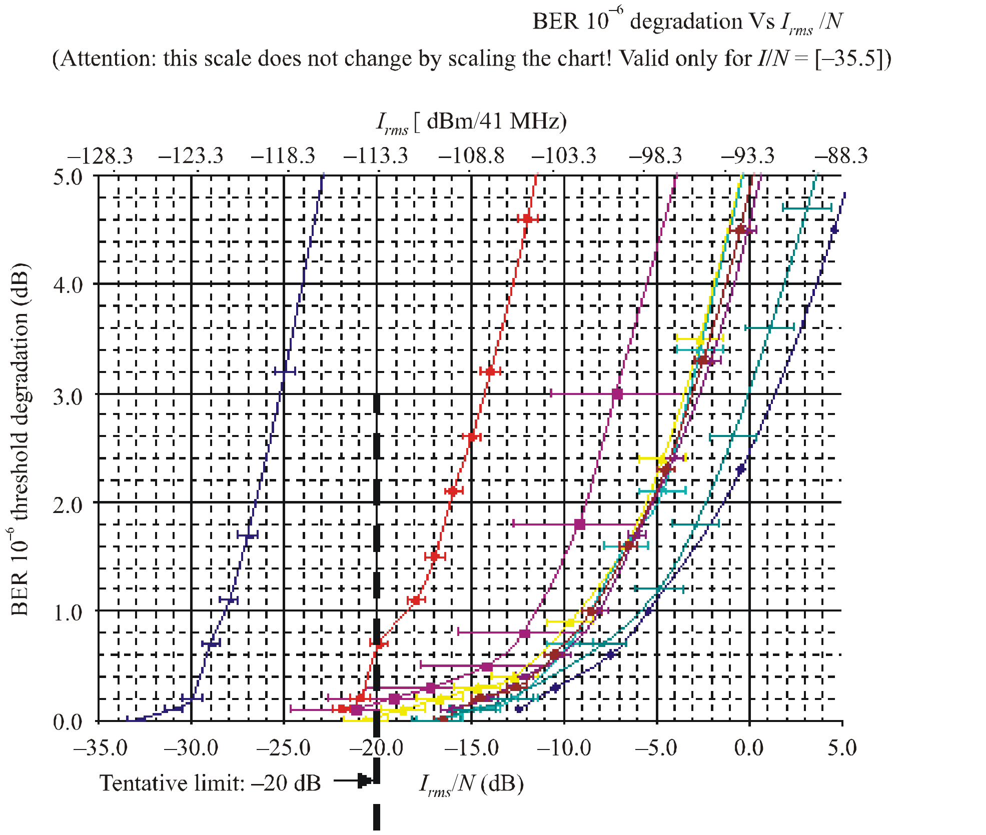
In all figures potential errors bars have been added for due feeling on the confidence of the following considerations.

For comparison, the CW interference test is shown. For this purpose, an $I_{CW\text{-}rms}$ "density" value is needed being the receiver bandwidth flat along its assumed to be: $I_{CW\text{-}rms} = I_{CW} - 10 \log 41$ while $I_{CW\text{-}peak}$ is assumed to be: $I_{CW\text{-}peak} = I_{CW} + 3$ dB.

The tentative proposed *I*/*N* practical objectives are also indicated as discussed later in this section.

FIGURE 342

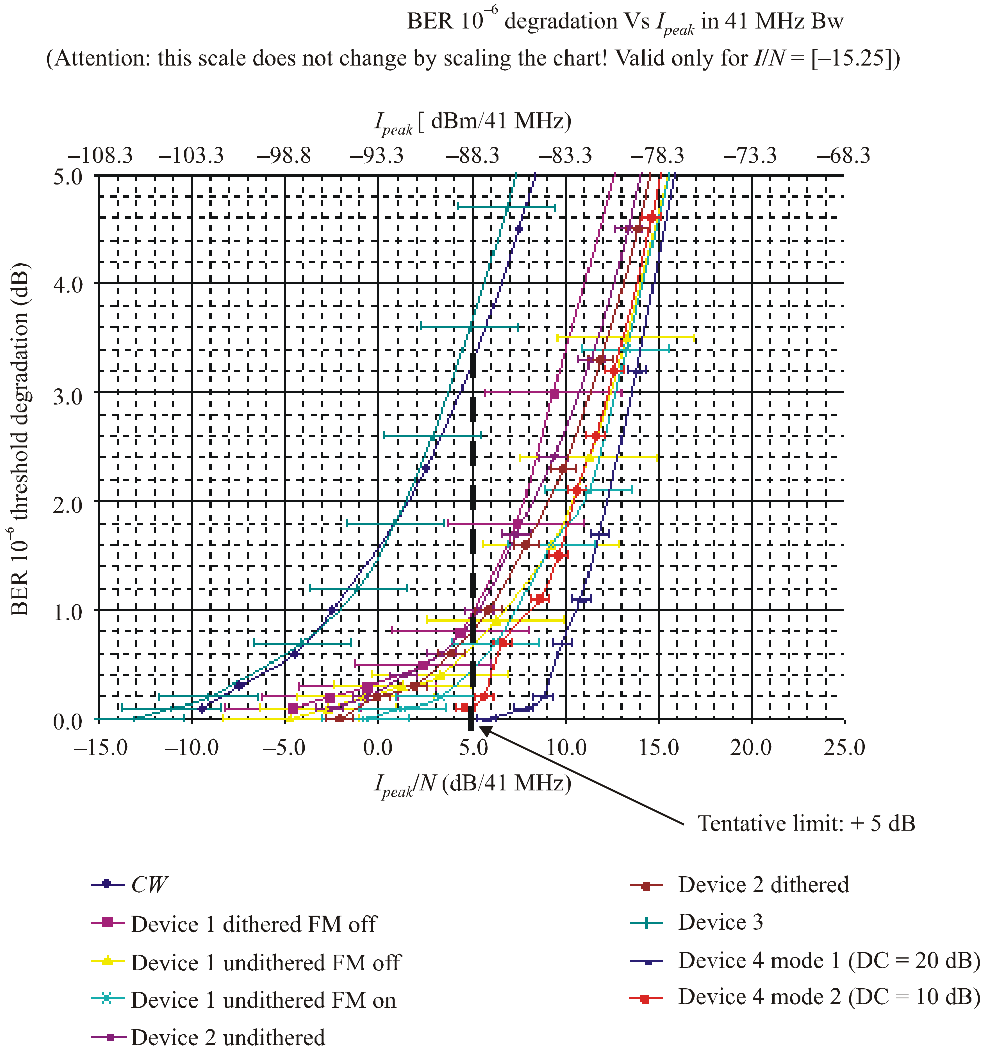
SRR r.m.s. impact on BER 10^{-6} FS threshold degradation



Rap 2057-342

FIGURE 343

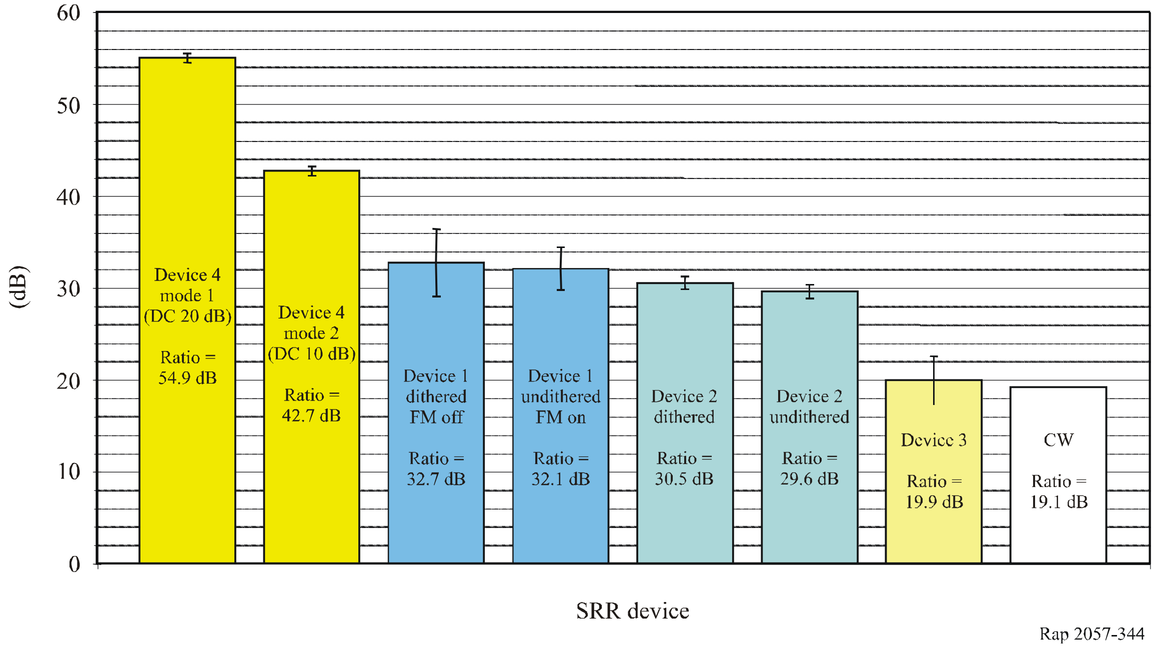
SRR peak impact on BER 10^{-6} FS threshold degradation



Rap 2057-343

FIGURE 344

$I_{PK@41}/I_{rms@1}$ **ratio for tested SRR devices**



4.1.3.4.2 Analysis of the behaviour in term of I_{rms}/N_{rms} and I_{PK41}/N_{rms41} ratios

CW interference is slightly better than noise theory; however the difference is within the possible measurement errors.

It seems clear that FS receiver degradation is generated by two different contributions one related to interferer r.m.s. power and another related to its peak power falling in the victim receiver band. The triggering level where degradation starts is obviously related to the peak to r.m.s. characteristic of the SRR device (see Fig. 344).

– For high peak to r.m.s. emissions (Device 4 FH sensors) the BER is initially caused by peak interference only and the degradation versus r.m.s. looks artificially worse.

– Unfortunately while the difference in function of Device 4 DC seems linear in the r.m.s. case, for the peak such linearity is not seen. This might be due to contribution of the r.m.s. phenomena that for Device 4 mode 2 (DC = 10 dB) is not negligible; it might be interesting having an additional test with even lower DC (e.g. DC = 30 dB).

– For low peak to r.m.s. ratio devices (Device 3 and CW), on the contrary, it is the BER degradation versus peak that looks artificially worse because errors are initially caused by r.m.s. contribution only.

– For intermediate cases such as Device 2 and Device 1 (that in Fig. 344 appears to have very close characteristics), the two contributions to BER degradation seems activated contemporarily.

– The crossover value between the two phenomena appears to be close to a $I_{PK41}/I_{rms1} \cong$ 30-32 dB, that, by the way is consistent with initial United States studies assumptions (–41 dBm/MHz and –10 dBm/50 MHz) before the peak limit be raised to 0 dBm/50 MHz in the final rule.

4.1.3.4.3 Validation of the interference objectives

In Figs. 342 and 343 the assumed long term interference objectives are shown considering that for wide band peak a 50 MHz conventional band is assumed instead of the actually tested 41 MHz[68].

– $I_{rms}/N \leq -20$ dB within 1 MHz: r.m.s. densities ratio within 1 MHz.

– $I_{PK}/N \leq +5$ dB within 50 MHz: I_{peak} to N_{rms} ratio within 50 MHz giving interference peak below noise peak for a probability $p >$ ~4%.

Analysing these values it might be notice that:

– For Device 4 devices, for which the I_{rms}/N objective would need to be tighter, would in any case limited by the peak limit to keeping the r.m.s. lower than the maximum allowed.

– For Device 3 device the situation is opposite, it would be bounded by I_{rms}/N while I_{PK}/N will be far lower than the limit.

– Device 2 and Device 1 are in intermediate situations and seems to be bounded by r.m.s. limit, however the peak limit is very close and actual final implementation would manage between those limits.

Note on possible regulatory framework

The problem of Peak evaluation within 50 MHz band aroused during the actual tests and further elaboration of the data; they need to be clarified/rectified in regulatory frameworks.

In the initial phase, when specific test equipment might not be available, some difficulty for assessing it might be present.

It was suggested that limits, drawn for 50 MHz bandwidth, be transformed into 3 MHz or even 1 MHz bandwidth assuming that the 20 log (50/Bres) is the worst case possible.

However, the absence of technical background for known examples, where that law is not theoretical true, led to some initial misinterpretation of the measurements (made at 3 MHz and transformed numerically to 41 MHz) for two type of devices:

– For Device 4 FH sensors there was an overestimation of the true 41 MHz peak due to the pulse bandwidth that was less (~20 MHz) than the 41 MHz and a corrected formula had to be used for correct evaluations.

– For Device 3 sensor there was an even higher overestimation because of its continuous and pseudorandom phase modulation that fit into a "noise-like" behaviour of 10 log (41/Bres) also for the peak power.

5 Test measurements on FSS degradation due to UWB interference

5.1 Measurements

The results of a number of physical measurements on FSS equipment were considered. It was noted that the analysis of the data did not take into consideration interference contributions from other inter-system sources, e.g. adjacent satellites, and terrestrial systems. Such sources need to be considered in order to predict the impact of UWB on FSS performance.

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[68] The difference with possible peak limit in 50 MHz band is in the worst case 20 log (50/41) – 10 log (50/41) ≅ 0.85 dB and is in the order of the potential errors. Therefore the same values might be assumed as proposed for 50 MHz bandwidth regulation.

This section summarizes these results from measurements made as presented as follows:

5.1.1 First study on measurements

One study presented the test results on the impact of UWB emissions, with PRFs from 200 kHz to 100 MHz, on a set of digital FSS modems from 64 kbit/s to 45 Mbit/s with receiver bandwidths of 56 kHz to 25 MHz respectively. Emissions from a 4 GHz device using UWB technology were injected into a 4 GHz FSS digital receiver and measurements were taken of the peak and r.m.s. levels when the digital modem suffered degraded performance or loss of synchronization. The UWB r.m.s. interference levels were measured with a 1 MHz video bandwidth and found to correlate with CW or noise like interference levels. The UWB peak power levels were measured with a 3 MHz bandwidth and did not cause any noticeable additional degradation on the modem performance. In other words the modem performance degradation was a function of the r.m.s. interference level. The impact of UWB peak power emissions on the FSS LNA or LNB was not tested.

The UWB testing also showed that UWB transmissions can produce very narrow spectral lines/peaks at intervals corresponding to the PRF of the UWB emission. The tests found that when a UWB spectral line fell within the noise bandwidth (55.8 kHz) of a 64 kbit/s digital carrier a higher C/I level of approximately 15 dB was required to avoid causing a loss of synchronization. The required C/I to avoid loss of synchronization for digital modems of 512 kbit/s or greater was from 4 to 11 dB. The reason for the higher C/I levels was the fact that the UWB r.m.s. emission levels were measured over a 1 MHz bandwidth and it was assumed the UWB emission was evenly distributed over the 1 MHz bandwidth.

Radiocommunication WP 4A is of the view that the emission levels from devices using UWB technology should be specified in and measured over the commonly used FSS standard bandwidth of 40 kHz, to ensure that narrowband FSS carriers are not impacted.

5.1.2 Second study on measurement

A second study presented laboratory experiments were performed to determine the threshold of UWB input signal strength at which significant signal degradation occurred. Tables 294, 295 and 296 show the laboratory test results for the 8-PSK receiver, the two QPSK receivers, and the FM analogue receiver, respectively.

TABLE 294

Laboratory test of 8-PSK digital receivers

UWB PRF (MHz)	Dithered/ undithered	Attenuation (dB)	UWB interference power (dBm)
50	Dithered	64.8	–88.7
50	Undithered	50.9	–91.1
20.8	Undithered	61.1	–98.0
20	Dithered	72.3	–89.2
20	Undithered	57.8	–96.4
5	Dithered	71.8	–96.7
5	Undithered	67.0	–96.5
1	Dithered	71.8	–94.7
1	Undithered	73.0	–95.7

TABLE 295

Laboratory test results for scientific atlanta powerVu D9225 and general instrument DSR4500 NTSC

Receiver	Desired signal level (dBm)	UWB signal level (dBm)	D/U (dB)	UWB PRF
Power	–85	–101	16	> 5 MHz
	–78	–91	13	> 5 MHz
General Instrument	–84.5	–98	13.5	> 1 MHz
	–77.5	–89	11.5	> 1 MHz
A dithered and undithered				

TABLE 296

Laboratory test of FM analogue receiver

UWB PRF (MHz)	Dithered/undithered	Attenuation (dB)	UWB interference power (dBm)
50	Dithered	–91	–96.7
50.1	Undithered	–89	–97.1
5	Dithered	–91	–96.7
5	Undithered	–91	–97.2
1	Dithered	–91	–100.7
1	Undithered	–88	–94.9
0.1	Dithered	–91	–87.7

Table 295 shows the receiver model validation results. "On the whole the variations between predicted and observed receiver sensitivities to UWB interference were considered to be well within the range of experimental precision."

TABLE 297

Receiver model validation results

Receiver simulation designation	Metric of comparison (dB)	Test value	Simulation value	Deviation (dB)
8-PSK	D/U ratio	8.1	13.2	+5.1
QPSK-1	D/U ratio	13	7.8	–5.2
QPSK-2	D/U ratio	11.5	10.7	–0.8
FM analogue	D/U ratio	5.7	6.5	+0.8

The impact of UWB interference is dependent on the distribution and density of the UWB emitters in the vicinity of the C-band earth stations. FSS receivers will experience complete reception failure at currently regulated UWB power levels assuming emitter densities currently found in the environment of common wireless-based consumer items.

One administration has adopted rules which allow protection of the FSS service with UWB operation. (*Editorial Note – Added by request of one Administration*.)

The 8-PSK receiver failed when the aggregate UWB power reached –102.4 dBm. This is equivalent to approximately 8 000 emitters uniformly distributed within a 5 km radius or about 0.8 devices per acre for an antenna elevation angle of 5 degrees. At antenna elevation angles of 7.5°, 10°, 12.5°, and 15° the critical densities in a uniform UWB environment are 1.9, 4.7, 7.4, and 9.3 devices per acre respectively. These densities are considered achievable in the early stages of an UWB-based network deployment or usage paralleling that of cordless telephones.

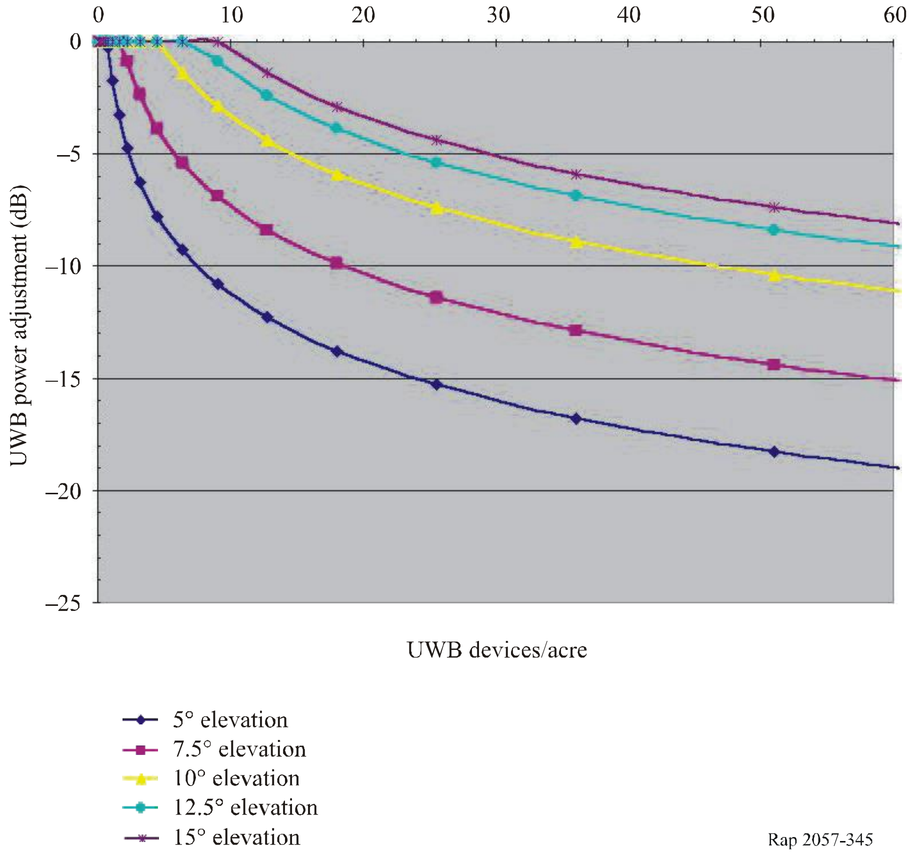
If, for instance, UWB becomes as ubiquitous as the cordless telephone, a market density of two per 1/4-acre residential lot is a reasonable projection. This is more than ten times the critical density we have previously identified. Deployment within an industrial park, for example, one UWB per 10′ × 10′ office, introduces significantly greater interference potential.

In considering vehicular devices using UWB technology, rush hour traffic in major metropolitan areas can result in concentrations of 150 to 190 vehicles per acre (1 acre = 4 047 m^2). If only ten percent of these vehicles are utilizing an device using UWB technology, the aggregate interference could be twenty times (13 dB) or more above the functional tolerance of nearby earth stations.

A combination of reduction in the power of individual interfering devices and a PRF limit would provide a balance against the earth station interference potential imposed by market growth. An UWB power adjustment versus the number of devices using UWB technology per acre for each of the studied C-band earth station elevation angles is shown in Fig. 345.

FIGURE 345

UWB power adjustments versus antenna elevation angle to prevent disruption of service



5.1.3 Third study on measurement

A third study gives the following elements:

TABLE 298

***C/I* protection ratios (Lab, short-pulse UWB)**

No.	Data rate (kbit/s)	Code rate	FEC[(1)]	*C/I* (Max. PSD)			*C/I* (channel power)		
				Average	Standard deviation	Range	Average	Standard deviation	Range
1	256	1/2	Vit	9.6	1.52	5.1-14.3	12.3	1.52	9.1-14.7
2			Vit+RS	7.2	0.80	5.3-9.1	7.8	1.00	5.5-10.2
3		3/4	Vit	11.4	1.99	7.6-14.7	13.9	1.22	11.8-15.9
4			Vit+RS	6.8	1.91	2.6-11.4	8.9	0.38	8.1-9.5
5			TPC	8.3	1.67	5.2-11.3	10.3	0.78	8.3-11.5
6		21/44	TPC (BPSK)	2.5	1.90	–1.9-5.4	3.8	0.74	2.7-5.7
7		5/16	TPC (BPSK)	0.2	2.21	–4.8-3.4	1.9	1.09	–0.2-4.5

TABLE 298 (*end*)

No.	Data rate (kbit/s)	Code rate	FEC(1)	*C/I* (Max. PSD)			*C/I* (channel power)		
				Average	Standard deviation	Range	Average	Standard deviation	Range
8	1 024	1/2	Vit	9.8	2.22	5.9-13.6	12.6	1.57	9.4-16.6
9			Vit+RS	6.3	2.77	–1.5-11.4	9.1	2.01	3.8-12.6
10		3/4	Vit	12.5	2.02	8.0-17.3	16.1	1.62	13.2-20.0
11			Vit+RS	7.3	1.64	3.9-11.4	10.2	0.90	8.6-13.0
12			TPC	9.0	1.76	5.2-11.9	12.5	1.06	10.7-16.6
13		21/44	TPC (BPSK)	2.9	2.48	–3.4-9.0	4.2	1.22	–0.1-5.9
14	2 048	1/2	Vit	12.7	2.30	8.3-15.8	15.6	1.71	12.0-18.8
15			Vit+RS	6.7	3.75	–1.2-12.5	8.7	2.94	2.1-12.9
16		3/4	Vit	16.0	2.23	11.8-19.8	19.9	1.88	17.3-23.4
17			Vit+RS	8.7	2.09	4.9-13.0	10.7	0.89	9.3-12.7

(1) Modulation type is QPSK unless otherwise indicated. Vit = Viterbi FEC, Vit+RS = Viterbi FEC with outer (220 200) Reed-Solomon code, TPC = Turbo Product Code.

NOTE 1 – *C/I* protection ratios varies from 2 to 20 dB depending on type of satellite service (data rate and FEC used).

NOTE 2 – When interferer power is measured using channel power technique, the *C/I* protection ratios required for short pulse UWB is about the same as that needed to protect against OFDM-type UWB, as shown in the previous Table 298.

NOTE 3 – RS outer coding seems to be particularly good to mitigate impact of low-PRF UWB.

NOTE 4 – Good correlation in results between laboratory and field measurements as presented in the following Table 299.

TABLE 299

C/I protection ratios (field)

No.	Data rate	Code rate	FEC	Field			Laboratory(1)		
				C/I (Max. PSD)			*C/I* (Max. PSD)		
				Average	Standard deviation	Range	Average	Standard deviation	Range
1	256 kbit/s	3/4	Vit	13.0	2.96	6.4-17.2	12.2	1.76	8.5-14.7
2			Vit+RS	1.9	2.21	–1.3-5.5	7.0	1.19	5.3-8.9
3	1 024 kbit/s	3/4	Vit	10.3	2.64	5.9-16.2	14.0	2.14	10.3-17.3
4		1/2		9.0	3.10	0.5-13.3	10.3	1.98	6.7-13.6
5	2 048 kbit/s	1/2	Vit	11.6	2.70	7.1-19.0	13.7	1.79	9.9-15.8
6			Vit+RS	4.6	1.89	1.9-8.1	9.0	1.93	5.2-12.5

(1) The average, standard deviation and range of the lab results have been recalculated, taking into account only the 12 or 24 UWB signal types (instead of 36) that were used in *both* the lab and field tests.

NOTE 1 – Highlight impact of aggregated UWB emissions on FSS as shown in Table 300.

TABLE 300

UWB signal aggregation

No. of active UWB devices	Increase in required attenuation to maintain zero BER (relative to single device scenario)		
	Average	Standard deviation	Range
1	–	–	–
2	2.9	1.73	0-5
3	4.9	1.64	2-6
4	6.3	1.49	3-7

NOTE 1 – Highlight results of field test with operational FSS, no degradation seen with short pulse or MBOA type UWB emitters operating at 6 m from satellite dish. It is perhaps due to narrow beam width giving protection from nearby emitters.

5.1.4 Impact of UWB interference on a C-band FSS receiver

In response to Question ITU-R 227/1 and Resolution COM7/3 (WRC-03), this section presents and discusses the results of a study undertaken by the IDA to determine the impact of UWB interference on an FSS receiver.

5.1.4.1 Summary

Most theoretical analyses of the impact of UWB interference on a victim receiver make the assumption that a certain minimum signal to interference ratio (C/I) can be used to determine the maximum permissible power level for a UWB signal, above which the victim receiver will experience a significant amount of interference. While this assumption generally holds quite well for Gaussian noise sources, its applicability to UWB interference has not been well-established.

We carried out a series of measurements in the lab and the field to determine the minimum C/I ratio needed to prevent a UWB interferer from causing bit errors in a C-band FSS downlink. Both short-pulse and multi-band OFDM (MB-OFDM) UWB signals were considered in this study. The MB-OFDM signal is based on the Multi-band OFDM Alliance (MBOA) v0.7 PHY specification.

Our lab test results show that C/I depends largely on the satellite modem configuration (data rate, code rate, etc.) and can range from about 2 dB to 20 dB. Furthermore, there appears to be very little difference between the severity of the interference caused by short-pulse UWB and MB-OFDM UWB signals as long as they introduce the same amount of power into the victim FSS receiver's pass-band.

In light of our field test results, we are aware that our lab test results may lead us to draw overly conservative conclusions. A test we carried out near a local satellite operator's C-band satellite dish with a very low elevation angle showed that an US-compliant short-pulse or MB-OFDM device using UWB technology operating in the vicinity of a satellite dish is unlikely to have any measurable impact on the satellite downlink.

5.1.4.2 Approach

This study consists of a lab test and two field tests. In the lab, all signals were conducted, and the uplink-to-downlink frequency translation was effected using a mixer and a local oscillator. In the first field test, we set up a temporary 3.7 m satellite dish to receive a signal relayed by MEASAT-2.

In the laboratory test and the first field test, we injected UWB interference into a satellite receiver to measure its impact on the downlink. We increased the amount of UWB interference gradually until one or more bit errors showed up at the FEC-corrected output of the FSS receiver within a 1-minute interval. We then measured the minimum *C*/*I* ratio, i.e. the ratio between the power of the downlink signal and the power of the UWB signal, that had to be maintained to protect the downlink signal from UWB interference. We measured *C*/*I* in two ways: (1) in terms of maximum power spectral density and (2) in terms of the total in-band channel power, both within the 3 dB bandwidth of the FSS receiver.

Finally, in the second field test, we worked with a local satellite operator to place a UWB transmitter in the vicinity of an operational satellite dish. This setup enabled us to make qualitative observations on the impact of UWB interference on an FSS system under realistic usage conditions.

5.1.4.3 Laboratory test

5.1.4.3.1 Preparation and setup

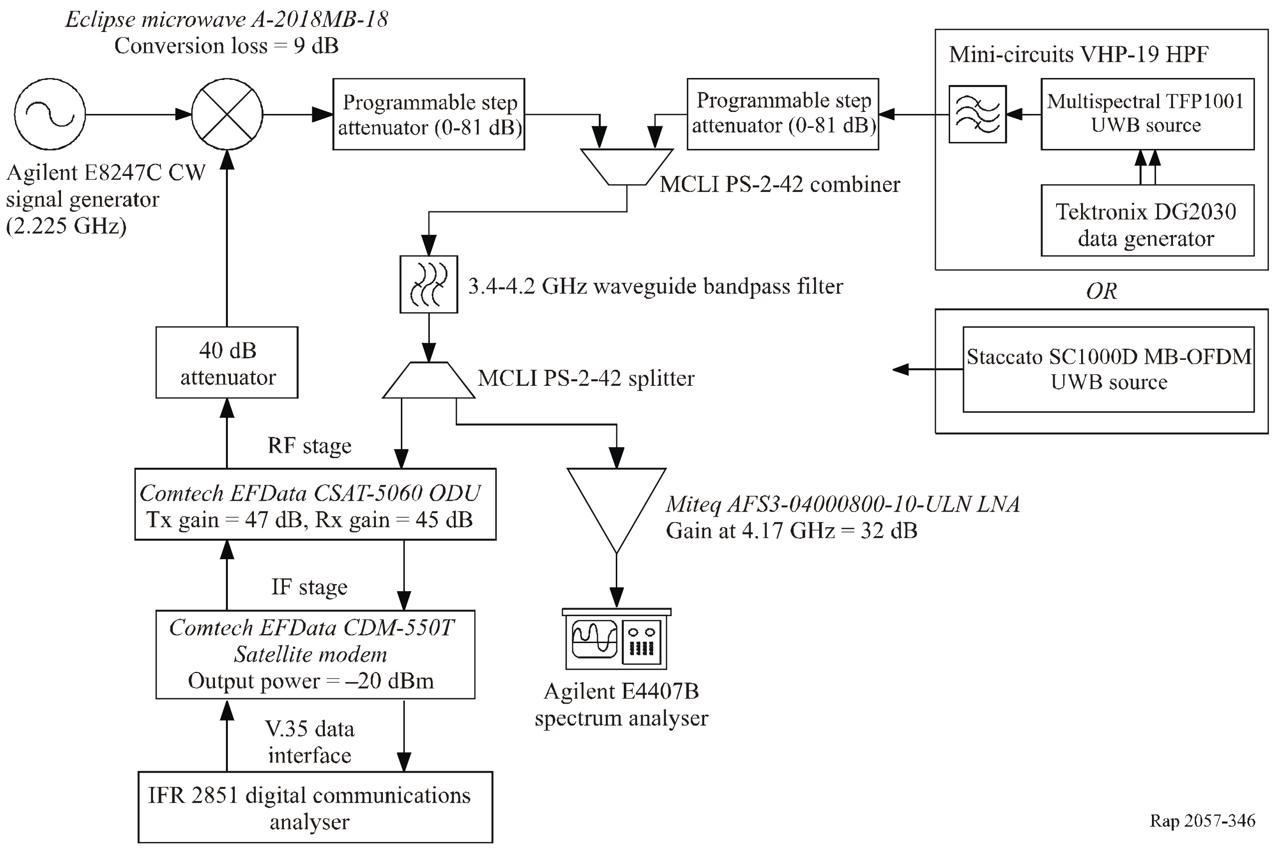
5.1.4.3.1.1 Overview

We began our interference study in the lab, where we studied the impact of UWB signals on a C-band FSS downlink in a controlled, static environment using only conducted signals. Using a set of scripts developed in Matlab, we automated the entire process of measuring the *C*/*I* ratios for many combinations of UWB signal types and satellite modem settings. In total, we carried out this portion of the study with 37 different UWB signal types (comprising 36 short-pulse UWB signal types and 1 MB-OFDM UWB signal type) and up to 17 different satellite modem settings (17 for short-pulse UWB and 12 for MB-OFDM UWB) for a total of 624 unique interference scenarios.

The complete setup for the lab test is shown in Fig. 346.

FIGURE 346

Lab measurement setup



For simplicity, GPIB and RS232 connections to the central control laptop are not shown in Fig. 346.

5.1.4.3.1.2 C-band FSS receiver configuration

The C-band FSS system we used comprised a Comtech EFData CDM-550T satellite modem, a Comtech EFData CSAT-5060 outdoor unit (ODU), and an Eclipse Microwave A-2018MB-18 mixer to translate the uplink signal from 6.39942 GHz down to 4.17442 GHz. These frequencies correspond to the ones we were assigned for the first field test. An Agilent E8247C CW signal generator served as the local oscillator (2.225 GHz) for the mixer. The UWB interference was added after down-conversion, before the receive band-pass filter.

We configured the satellite modem to use QPSK modulation at data rates of 256 kbit/s, 1 024 kbit/s and 2 048 kbit/s, code rates of 1/2 and 3/4, and with both Viterbi and Viterbi+Reed-Solomon (220,200) FEC, for a total of 12 different configurations. In addition, we plugged in the Turbo Product Codec option and repeated our test five more times with rate 3/4 QPSK, rate 21/44 BPSK and rate 5/16 BPSK turbo product coding at 256 kbit/s, and with rate 3/4.

QPSK and Rate 21/44 BPSK turbo product coding at 1 024 kbit/s. Note that the Turbo Product Codec was not tested with the MB-OFDM UWB signal type because the codec hardware was not available when the MB-OFDM UWB tests were being carried out.

We attenuated the downlink signal to ensure that the satellite modem receiver operated just above the E_b/N_0 value required for a BER of 10^{-7}. These E_b/N_0 target values can be found on page 14-3 of the CDM-550T manual (Rev. 1.3) and are reproduced here in Table 301. Note that the E_b/N_0 targets are independent of data rate.

TABLE 301

E_b/N_0 target values (BER = 10^{-7})

FEC type	Code rate	E_b/N_0 target
Viterbi	1/2	6.7
	3/4	8.2
Viterbi + Reed-Solomon (220, 200)	1/2	4.5
	3/4	6.0
Turbo product coding	3/4 QPSK	4.1
	21/44 BPSK	3.1
	5/16 BPSK	2.6

5.1.4.3.1.3 UWB transmitter configuration

5.1.4.3.1.3.1 Short-pulse UWB

The short-pulse UWB transmitter used in all of the lab tests is the Multispectral TFP1001 impulse source, which can be externally triggered to produce both positive and negative pulses (typical pulse width = 250 ps) with a pulse repetition frequency exceeding 100 MHz. The very short rise time of the pulse results in spectral energies from DC to well beyond 10 GHz, though the bulk of the energy actually lies below 1 GHz. To prevent signal compression at the ODU input, we placed a Mini-Circuits VHP-19 high-pass filter at the output of the step attenuator to which the TFP1001 was connected, and further band-limited the signal with a 3.4-4.2 GHz waveguide band-pass filter, which also helped to suppress the LO feed-through and its harmonics.

We used a Tektronix DG2030 data pattern generator to drive the TFP1001 using trigger sequences assembled in Matlab and uploaded to the DG2030. A trigger sequence is basically a binary data stream. Each rising edge in the data stream (i.e. a transition from 0 to 1) will cause the TFP1001 to produce a single UWB pulse. The polarity of the pulse depends on whether the rising edge is seen at the positive pulse trigger input or the negative pulse trigger input. We wrote a custom program in Matlab to generate the appropriate trigger sequences to produce both mono-phase and bi-phase UWB signals with user-specifiable PRF and PPM settings. The PPM value refers to the number of positions in which a pulse can appear within each period (= 1/PRF). For example, if PPM is set at 8, then a pulse can appear in one of eight evenly-spaced locations within each interval of 1/PRF s. The higher the PPM number, the greater the amount of time dithering in the UWB signal.

In total we used up to 36 combinations of PRF, PPM and signal polarity (i.e. mono-phase or bi-phase) in the lab test. PRF ranged from 0.1 MHz to 100 MHz, while PPM ranged from 1 to 8. The complete list of UWB signal combinations can be found in Table 308. Please refer to Appendix 4 to Annex 7 for more information about the short-pulse UWB transmitter.

5.1.4.3.1.3.2 Multi-band OFDM (MB-OFDM) UWB

The MB-OFDM signal was generated using Staccato Communication's SC1000D transmitter. The SC1000D generates an MB-OFDM signal based on version 0.7 of the Multi-Band OFDM Alliance (MBOA) PHY layer specification, which, at the time of writing, was one of the two proposals that were being considered for the IEEE 802.15.3a standard. The signal comprises three 528 MHz OFDM bands centred at 3.432 GHz, 3.960 GHz and 4.488 GHz. The three bands are switched in a 1-2-3-1-2-3-… sequence so that at any moment in time, the UWB signal occupies only 528 MHz.

5.1.4.3.2 Measurement procedure

5.1.4.3.2.1 Overview

For each of the 624 combinations of UWB signal parameters and satellite modem settings, we measured the minimum *C*/*I* protection ratio that had to be maintained to prevent any bit-errors in the downlink over a one-minute period. Although a longer measurement period is generally desirable to obtain a more accurate BER reading, especially for low data rate signals, we chose a 1 min observation period to ensure that the entire study could be completed within a reasonable period of time. The BER of the downlink signal was monitored using an IFR 2851 Digital Communications Analyser, while the *C*/*I* protection ratios were calculated based on measurements made using an Agilent E4407B spectrum analyser with a Miteq LNA as a pre-amp. The IFR 2851 and the Agilent E4407B communicated with our Matlab program running on our central control laptop over an RS232 and a GPIB interface respectively.

5.1.4.3.2.2 Measuring *C*/*I*

The *C*/*I* ratio captures the relative difference in power level between the desired FSS downlink signal (*C*) and the UWB interference (*I*). We define *C* as the minimum power of the satellite signal at which the threshold E_b/N_0 target required to achieve a BER of 10^{-7} (see Table 301) for a particular choice of data rate, code rate and FEC type can be met. *I* is the power of the UWB interference above which the BER of the downlink measured over a period of 1 min will be non-zero. Programmable step attenuators placed after the uplink/downlink down-conversion stage and at the output of the UWB source enabled us to control both *C* and *I* in 1 dB steps.

We measured *C*/*I* in two ways: in terms of maximum PSD, and in terms of total in-band power within the 3 dB bandwidth of the FSS receiver. The size of the 3 dB bandwidth is equal to the symbol rate of the FSS signal and was calculated separately for each satellite modem setting.

To measure *I* in the first approach, we used a resolution bandwidth (RBW) of 1 MHz, a video bandwidth (VBW) of 3 MHz and an RMS detector on the spectrum analyser to obtain a trace of the UWB signal PSD. We then took down the maximum reading observed after turning on Peak Hold for a few seconds. This approach is similar to the procedure described in United States rules (FCC Part 15 Subpart F) for measuring the maximum RMS average power of the UWB signal. The procedure for measuring *C*, the peak PSD of the FSS signal, is similar, except that we changed the RBW and VBW to 10 kHz and 30 kHz respectively to ensure that the RBW was always smaller than the bandwidth of the FSS signals used in our study. We then added 20 dB to our *C* reading to convert its units from per 10 kHz to per MHz.

In the second approach, we used the "channel power" measurement function of the Agilent E4407B spectrum analyser to measure *C* and *I* automatically. The integration bandwidth, i.e. the bandwidth across which power density is integrated, was specified to match the 3 dB bandwidth of the FSS receiver. The other measurement parameters were chosen automatically by the spectrum analyser.

In both approaches, the values obtained for *C* and *I* were sometimes fairly close to the noise floor of the measurement setup. To determine *C*/*I* more accurately, we linearly subtracted out the measurement noise floor (which varies with RBW, VBW and integration bandwidth) from both readings first before calculating the final *C*/*I* ratio.

5.1.4.3.3 Results and analysis

5.1.4.3.3.1 Overview

Table 302 shows the *C*/*I* values, in terms of both maximum PSD and total in-band channel power, obtained for the 36 short-pulse UWB signal types. Given the large number of measurements in this data set, only the average, standard deviation and range of the *C*/*I* values for each satellite modem configuration are reported here. Table 303 shows the corresponding *C*/*I* values for the remaining MB-OFDM UWB test cases.

Note that we did not include in our computation the *C*/*I* values corresponding to the short-pulse UWB signal types for which there was very little spectral energy within the 3 dB bandwidth of the FSS receiver. Specifically, we did not consider the PRF = 1 MHz, 5 MHz, 10 MHz, 50 MHz and 100 MHz, PPM = 1, mono-phase UWB signal types for the 256 kbit/s test cases, the PRF = 5 MHz, 10 MHz, 50 MHz and 100 MHz, PPM = 1, mono-phase UWB signal types for the 1 024 kbit/s test cases, and the PRF = 10 MHz, 50 MHz and 100 MHz, PPM = 1, mono-phase UWB signal types for the 2 048 kbit/s test cases. All PPM = 1, mono-phase short-pulse UWB signals have their spectral energies concentrated only in evenly-spaced spectral lines with almost no energy between them. At high PRFs, the spectral lines are so far apart that none of them actually falls within the bandwidth of the FSS receiver. Although such UWB signals can still produce errors in the FSS downlink, they do so as OoB interference. The amount of in-band interference (i.e. the *I* power level we measure) is in fact very low, so using this value to calculate *C*/*I* will grossly overestimate the *C*/*I* protection ratio needed to protect the FSS link. For the most part, the impact of spectral lines falling within the bandwidth of the FSS receiver is already accounted for in our results for the PRF = 0.1 MHz, PPM = 1, mono-phase test cases.

We can see from each row in Table 302 that, in most cases, the range of *C*/*I* (channel power) values is smaller than the corresponding range of *C*/*I* (maximum PSD) values for any given satellite modem configuration. In other words, compared to *C*/*I* (maximum PSD), *C*/*I* (channel power) is a much better predictor of interference impact. This makes sense because *C*/*I* (channel power) uses as a basis the total amount of UWB energy within the FSS receiver's pass-band. By contrast, *C*/*I* (maximum PSD) does not take into account how the UWB energy is distributed within the FSS receiver's pass-band. A UWB signal comprising only discrete spectral lines may have very high PSDs where its spectral lines are, although the total amount of UWB energy seen by the FSS receiver may be very low. On the other hand, a noise-like UWB signal (e.g. an MB-OFDM UWB signal) with the same maximum PSD can introduce significantly more UWB energy into the receiver's pass-band (see Fig. 347). It is important to note that the impact of short-pulse UWB interference on the FSS receiver's performance is more a function of the total amount of UWB energy seen by the FSS receiver than of the distribution of that energy within the receiver's bandwidth. Interestingly, the short-pulse UWB *C*/*I* (channel power) ratios are very similar to those obtained for the MB-OFDM UWB signal type. This observation suggests that, for the purpose of establishing emission limits, short-pulse and MB-OFDM UWB can be treated the same way provided that the appropriate signal measurement techniques are used.

The wide range of *C*/*I* (maximum PSD) values we observed (note their large standard deviations) in Table 302 for the short-pulse UWB signal types was not entirely because varying the PRF, PPM and pulse polarity led to dramatically different interference effects, but because this particular measure of *C*/*I* does not accurately capture the amount of short-pulse UWB energy seen by the FSS receiver. By contrast, the *C*/*I* (maximum PSD) and *C*/*I* (channel power) values obtained for the MB-OFDM UWB signal type are quite close because the MB-OFDM UWB signal has a rather uniform PSD across the FSS receiver's pass-band.

Not surprisingly, the highest average *C*/*I* (channel power) value (19.9 dB for short-pulse UWB and 19.5 dB for MB-OFDM UWB) was obtained for arguably the least robust satellite modem configuration in our study (highest data rate, highest E_b/N_0 requirement): 2 048 kbit/s, plain Viterbi FEC, and 3/4 code rate. Conversely, the lowest average *C*/*I* value (1.9 dB, short-pulse UWB) was obtained for the most robust satellite modem configuration (lowest data rate, lowest E_b/N_0 requirement): 256 kbit/s, Turbo Product Code FEC, and 5/16 code rate.

In summary, the required *C*/*I* protection ratio depends to a large extent on the specific satellite modem configuration. In some cases, a *C*/*I* ratio of up to 20 dB may be needed to calculate an appropriate emission limit for both short-pulse and MB-OFDM devices using UWB technology operating in the C-band satellite downlink band.

TABLE 302

***C*/*I* protection ratios (Lab, short-pulse UWB)**

No.	Data rate (kbit/s)	Code rate	FEC(1)	*C*/*I* (Maximum PSD)			*C*/*I* (channel power)		
				Average	Standard deviation	Range	Average	Standard deviation	Range
1	256	1/2	Vit	9.6	1.52	5.1-14.3	12.3	1.52	9.1-14.7
2			Vit+RS	7.2	0.80	5.3-9.1	7.8	1.00	5.5-10.2
3		3/4	Vit	11.4	1.99	7.6-14.7	13.9	1.22	11.8-15.9
4			Vit+RS	6.8	1.91	2.6-11.4	8.9	0.38	8.1-9.5
5			TPC	8.3	1.67	5.2-11.3	10.3	0.78	8.3-11.5
6		21/44	TPC (BPSK)	2.5	1.90	–1.9-5.4	3.8	0.74	2.7-5.7
7		5/16	TPC (BPSK)	0.2	2.21	–4.8-3.4	1.9	1.09	–0.2-4.5

TABLE 302 (*end*)

No.	Data rate (kbit/s)	Code rate	FEC(1)	*C/I* (Maximum PSD)			*C/I* (channel power)		
				Average	Standard deviation	Range	Average	Standard deviation	Range
8	1 024	1/2	Vit	9.8	2.22	5.9-13.6	12.6	1.57	9.4-16.6
9			Vit+RS	6.3	2.77	–1.5-11.4	9.1	2.01	3.8-12.6
10		3/4	Vit	12.5	2.02	8.0-17.3	16.1	1.62	13.2-20.0
11			Vit+RS	7.3	1.64	3.9-11.4	10.2	0.90	8.6-13.0
12			TPC	9.0	1.76	5.2-11.9	12.5	1.06	10.7-16.6
13		21/44	TPC (BPSK)	2.9	2.48	–3.4-9.0	4.2	1.22	–0.1-5.9
14	2 048	1/2	Vit	12.7	2.30	8.3-15.8	15.6	1.71	12.0-18.8
15			Vit+RS	6.7	3.75	–1.2-12.5	8.7	2.94	2.1-12.9
16		3/4	Vit	16.0	2.23	11.8-19.8	19.9	1.88	17.3-23.4
17			Vit+RS	8.7	2.09	4.9-13.0	10.7	0.89	9.3-12.7

(1) Modulation type is QPSK unless otherwise indicated. Vit = Viterbi FEC, Vit+RS = Viterbi FEC with outer (220,200) Reed-Solomon code, TPC = Turbo Product Code.

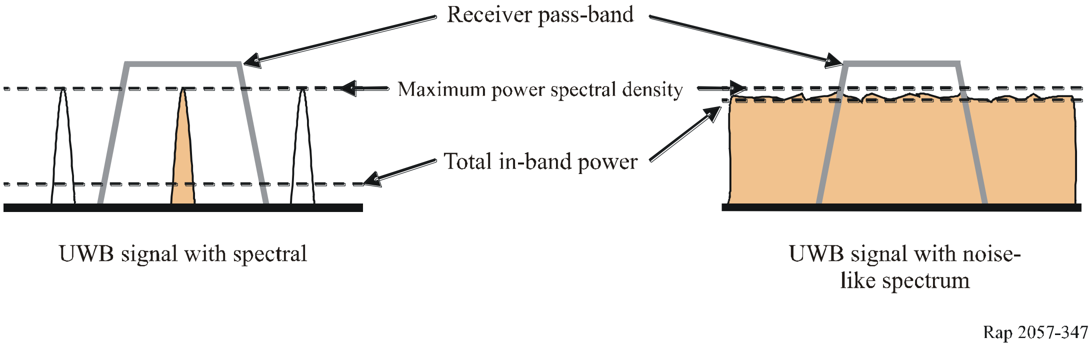
TABLE 303

C/I protection ratios (Lab, MB-OFDM UWB)

No.	Data rate (kbit/s)	Code rate	FEC	*C/I* (Max. PSD)	*C/I* (Channel power)
1	256	1/2	Vit	11.5	11.3
2			Vit+RS	8.2	8.0
3		3/4	Vit	15.6	14.2
4			Vit+RS	10.1	10.0
5	1 024	1/2	Vit	13.6	15.7
6			Vit+RS	8.1	9.5
7		3/4	Vit	14.2	17.0
8			Vit+RS	8.9	10.7
9	2 048	1/2	Vit	12.0	13.6
10			Vit+RS	11.0	12.4
11		3/4	Vit	14.8	19.5
12			Vit+RS	11.3	11.3

FIGURE 347

Max. power spectral density vs. total in-band power



5.1.4.3.3.2 Relationship between *C*/*I* and FSS receiver configuration

Table 302 clearly shows that the choice of FEC type and code rate has a large impact on the *C*/*I* ratio needed to protect the FSS receiver from UWB interference. This should not be surprising, since the FEC type and code rate also determine the E_b/N_0 the receiver needs in order to achieve a certain BER. Our results also show that using a Reed-Solomon outer code, switching to turbo product coding, stepping down from QPSK to BPSK modulation, and increasing the amount of coding gain all contribute toward making the FSS downlink more resilient to UWB interference.

5.1.4.3.3.3 Use of Reed-Solomon coding to mitigate impact of low-PRF UWB

For rows 9 and 15 of Table 302, we observed that the *C*/*I* (Channel power) values are markedly lower for the 6 PRF = 0.1 MHz UWB signal types than for the other 30 signal types. Table 303 compares the average *C*/*I* (Channel power) values for only the PRF = 0.1 MHz short-pulse UWB signal types with the average *C*/*I* obtained from all 36 signal types.

We believe that the Reed-Solomon outer code employed in these two satellite modem configurations was particularly effective in dealing with short-pulse UWB interference when the PRF was lowered to 0.1 MHz. When the PRF is small compared to the bandwidth of the victim FSS receiver, short-pulse UWB interference may appear as intermittent bursts of energy, sporadically corrupting the bits transported by the downlink signal. Reed-Solomon outer coding is able to deal with this type of interference especially well.

TABLE 304

***C*/*I* (Channel power) for PRF = 0.1 MHz short-pulse UWB signal type**

	***C*/*I* (PRF = 0.1 MHz)**	***C*/*I* (overall)**
Row 9 1 024 kbit/s, Code rate = 1/2, Vit+RS	6.7	9.1
Row 15 2 048 kbit/s, Code rate = 1/2, Vit+RS	3.4	8.7

5.1.4.4 Field test with temporary satellite dish

5.1.4.4.1 Preparation and setup

5.1.4.4.1.1 Overview

We repeated a subset of the lab measurements in the field using a C-band FSS link we set up on the rooftop of Teletech Park building in Science Park 2 to ascertain that our lab results are equally applicable under field conditions. Unlike the lab test, this field test involved no signal loop-back. The downlink FSS signal received from the MEASAT-2 satellite originated from another FSS station at Temasek Polytechnic, located in another part of Singapore. Temasek Polytechnic very generously provided about 2 MHz of satellite capacity for this field test.

Note that the MB-OFDM UWB signal type was not considered in this portion of the study because the Staccato SC1000D transmitter was not available at the time of the test.

5.1.4.4.1.2 C-band FSS receiver configuration

We used the same ODU and satellite modem for both this field test and the lab test. Additionally, we used a Robinson Satellite Communications Model 3346 LNA with a bias-tee and a 3.7 m Suman SM-T3.7RC antenna in the field. As in the lab test, we used a splitter to monitor the signal entering the ODU on a spectrum analyser. Table 305 highlights the key specifications of the FSS receiver system. Figure 348 shows a complete diagram of the setup. See Figure 349 for an annotated photograph of the setup.

TABLE 305

FSS receiver specifications (field)

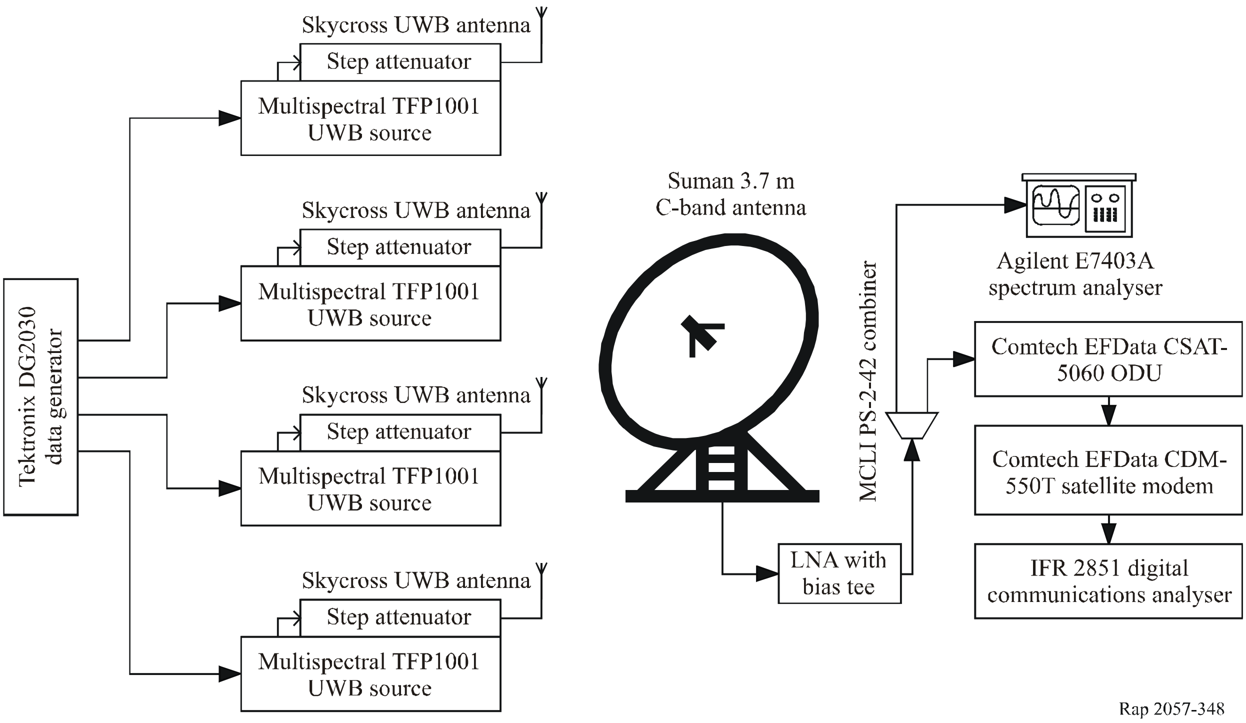
Receiver location	Teletech park, Science park 2 (Singapore)	
	Latitude	1° 17′ 12.0″ N
	Longitude	103° 46′ 56.7″ E
	Height above sea level	32 m (approximately)
	Antenna elevation	39.0°
	Antenna azimuth	91.3°
Satellite description	MEASAT-2	
	Orbital location	148° E
	Uplink frequency	6.39942 GHz
	Downlink frequency	4.17442 GHz

TABLE 305 (*end*)

Antenna specifications	Suman C-band SM-T3.7RC dual-reflector antenna	
	Aperture size	3.7 m
	Receive bandwidth	3.625-4.2 GHz
	Mid-band gain	42.3 dBi
	3 dB receive beamwidth	1.29°
	Antenna noise temp.	21°K (at 30° elevation)
	Side-lobes	29-25 log θ, 1°< θ < 20°
LNA specifications	Robinson satellite communications model 3346 LNA	
	Gain	> 50 dB
	Noise temperature	40°K
ODU specifications	Comtech EFData CSAT-5060	
	Conversion gain	35 dB
	Maximum power	10 W

FIGURE 348

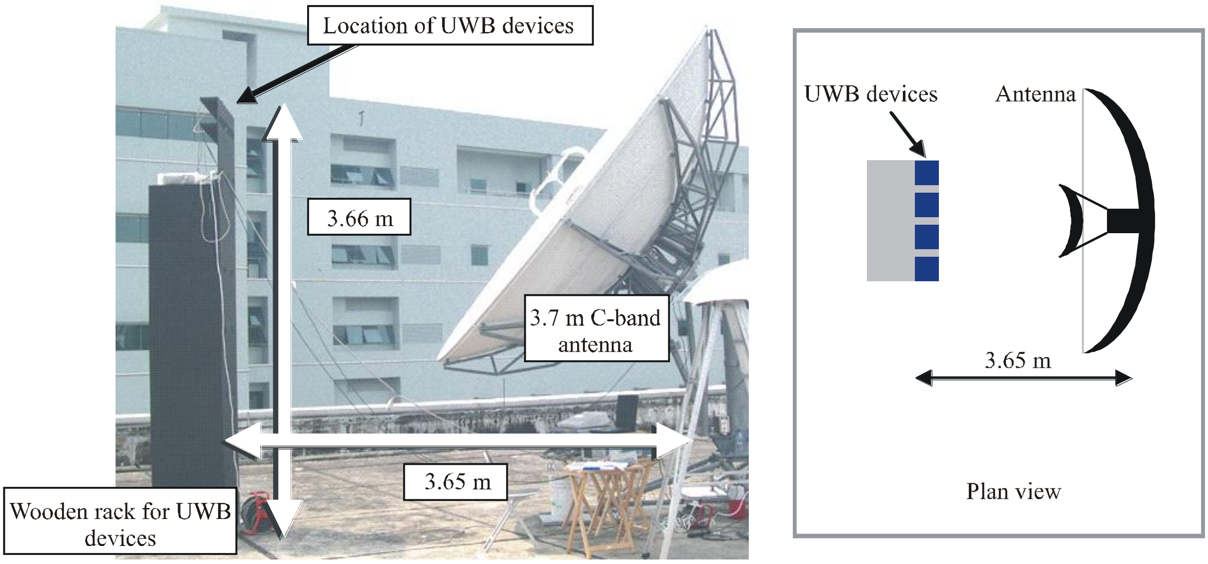
Field measurement setup



For simplicity, the transmitter station at Temasek Polytechnic, and the GPIB and RS232 connections to the central controller laptop are not shown.

FIGURE 349

Field measurement setup – Photo



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5.1.4.4.1.3 UWB transmitter configuration

To radiate UWB signals, we attached a Skycross UWB antenna to the step attenuator output of each UWB transmitter block. The Skycross antenna provides a gain of about 3.5 dBi at 4.2 GHz, is linearly polarized, and has an omni-directional antenna pattern in the horizontal plane. Up to four UWB transmitters were placed side by side on top of a 3.66 m wooden rack erected at a horizontal distance of 3.65 m from the FSS antenna's feed horn (see Fig. 349). The exact amount of coupling between each of the four Skycross UWB antennas and the FSS antenna was measured by injecting a 4.17442 GHz CW signal of a known power level into the input of the step attenuator and measuring the strength of this signal at the output of the FSS receiver's LNA. The difference in these two readings gave us a correction factor, which we added to the output power level of the Multispectral TFP1001 to calculate the power level of the UWB signal entering the ODU.

Note that only the Multispectral short-pulse UWB transmitter was used in this field test.

5.1.4.4.2 Measurement procedure

Given the difficulty of carrying out a protracted field test and that it was not possible to fully automate the data collection process in the field, we decided to focus only on a subset of the lab test cases. We measured *C*/*I* (maximum PSD) with only 24 short-pulse UWB signal types corresponding to PRFs of between 1 MHz and 100 MHz and three common satellite modem settings: (1) 256 kbit/s at 3/4 code rate, (2) 1 024 kbit/s at 1/2 code rate, and (3) 2 048 kbit/s at 1/2 code rate. In all three cases, QPSK modulation and only Viterbi FEC were used. In addition, we repeated our experiment for 12 UWB signal types (rows 19-30 of Table 35 in Appendix A to Attachment A7.5, corresponding to PRF = 5 MHz and 10 MHz only) after turning on Reed-Solomon (220,200) FEC for the 256 kbit/s and 2 048 kbit/s test cases, and switching the code rate from 1/2 to 3/4 for the 1 024 kbit/s test case. In all these test cases, the FSS downlink signal strength was lowered to just exceed the E_b/N_0 threshold values given in Table 298.

Additionally, we introduced a new scenario in the field test involving up to 4 short-pulse devices using UWB technology. We repeated the 2 048 kbit/s (code rate 1/2, Viterbi FEC) test case with 2, 3 and 4 active UWB transmitters operating simultaneously. Each time we turned on an additional transmitter, we took down the additional attenuation we needed to apply to all the active UWB transmitters to maintain a zero BER over one minute.

All active devices using UWB technology were set up to transmit the same UWB signal type and given the same amount of signal attenuation, although the actual "data streams" carried by the UWB signal were randomized for each transmitter. Because of time constraints, we used only 8 short-pulse UWB signal types here corresponding to PRF = 5 MHz and 10 MHz, and PPM = 1 and 8 only.

5.1.4.4.3 Results and analysis

5.1.4.4.3.1 Results for single short-pulse device using UWB technology

Table 306 shows that the average *C*/*I* (maximum PSD) ratios we obtained in the field agree reasonably well with our lab results for the test cases where only Viterbi FEC was used. However, where Reed-Solomon outer coding was also used, the *C*/*I* values measured in the field were significantly lower than those obtained in the lab. This effect, which merits further investigation, strongly suggests that Reed-Solomon is very effective at coping with short-pulse UWB interference under actual deployment conditions.

TABLE 306

***C*/*I* protection ratios (field)**

No.	Data rate	Code rate	FEC	Field			Lab(1)		
				C/*I* (Maximum PSD)			*C*/*I* (maximum PSD)		
				Average	Standard deviation	Range	Average	Standard deviation	Range
1	256 kbit/s	3/4	Vit	13.0	2.96	6.4-17.2	12.2	1.76	8.5-14.7
2			Vit+RS	1.9	2.21	–1.3-5.5	7.0	1.19	5.3-8.9
3	1 024 kbit/s	3/4	Vit	10.3	2.64	5.9-16.2	14.0	2.14	10.3-17.3
4		1/2		9.0	3.10	0.5-13.3	10.3	1.98	6.7-13.6
5	2 048 kbit/s	1/2	Vit	11.6	2.70	7.1-19.0	13.7	1.79	9.9-15.8
6			Vit+RS	4.6	1.89	1.9-8.1	9.0	1.93	5.2-12.5

(1) The average, standard deviation and range of the lab results have been recalculated, taking into account only the 12 or 24 UWB signal types (instead of 36) that were used in both the lab and field tests.

5.1.4.4.3.2 Impact of multiple short-pulse devices using UWB technology

Table 307 shows how much attenuation we needed to apply to all the active UWB transmitters each time we turned on an additional UWB transmitter in order to maintain the one-minute BER at 0. Recall that only 8 UWB signal types and one satellite modem setting (2 048 kbit/s, 1/2 code rate, Viterbi FEC) was used in this test scenario.

Assuming that UWB signal power grows linearly with the number of devices using UWB technology, we should expect to see a 3 dB increase in the amount of applied attenuation when we increase the number of devices from 1 to 2, and from 2 to 4. Indeed, this is exactly what Table 307 shows.

Since each UWB transmitter contributed a slightly different amount of interference, a consequence of not all being in the same location, this experiment could not serve as a precise means of quantifying the interference aggregation effect. Nevertheless, it is fairly representative of how UWB signals might aggregate in real life, where the nature of the propagation channel between the device using UWB technology and the victim antenna is likely to vary dramatically from device to device.

TABLE 307

UWB signal aggregation

No. of active UWB devices	Increase in required attenuation to maintain zero BER (relative to single device scenario)		
	Average	Standard deviation	Range
1	–	–	–
2	2.9	1.73	0 – 5
3	4.9	1.64	2 – 6
4	6.3	1.49	3 – 7

5.1.4.5 Field test with satellite operator

5.1.4.5.1 Overview

In the final part of this study, made possible by the kind support of a local satellite operator, we were able to examine the impact of UWB interference on an actual FSS system in a realistic usage scenario.

We placed a UWB transmitter approximately 6 m away from the edge of an 11 m C-band satellite dish directed at PamAmSat's PAS-2 satellite (see Figs. 350 and 351), simulating a passer-by using a handheld device using UWB technology in the vicinity of a satellite installation. The elevation angle of the dish was about 16°, which is lower than that of most C-band dishes deployed in Singapore (a dish directed at Intelsat 802 or Intelsat 804, both of which are also used in Singapore, will require a lower elevation angle of about 11° and 9° respectively). The downlink was a QPSK-modulated multiplexed digital video signal with a carrier frequency of 3.7435 GHz, a symbol rate (i.e. 3 dB bandwidth) of 21.799 MHz, a code rate of 3/4, and Reed-Solomon outer coding. The satellite operator agreed to participate in this study because the satellite link was used primarily to uplink video content; the downlink was for their own monitoring purposes only. Therefore, even if harmful interference was experienced on the downlink during the experiment, their customers would not be affected.

We carried out the experiment with the Multispectral short-pulse UWB transmitter using 7 combinations of PRF, PPM and pulse polarity as well as with the Staccato MB-OFDM UWB transmitter. A Skycross UWB antenna was placed at the output of both transmitters to radiate the UWB signal. In addition, we placed a Mini-Circuits VHP-19 high-pass filter between the output of the Multispectral transmitter and the Skycross antenna. The step attenuator connected to the output of the Multispectral transmitter was adjusted for each signal type to obtain an e.i.r.p. density of about –41.3 dBm/MHz at the downlink carrier frequency. No step attenuator was required for the Staccato transmitter, which already produces an output of around –41.3 dBm/MHz between 3.2 GHz and 4.8 GHz. In fact, taking into account the small gain of the Skycross antenna, the Staccato transmitter would actually exceed the United States limit by about 2 dB.

Note that the choice of downlink carrier frequency (3.7435 GHz) is somewhat less than optimal because it does not fall in the middle of any one of the three bands of the MB-OFDM signal, where the e.i.r.p. density is highest. Figure 352 shows a spectral plot (centre frequency = 3.7435 GHz, span = 25 MHz, RBW = 1 MHz, RMS detector) of the output of the MB-OFDM transmitter within the bandwidth of the satellite operator's FSS receiver. We can see that the e.i.r.p. density of the MB-OFDM signal within this range of frequencies is about 5-7 dB lower than the –41.3 dBm/MHz United States limit.

Once the UWB transmitter was turned on, we looked out for any changes in the spectrum, video quality, E_b/N_0 and pre-Viterbi decoder BER of the downlink. In the absence of UWB interference, E_b/N_0 is 10.1 dB and the pre-Viterbi BER is 0.

FIGURE 350

Setup for field test with satellite operator

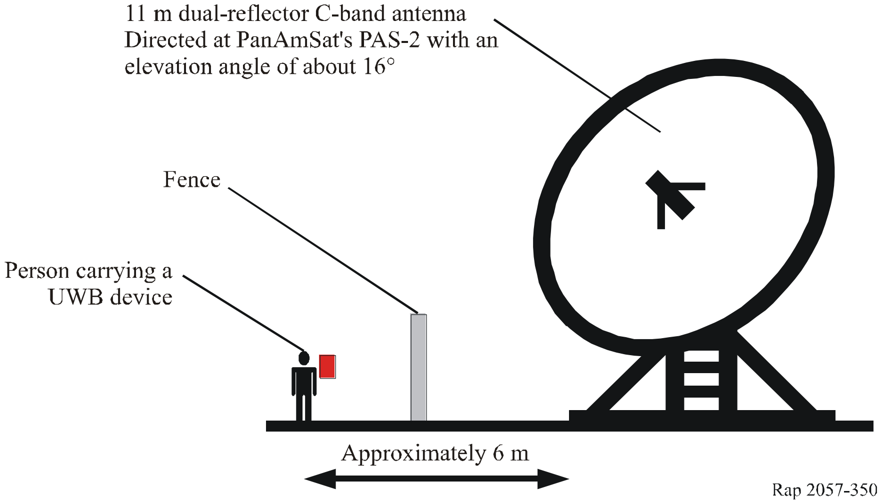

FIGURE 351

Field test with satellite operator – Photo

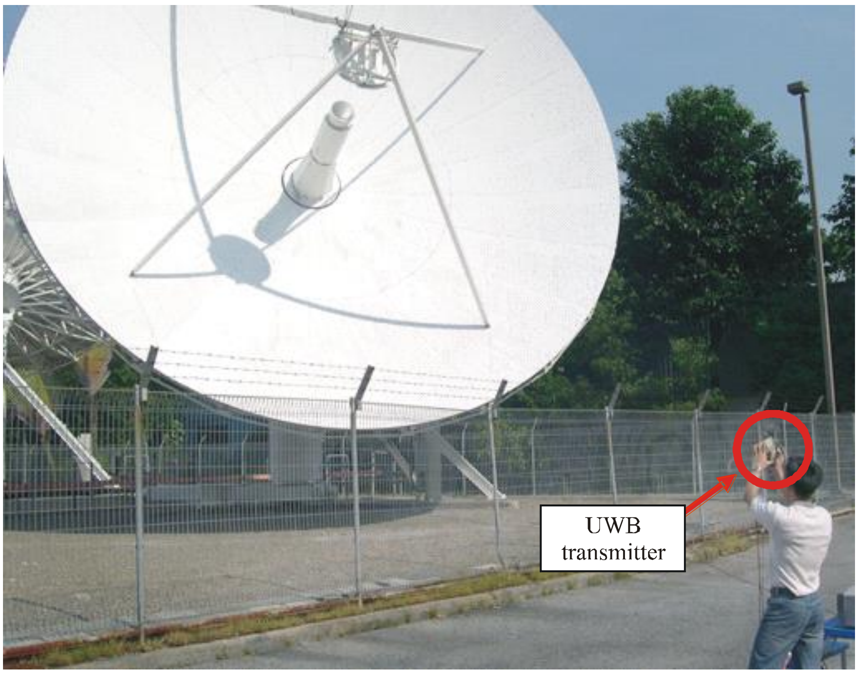

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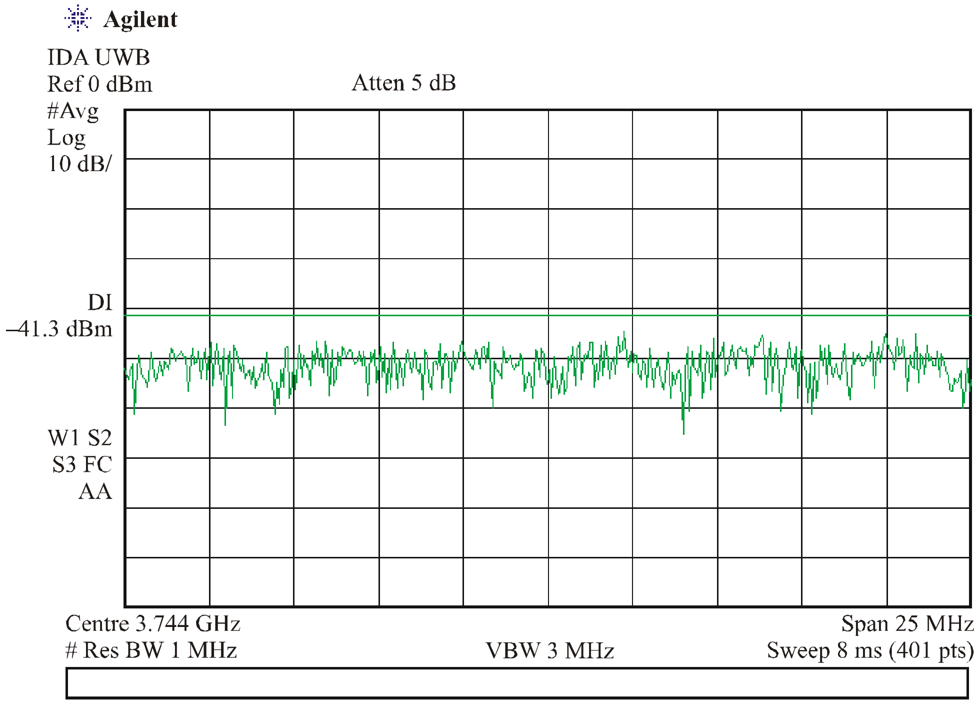
FIGURE 352

MB-OFDM signal spectral plot within FSS receiver bandwidth



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5.1.4.5.2 Results

Under these test conditions, we detected no changes in the spectrum, video quality, E_b/N_0 or pre-Viterbi BER of the FSS downlink signal when the UWB transmitter was turned on. We tried moving the UWB transmitter around the area outside the fence and changing the transmitter's orientation with respect to the satellite dish, but still we could not observe any degradation in the downlink. Only when we placed the UWB transmitter right against the bottom edge of the satellite dish and pointed it straight at the feed horn did we notice any performance degradation – a decrease in E_b/N_0 of about 2 dB.

The results of this experiment suggest that, despite theoretical calculations showing that a large separation distance between an FSS antenna and a UWB transmitter is required to protect an FSS downlink from harmful UWB interference, the near-field behaviour of the FSS antenna is such that it is unlikely to be affected by a device using UWB technology operating nearby. Only in the unlikely event that the UWB transmitters are placed close to the pointing angle of the antenna (as they were in the field test described in § 5.1.4.4) will the impact of UWB be significant.

5.1.4.6 Conclusions

We believe that a C/I ratio of up to 20 dB may be needed for calculating an appropriate emission limit for devices using UWB technology in the C-band FSS downlink frequency band (3.4-4.2 GHz). This ratio applies to both short-pulse and MB-OFDM devices using UWB technology. If the impact of multiple devices using UWB technology is to be incorporated into the analysis, note that our field test results for short-pulse UWB signals support the popular assumption that UWB signal power adds linearly. However, it should also be noted that our field test with a local satellite operator failed to produce any evidence that, under reasonable usage conditions, a United States-compliant device using UWB technology (short-pulse or MB-OFDM) transmitting in the vicinity of a satellite dish would result in any measurable amount of interference.

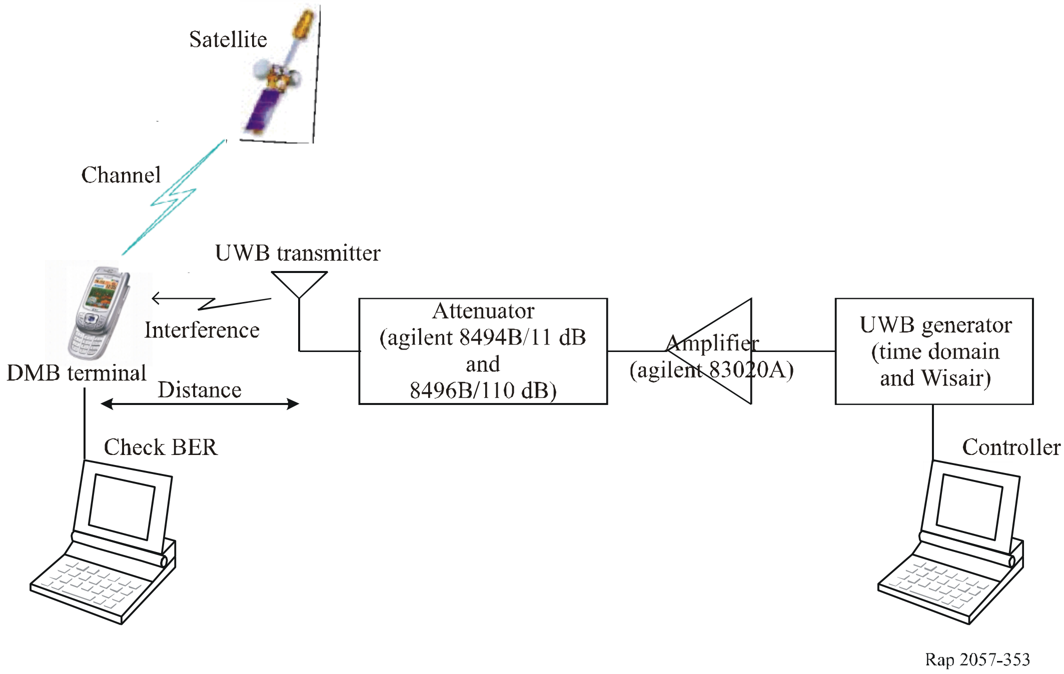
We acknowledge that our study, while fairly extensive, is not complete. First of all, we did not investigate the interference impact of very low PRF UWB signals, which could require a different *C*/*I* protection ratio. Additionally, it would be worthwhile to repeat the laboratory portion of this study using other FSS receivers, particularly those that support much larger receiver bandwidths and data rates. We hope to address some of these outstanding areas in a subsequent submission to the ITU.

6 Experimental measurement of interference from UWB to satellite digital multimedia broadcasting

This section presents the measurement results of interference from certain devices using UWB technology (PulsON200TM impulse UWB transmitter from Time Domain and MB-OFDM EVT OFDM transmitter from Wisair) to a typical satellite digital multimedia broadcasting (SDMB) receiver. The purpose of the experiment was to complement the theoretical study result described in § 2.2. The conceptual diagram of test measurement set-up is shown in Fig. 353.

FIGURE 353

Test set-up



The characteristics of the SDMB receiver are described in § 2.2 as Table 308.

TABLE 38

Characteristics of SDMB receiver

Parameter	Value
Centre frequency (MHz)	2 642.5
Bandwidth (MHz)	25
Antenna noise temperature (K)	150.0
Noise figure (dB)	3.0
Noise temperature (K)	438.6
Noise spectral density (N_0) (dBm/Hz)	–172.2
Maximum allowable interference (dBm/MHz)	–132.2
Required BER (ratio)	2×10^{-4}

The received power level of SDMB was –95 dBm. The characteristics of UWB test source are shown in Table 39.

TABLE 39

Characteristics of UWB test source

Specifications	Pulsed UWB	MB-OFDM UWB
Pulse repetition frequency (PRF)	9.6 MHz	–
Center frequency (radiated)	4.7 GHz	Variable (3 channels)
10 dB – bandwidth	3.2 GHz	528 MHz
Average PSD (e.i.r.p.)	–41.25 dBm/MHz	–41.25 dBm/MHz
Average PSD (e.i.r.p) at 2 642.5 MHz	–61.3 dBm/MHz	–72.3 dBm/MHz

The performance degradation according to the distance between SDMB receiver and devices using UWB technology is shown in Tables 40 and 41.

TABLE 40

BER degradation from PulsON200TM

Distance	1 m	1.5 m	2 m	2.1 m	2.3 m	2.5 m	3 m
Average BER	8×10^{-3}	1×10^{-3}	5×10^{-5}	1×10^{-6}	1×10^{-6}	No error	No error

TABLE 41

BER degradation from MB-OFDM EVT

Distance	0.3 m	0.4 m	0.5 m	0.6 m	0.8 m	1 m
Average BER	2×10^{-2}	3×10^{-3}	3×10^{-4}	2×10^{-4}	2×10^{-6}	1×10^{-6}

It is derived from the results that even the United States outdoor limit of –61.3 dBm/MHz at the SDMB frequency band can degrade the performance of SDMB receiver when the device using UWB technology is located within 2 m from the SDMB receiver. Taking PSD limit of –72.3 dBm/MHz at the SDMB frequency band, the minimum allowable distance can be reduced to 0.8 m.

Appendix 1
to Annex 7

Lab measurements of the impact of short-pulse UWB emissions on IEEE 802.11a systems UWB spectral plots (Cellonics, PRF = 25 MHz)

Figures 354 to 357 contain the spectral plots of a PRF = 25 MHz Cellonics UWB signal at PPM = 1, 2, 4 and 8 respectively. These plots were captured directly from an Agilent E4407B spectrum analyser. An RMS detector and a resolution bandwidth (RBW) of 1 MHz were used. Each plot is centred at 5.18 GHz and spans 100 MHz. Note that a Miteq AFS5-00101000-20-10P-5 LNA was placed at the output of the Cellonics transmitter to amplify the signal.

The purpose of these plots is to reveal the spectral structure of these signals. The power levels of the signals shown here have not been adjusted to comply with any emission limit.

FIGURE 354

PRF = 25 MHz, PPM = 1

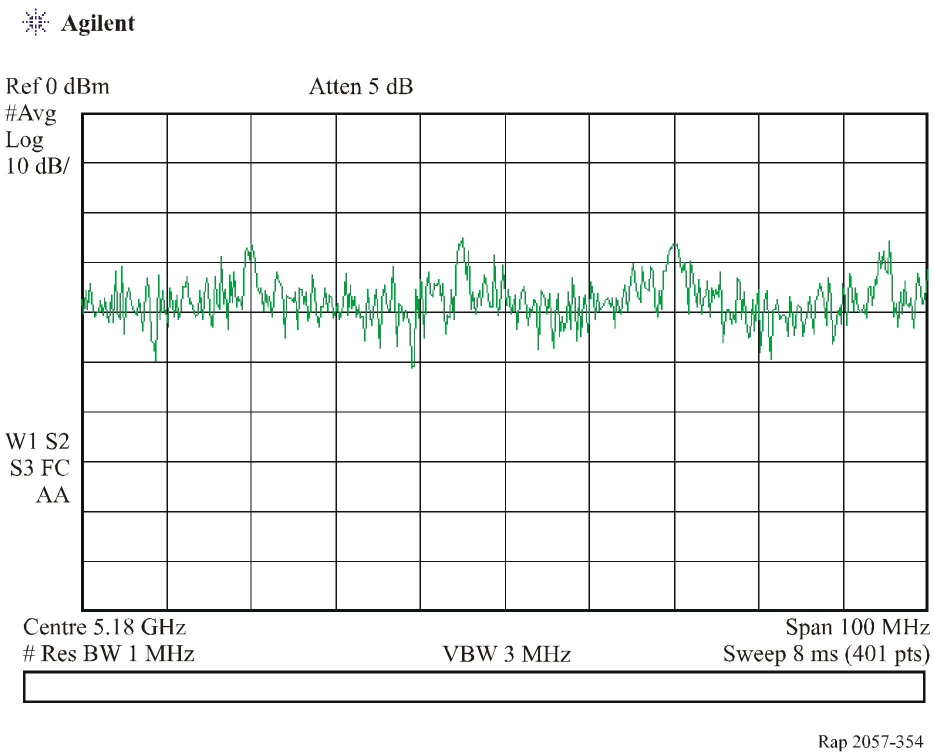


FIGURE 355

PRF = 25 MHz, PPM = 2

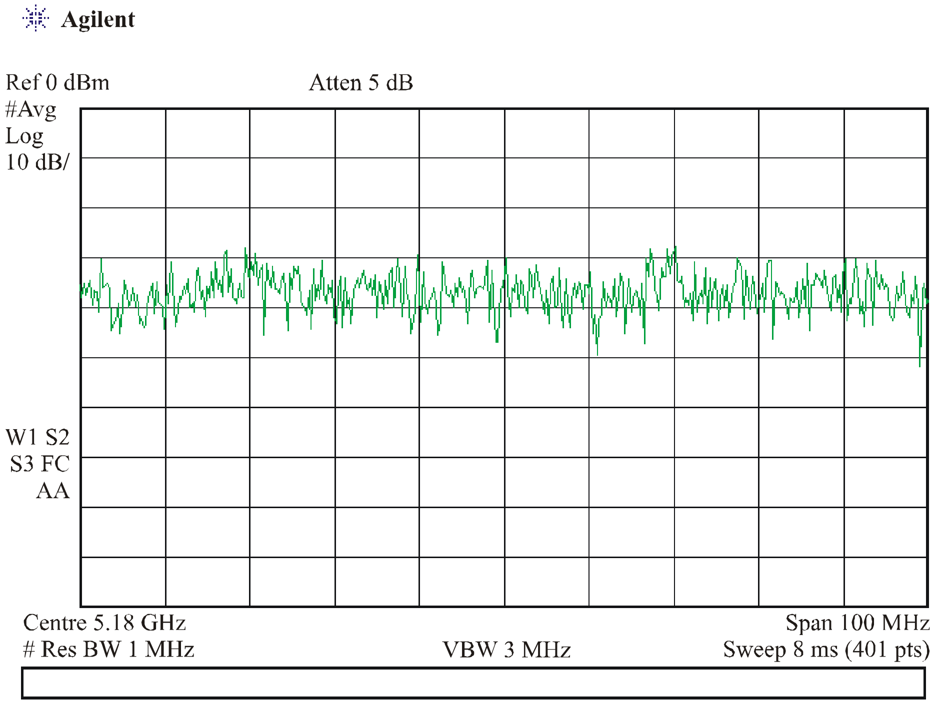


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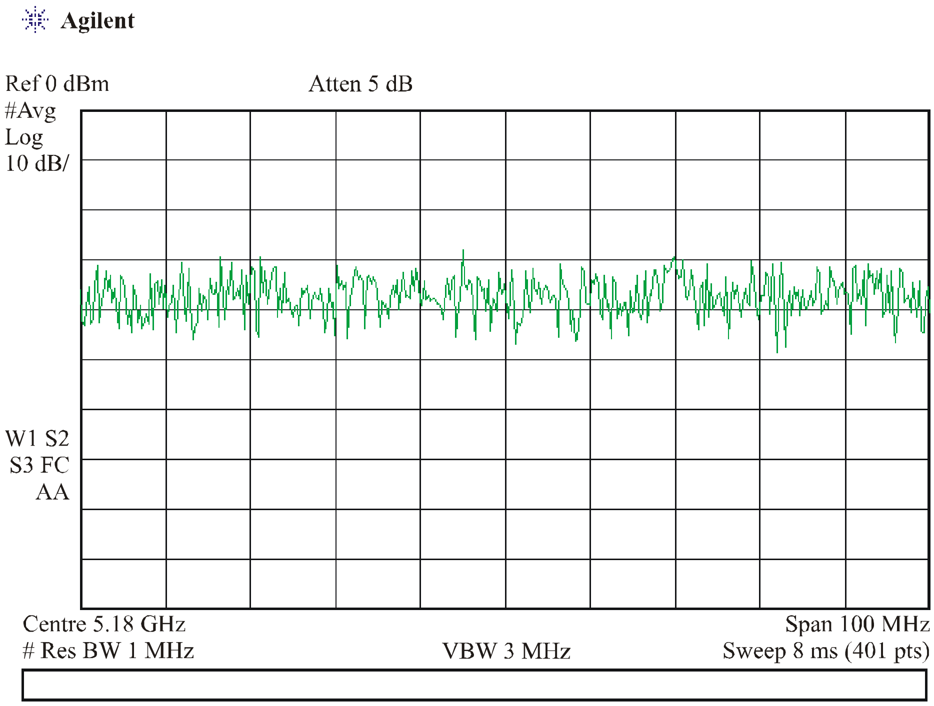
FIGURE 356

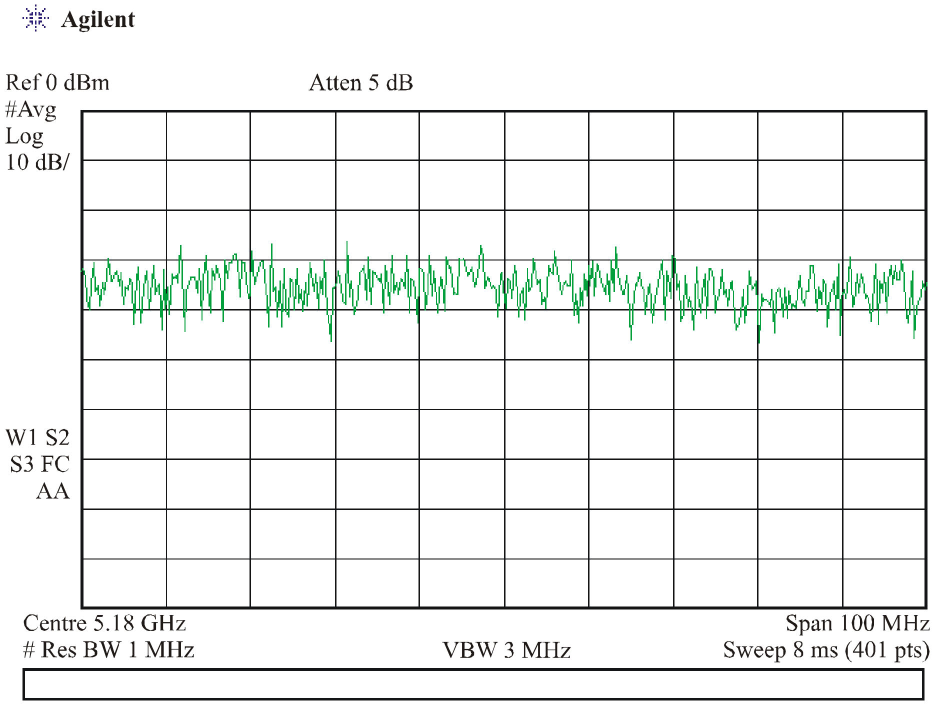
PRF = 25 MHz, PPM = 4



Rap 2057-356

FIGURE 357

PRF = 25 MHz, PPM = 8



Rap 2057-357

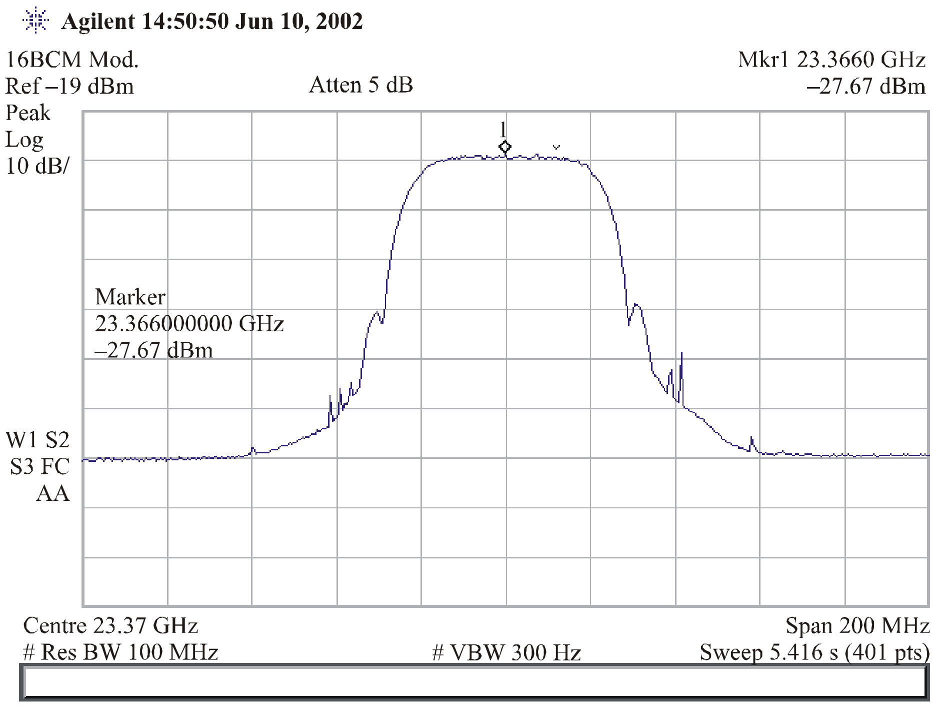
Appendix 2
to Annex 7
(Ref: § 7.4)

Fixed service receiver characteristics used for test in § 7.4

1 Spectral characteristics

FIGURE 358

FS system spectral emission



Rap 2057-358

Test conditions: Transmitter Pout = + 13.5 dBm
SA input power (after cable loss and 6 dB fixed att) = -0.5 dB

2 Other relevant FS system characteristics

– Payload capacity: STM-1 (155.52 Mbit/s SDH hierarchy)
– Physical modulation format: 16-QAM
– Coded modulation: 16 BCM (block coded modulation, 16/15 block redundancy)
– S_R (symbol rate) = 1/4 * 155.52 *16/15 = 41.472 Mbit/s (continuous transmission)
– Block code duration: 16 * $1/S_R \cong$ 386 nS
– Noise figure measured at Section E of test set-up (Rx antenna port) = 4.5 dB
– Noise r.m.s. power density at Section E: $N_{RMS} = -144 + NF = -109.5$ (dBm/MHz)
– Received signal level (RSL) for BER=10^{-6}: $\cong -74.2$ dBm

– Received signal level (RSL) for BER = 10^{-8}: ≅ –72.7 dBm
– *S*/*N* (normalized to the symbol rate bandwidth) derived according the formula:

$$S/N = RSL -(-114 + NF + 10 \log S_R = RSL + 93.3$$

Appendix 3
to Annex 7
(Ref: § 7.5)

UWB signals – Additional information

1 Implementation overview

Two types of UWB transmitters were used in this study: the Multispectral TFP1001 UWB impulse source and the pulse generator developed by the Centre for Wireless Communications (CWC) at the University of Oulu, Finland. Both transmitters can be triggered by a Tektronix DG2030 data pattern generator to produce UWB signals with the desired pulse repetition frequency (PRF), number of PPM steps, and polarity (either mono-phase or bi-phase). PPM refers to the number of possible positions in time a pulse can occupy within a time interval *T*, the reciprocal of the PRF. There is always one and only pulse within any interval *T*, but the polarity and/or position of the pulse can change from interval to interval. Bi-phase, high-PPM UWB signals are almost noise-like, while mono-phase, PPM = 1 (no time dithering) UWB signals consist of distinct, evenly-spaced spectral lines in the frequency domain.

The Multispectral transmitter was used primarily for the lower PRF signals (≤ 50 MHz), while the CWC transmitter, which could be triggered at higher clock rates, was used for the higher PRF signals. In general, the higher the PRF, the greater the power spectral density of the signal generated by the UWB transmitter. The power level of the UWB signal can be adjusted in 1 dB steps using the step attenuator (0-81 dB) connected to the output of the transmitter. This is useful for lowering the output level to meet a certain emission mask requirement.

Because the Multispectral transmitter generates a lot of spectral energy, particularly at low (< 1 GHz) frequencies, we placed a Mini-circuits VHP-16 high-pass filter at the output of the transmitter. In the radiated tests, an actual UMTS antenna was used to maximize the amount of UWB energy radiated in the frequency band of operation. This was so that we could raise the e.i.r.p. spectral density to as high as –41 dBm/MHz for some of the test cases.

The CWC transmitter already produces a filtered output that, when radiated through the modified bowtie antenna provided with the transmitter, conforms to the United States limits for indoor device using UWB technology. Thus, neither the high-pass filter nor the mobile cellular antennas was necessary for the experiments.

2 Signal parameters used in experiments

We used 12 different combinations of PRF, PPM and signal polarity with the Multispectral transmitter, and 5 combinations with the CWC transmitter. These are listed in Tables 308 and 309 respectively. Note that not all the combinations were used in every test case.

TABLE 308

UWB transmitter settings (Multispectral)

Type	**PRF (MHz)**	**PPM**	**Polarity**
1	5	1	Mono-phase
2	5	8	Bi-phase
3	50	2	Bi-phase
4	1	1	Mono-phase
5	1	1	Bi-phase
6	1	8	Mono-phase
7	5	1	Bi-phase
8	5	8	Mono-phase
9	10	1	Bi-phase
10	10	8	Mono-phase
11	50	1	Bi-phase
12	0.1	1	Mono-phase

TABLE 309

UWB transmitter settings (CWC)

Type	**PRF (MHz)**	**PPM**	**Polarity**
1	25	1	Bi-phase
2	50	1	Bi-phase
3	100	1	Bi-phase
4	200	1	Bi-phase
5	100	2	Bi-phase

3 Spectral plots

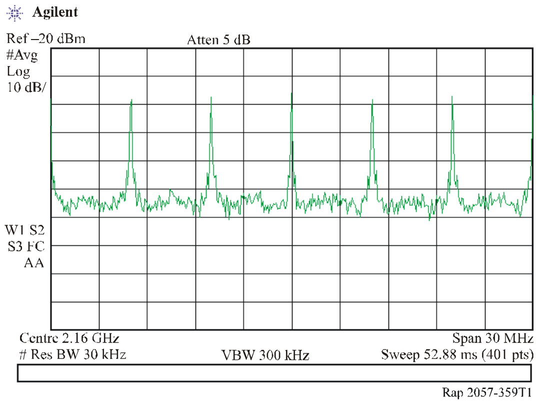
Figures 359 and 360 show the spectra of all 12 Multispectral UWB signal types captured directly from an Agilent E4407B spectrum analyser. Figure 361 shows the spectra of the 5 CWC UWB signal types. The plots are centred at 2 160 MHz and span 30 MHz. The spectrum analyser was configured to use an RMS detector and a resolution bandwidth (RBW) of 30 kHz. Note that the Multispectral UWB signals shown did not have their power level adjusted to meet any specific limits.

The sharp-eyed reader will notice that distinct spectral lines occurring at multiples of (PRF × PPM) are present even in the bi-phase UWB signals. This is because the positive and negative pulses generated by both the Multispectral and the CWC transmitters are not perfectly matched in amplitude. The energy difference between the positive and the negative pulses are concentrated in these spectral lines.

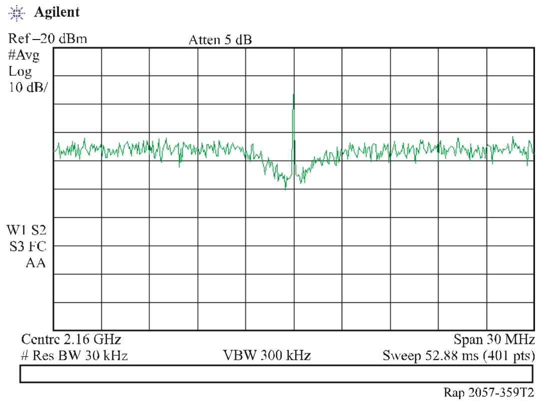
FIGURE 359

Multispectral UWB spectral plots (Types 1-6)
(centre frequency = 2 160 MHz, span = 30 MHz)

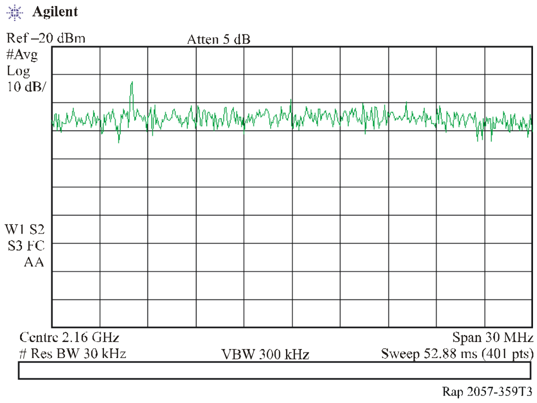
TYPE 1
PRF = 5 MHz, PPM = 1, Mono-phase



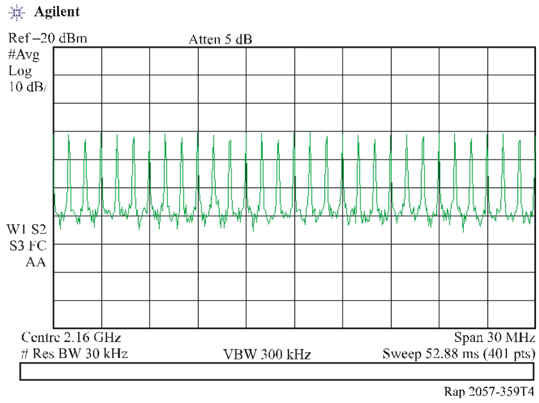
TYPE 2
PRF = 5 MHz, PPM = 8, Bi-phase



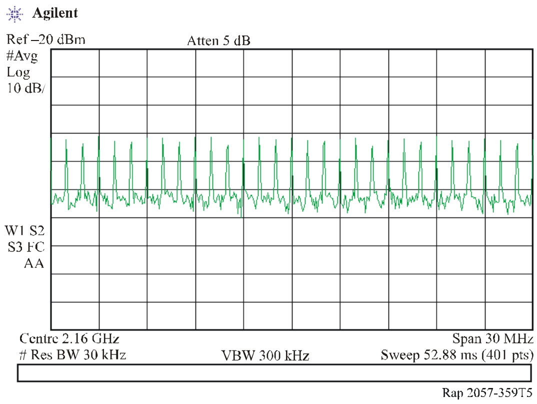
TYPE 3
PRF = 50 MHz, PPM = 2, Bi-phase



TYPE 4
PRF = 1 MHz, PPM = 1, Mono-phase



TYPE 5
PRF = 1 MHz, PPM = 1, Bi-phase



TYPE 6
PRF = 1 MHz, PPM = 8, Mono-phase

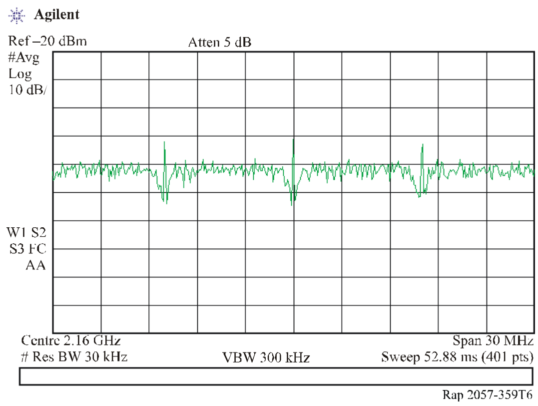


FIGURE 360

Multispectral UWB spectral plots (Types 7-12)
(centre frequency = 2 160 MHz, span = 30 MHz)

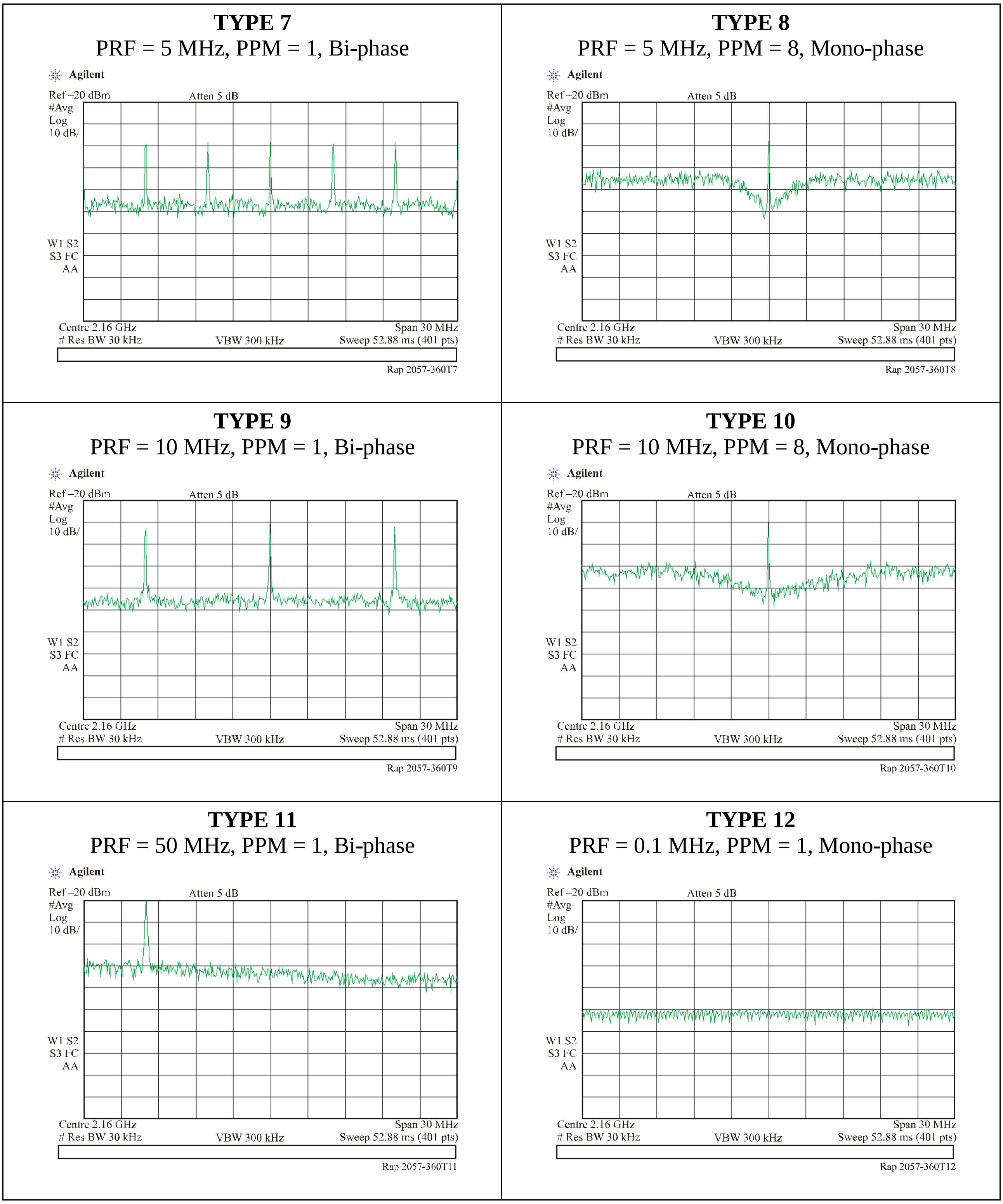
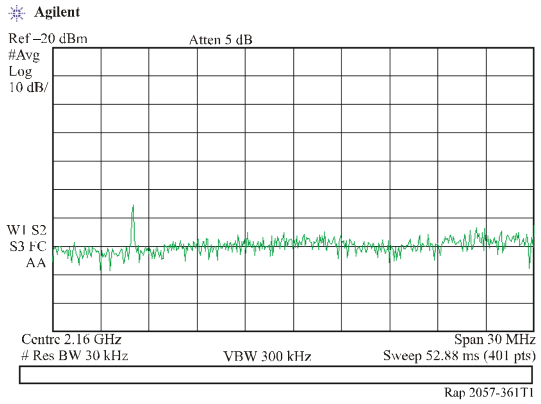


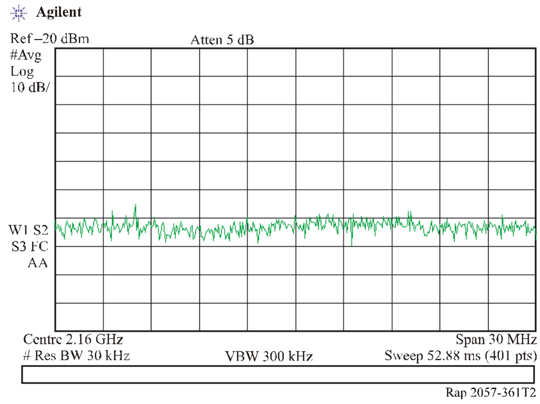
FIGURE 361

CWC UWB spectral plots (Types 1-5)
(centre frequency = 2 160 MHz, span = 30 MHz)

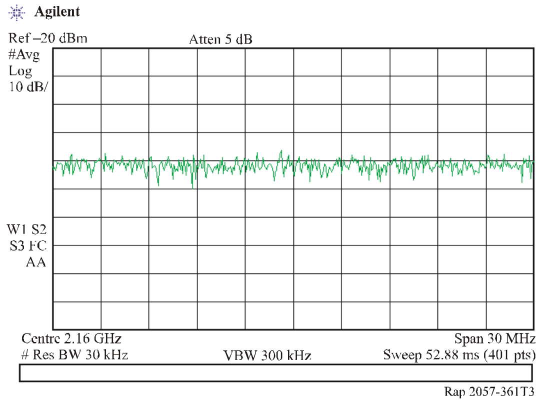
TYPE 1
PRF = 25 MHz, PPM = 1, Bi-phase



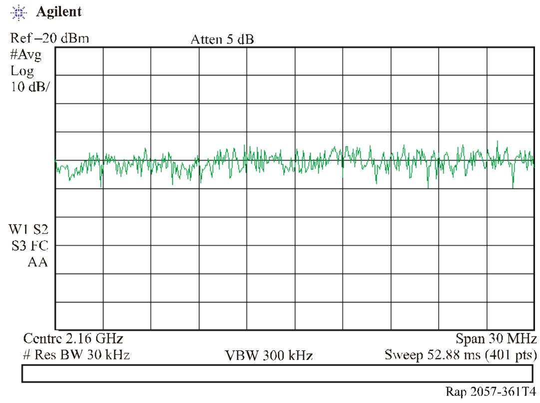
TYPE 2
PRF = 50 MHz, PPM = 1, Bi-phase



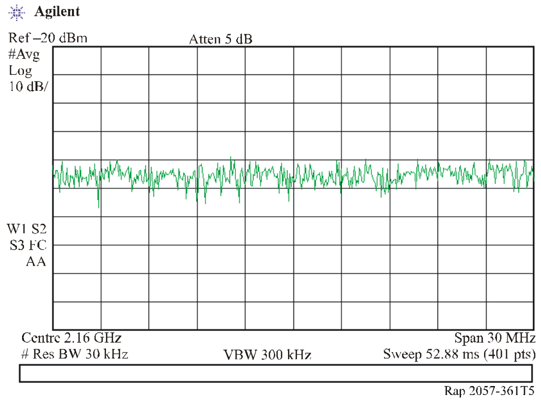
TYPE 3
PRF = 100 MHz, PPM = 1, Bi-phase



TYPE 4
PRF = 200 MHz, PPM = 1, Bi-phase



TYPE 5
PRF = 100 MHz, PPM = 2, Bi-phase



Appendix 4
to Annex 7
(Ref: § 7.5)

Short-pulse UWB transmitter – Additional information

1 Summary

The IDA's short-pulse UWB transmitter is a Multispectral TFP1001 UWB impulse source triggered by a Tektronix DG2030 data pattern generator. The user operates the DG2030 remotely using Matlab scripts developed in-house to control the PRF, the number of PPM steps, and the polarity (either mono-phase or bi-phase) of the UWB signal. PPM refers to the number of possible positions in time a pulse can occupy within any time interval *T*, the reciprocal of the PRF. There is always one and only pulse within every *T*, but the polarity and/or position of the pulse can change from interval to interval. Bi-phase, high-PPM UWB signals are almost noise-like, while mono-phase, PPM = 1 UWB signals consist of distinct, evenly-spaced spectral lines in the frequency domain.

In general, the higher the PRF, the greater the power spectral density of the signal generated by the UWB transmitter. The power level of the UWB signal can be adjusted in 1 dB steps using the step attenuator (0-81 dB) connected to the output of the TFP1001. This is useful for lowering the output of the transmitter to meet a certain emission mask requirement.

The TFP1001 generates a lot of spectral energy, particularly at low (< 1 GHz) frequencies. It is often desirable to place a high-pass or band-pass filter at the output of the TFP1001 to suppress any unwanted energy to avoid any unintended signal overloading effects.

For radiated experiments, a broadband antenna, such as the Skycross UWB antenna, can be used.

2 Signal parameters used in experiments

Table 308 shows the 36 different combinations of PPM, PRF and pulse polarity we used in our experiments. Not all of the 36 combinations were used in every test case.

TABLE 310

UWB transmitter settings

No.	**PRF (MHz)**	**PPM**	**Polarity**
1	0.1	1	Mono-phase
2	0.1	1	Bi-phase
3	0.1	4	Mono-phase
4	0.1	4	Bi-phase
5	0.1	8	Mono-phase
6	0.1	8	Bi-phase
7	0.5	1	Mono-phase
8	0.5	1	Bi-phase
9	0.5	4	Mono-phase
10	0.5	4	Bi-phase

TABLE 310 (*end*)

No.	PRF (MHz)	PPM	Polarity
11	0.5	8	Mono-phase
12	0.5	8	Bi-phase
13	1	1	Mono-phase
14	1	1	Bi-phase
15	1	4	Mono-phase
16	1	4	Bi-phase
17	1	8	Mono-phase
18	1	8	Bi-phase
19	5	1	Mono-phase
20	5	1	Bi-phase
21	5	4	Mono-phase
22	5	4	Bi-phase
23	5	8	Mono-phase
24	5	8	Bi-phase
25	10	1	Mono-phase
26	10	1	Bi-phase
27	10	4	Mono-phase
28	10	4	Bi-phase
29	10	8	Mono-phase
30	10	8	Bi-phase
31	50	1	Mono-phase
32	50	1	Bi-phase
33	50	2	Mono-phase
34	50	2	Bi-phase
35	100	1	Mono-phase
36	100	1	Bi-phase

3 Spectral plots

Figures 362 to 365 contain a few representative spectral plots of PRF = 10 MHz short-pulse UWB signals captured directly from an Agilent E4407B spectrum analyser. An RMS detector and a RBW of 1 MHz were used. Each plot is centred at 4.71442 GHz and spans 100 MHz.

The plot in Fig. 362 (PPM = 1, mono-phase) consists of a series of spectral lines spaced 10 MHz apart. The broadening of the spectral lines is due to the large spectrum analyser RBW. When PPM is increased to 8, we obtain the plot shown in Fig. 364 (PPM = 8, mono-phase). This UWB signal type, which, for the most part, is fairly noise-like, contains weak spectral lines at every multiple of PRF × PPM = 10 × 8 = 80 MHz. The spectral line in the figure occurs at 4 160 MHz.

Figures 363 and 365 show bi-phase UWB signals, without and with PPM dithering respectively. These spectra appear almost completely noise-like.

FIGURE 362

PRF = 10 MHz, PPM = 1, mono-phase

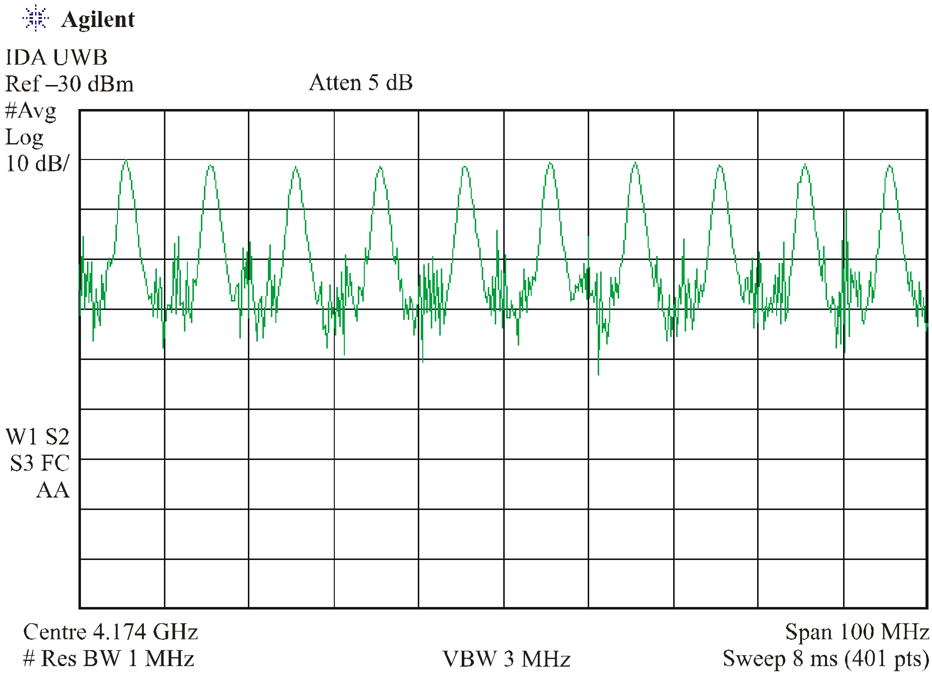


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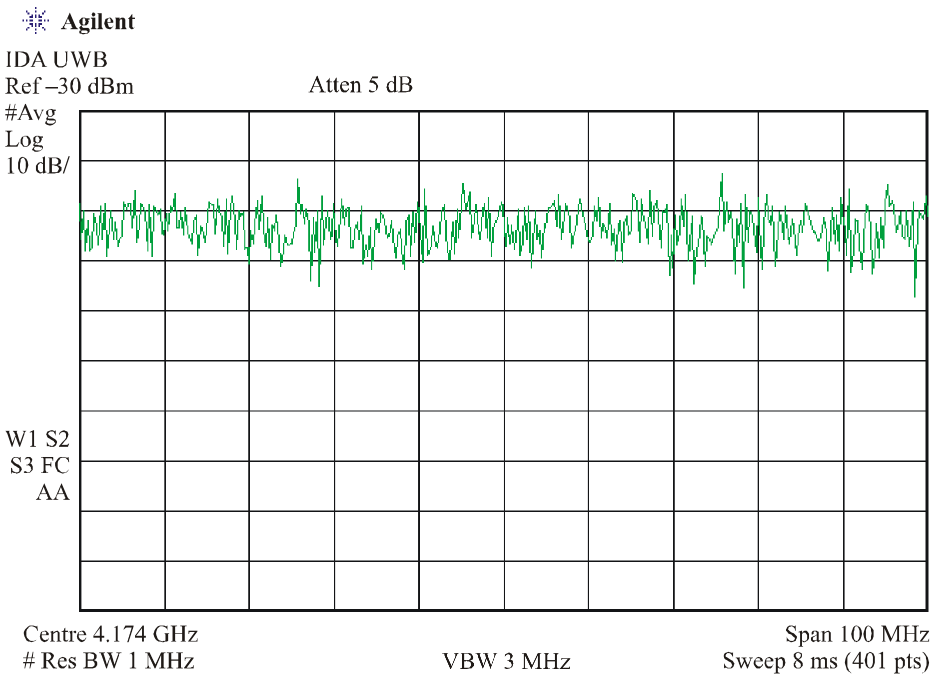
FIGURE 363

PRF = 10 MHz, PPM = 1, bi-phase



Rap 2057-363

FIGURE 364

PRF = 10 MHz, PPM = 8, mono-phase

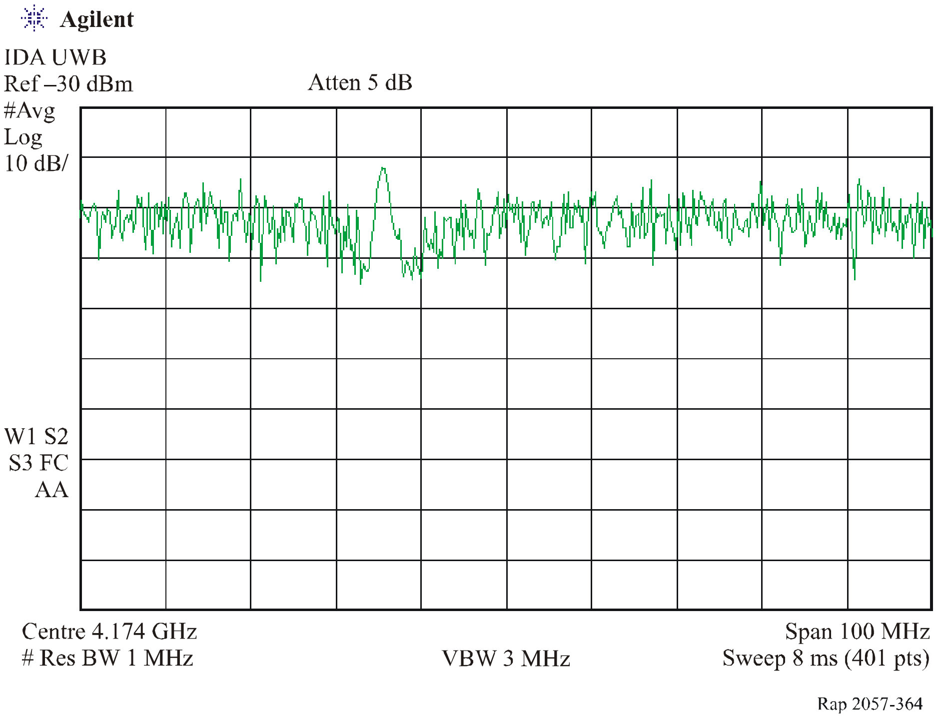
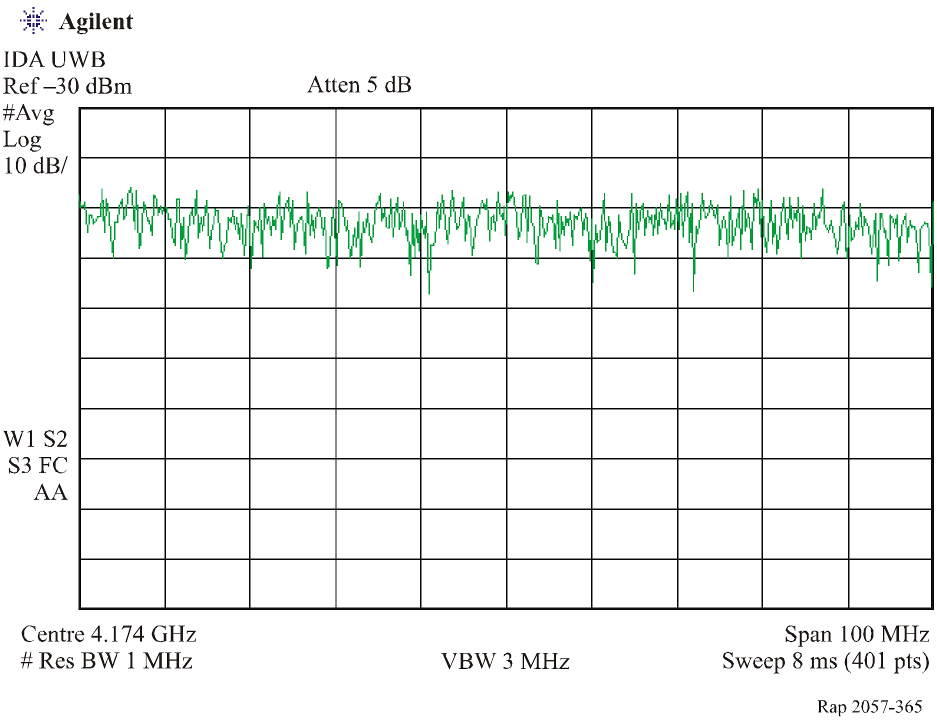


FIGURE 365

PRF = 10 MHz, PPM = 8, bi-phase



Appendix 5
to Annex 7

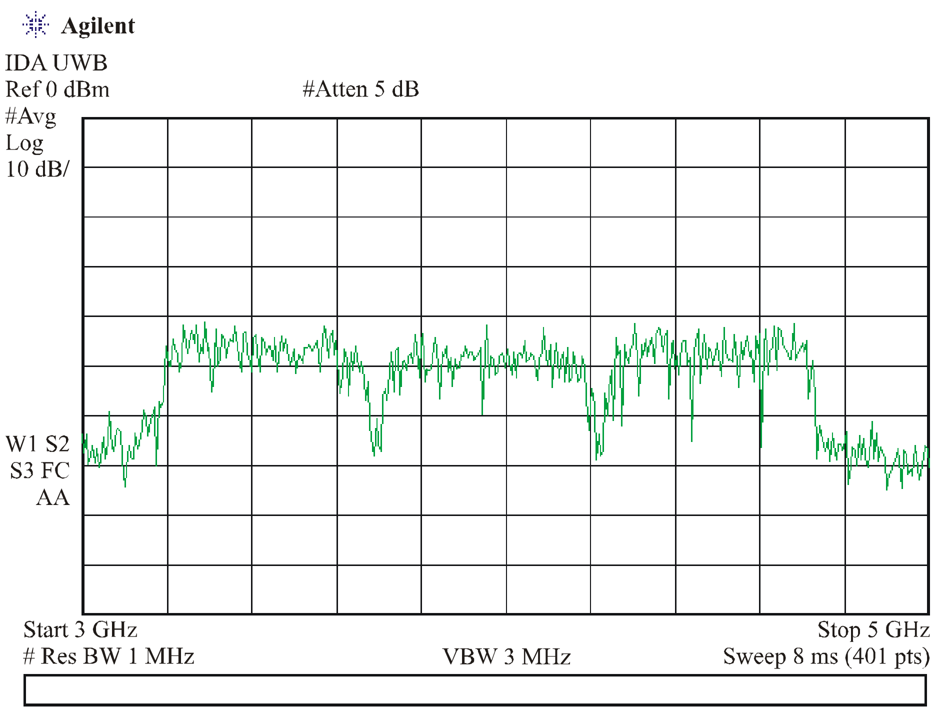
(Ref: § 7.5)

MB-OFDM UWB transmitter – Additional information

Figure 366 is a spectral plot of the output of the Staccato SC1000D MB-OFDM UWB transmitter captured directly from an Agilent E4407B spectrum analyser. An RMS detector and a RBW of 1 MHz were used. The plot, which begins at 3 GHz and stops at 5 GHz, shows the three OFDM bands that make up the signal. Note that the maximum power spectral density of the signal is around – 41 dBm/MHz.

FIGURE 366

MB-OFDM UWB signal



Rap 2057-366

Annex 8

Characteristics and protection criteria of radiocommunication services

Introduction

Interference analyses between devices using UWB technology and radiocommunication services require knowledge of the protection criteria and technical characteristics of potentially affected systems. Several ITU-R Recommendations exist which provide such information.

This annex contains lists of relevant ITU-R Recommendations and Reports on technical characteristics and protection criteria of radiocommunication services.

This section also contains provisional technical characteristics and protection criteria of potential victim systems based on input contributions and liaison statements of various Radiocommunication Working Parties and Study Groups. These characteristics and criteria are intended to aid studies on the impact of devices using UWB technology on radiocommunication services at the time of preparing this Report. Please note that some Radiocommunication Study Groups may have developed or adopted different values since then. The structure of this Annex is identical to the structure used in the corresponding Annexes 1-6 containing the detailed studies.

1 Mobile services

1.1 Land mobile services except IMT-2000

– Rec. ITU-R M.478 – Technical characteristics of equipment and principles governing the allocation of frequency channels between 25 and 3 000 MHz for the FM land mobile service

– Rec. ITU-R M.1032 – Technical and operational characteristics of land mobile systems using multi-channel access techniques without a central controller

– Rec. ITU-R M.1033 – Technical and operational characteristics of cordless telephones and cordless telecommunication systems

– Rec. ITU-R M.1073 – Digital cellular land mobile telecommunication systems

– Report ITU-R M.2014 – Spectrum efficient digital land mobile systems for dispatch traffic

– Rec. ITU-R M.1808 – Technical and operational characteristics of conventional and trunked land mobile systems operating in the mobile service allocations below 869 MHz to be used in sharing studies.

1.2 Maritime mobile service

ITU-R Recommendations that may be relevant to UWB interference analysis with the maritime and aeronautical mobile services include:

– Rec. ITU-R M.441 – Signal-to-interference ratios and minimum field strengths required in the aeronautical mobile (R) service above 30 MHz

– Rec. ITU-R M.489 – Technical characteristics of VHF radiotelephone equipment operating in the maritime mobile service in channels spaced by 25 kHz

– Rec. ITU-R M.589 – Technical characteristics of methods of data transmission and interference protection for radionavigation services in the frequency bands between 70 and 130 kHz

– Rec. ITU-R M.627 – Technical characteristics for HF maritime radio equipment using narrow-band phase-shift keying (NBPSK) telegraphy

– Rec. ITU-R M.628 – Technical characteristics for search and rescue radar transponders
– Rec. ITU-R M.824 – Technical parameters of radar beacons (racons)
– Rec. ITU-R M.1085 – Technical and operational characteristics of wind profiler radars for bands in the vicinity of 400 MHz
– Rec. ITU-R M.1174 – Technical characteristics of equipment used for on-board vessel communications in the bands between 450 and 470 MHz
– Rec. ITU-R M.1176 – Technical parameters of radar target enhancers
– Rec. ITU-R M.1227 – Technical and operational characteristics of wind profiler radars in bands in the vicinity of 1 000 MHz
– Rec. ITU-R SM.1140 – Test procedures for measuring aeronautical receiver characteristics used for determining compatibility between the sound-broadcasting service in the band of about 87-108 MHz and the aeronautical services in the band 108-118 MHz.

1.3 Aeronautical service

1.3.1 System characteristics

1.3.1.1 Introduction

Aeronautical services are recognized internationally to be prime users of radio frequencies without which aircraft operations would not be capable of meeting the global demand for safe, efficient and cost-effective transport. Aeronautical radionavigation service (ARNS) service provides radionavigation relating to safety and regularity of flight. The aeronautical mobile (R) service (AM(R)S) and aeronautical mobile satellite (R) service (AMS(R)S) provide communications relating to safety and regularity of flight. The prominent safety-of-life element, present during all phases of an aircraft's flight, is accorded special treatment internationally and is granted protection from harmful interference through agreed measures. Provision No. 4.10 of the RR recognizes that radionavigation and other safety services require special measures to ensure freedom from harmful interference and that it is necessary to take this factor into account in the assignment and use of frequencies.

With respect to the RR spectrum allocated for aeronautical use is divided currently into two main functions: ground-air communications and radionavigation. The future will also see the gradual introduction of more satellite-based services in accordance with the communications, navigation and surveillance/air traffic management (CNS/ATM) policies agreed at Air Navigation Conferences and approved by the ICAO Council.

Aeronautical Mobile (OR) Services are generally used on a national basis to provide similar safety services for State aircraft

A list of the bands allocated to aeronautical services considered in this Report and where further information can be found is given below. In addition there are secondary allocations for aeronautical non-safety applications such as AMSS in the 14-14.5 GHz band which may need to be taken into account

List of frequency bands allocated to services used by aviation

Band	Service	Aviation use	Relevant section
90-110 kHz	RNS	LORAN-C	1.3.1.4.2.1
190-535 kHz	ARNS	NDB/locator	1.3.1.4.2.2
2 850-22 000 kHz	AM(R)S	Air-ground communications	1.3.1.2.2
3 025-23 350 kHz	AM(OR)S	Air-ground communications	1.3.1.3
3 023 and 5 680 kHz	AM(R)S	Search and rescue	1.3.1.2.2
74.8-75.2 MHz	ARNS	Marker beacon	1.3.1.4.2.3
108-117.975 MHz	ARNS AM(R)S	ILS localizer GBAS VOR VDL Mode 4	1.3.1.4.2.4 1.3.1.4.2.5 1.3.1.4.2.6 1.3.1.2.2
117.975-137 MHz	AM(R)S AMS(R)S	Air-ground and air-air communications	1.3.1.2.2
132-146 MHz	AM(OR)S	Air-ground communications	1.3.1.2.3
121.5, 123.1 and 243 MHz	AM(R)S MSS	Emergency frequencies	1.3.1.2.2 6.1
328.6-335.4 MHz	ARNS	ILS glide path	1.3.1.4.2.4
406-406.1 MHz	MSS	Search and rescue	6.1
960-1 215 MHz	ARNS	DME TACAN	1.3.1.4.2.7 1.3.1.4.2.8
1 164-1 215 MHz	RNSS	GNSS	6.2
1 030 and 1 090 MHz	ARNS	SSR ACAS	1.3.1.4.2.9 1.3.1.4.2.10
1 215-1 400 MHz	RLS RNSS ARNS	GNSS Primary surveillance radar	6.2 1.3.1.4.2.11
1 525-1 559 MHz	MSS (s-E)	Satellite communications	6.1
1 626.5-1 660.5 MHz	MSS (E-s)	Satellite communications	6.1
1 559-1 626.5 MHz	ARNS RNSS	GNSS	6.1
2 700-3 400 MHz	ARNS RNS RLS	Primary surveillance radar	1.3.1.4.2.11
4 200-4 400 MHz	ARNS	Radio altimeter	1.3.1.4.2.12
5 000-5 150 MHz	AMS(R)S	Satellite communications	6.1

List of frequency bands allocated to services used by aviation

Band	Service	Aviation use	Relevant section
5 000-5 250 MHz	ARNS	MLS	1.3.1.4.2.13
5 350-5 470 MHz	ARNS	Airborne weather radar	1.3.1.4.2.14
8 750-8 850 MHz	ARNS/RLS	Airborne doppler radar	1.3.1.4.2.14
9 000-9 500 MHz	ARNS/RNS	Precision approach radar/ASDE	1.3.1.4.2.11 1.3.1.4.2.15
13.25-13.4 GHz	ARNS	Airborne doppler radar	1.3.1.4.2.14
15.4-15.7 GHz	ARNS	ASDE/other systems	1.3.1.4.2.15
24.25-24.65 GHz	RNS	ASDE	1.3.1.4.2.15
31.8-33.4 GHz	RNS	ASDE	1.3.1.4.2.15

List of abbreviations

NDB Non-directional beacon

VOR VHF omnidirectional ranging

ILS Instrument landing system

GBAS Ground-based augmentation system

VDL VHF data link

DME Distance measuring equipment

TACAN Tactical air navigation

SSR Secondary surveillance radar

GNSS Global navigation satellite service

MLS Microwave landing system

ASDE Airport surface detection system

ACAS Airborne collision avoidance system

LORAN Long range navigation

1.3.1.2 Aeronautical mobile (R) service

1.3.1.2.1 References

Recommendation ITU-R M.441 – Signal-to-interference ratios and minimum field strengths required in the aeronautical mobile (R) service above 30 MHz.

Recommendation ITU-R M.1459 – Protection criteria for telemetry systems in the aeronautical mobile service and mitigation techniques to facilitate sharing with geostationary broadcasting-satellite and mobile-satellite services in the frequency bands 1 452-1 525 MHz and 2 310-2 360 MHz.

ICAO Annex 10 to the Convention on International Civil Aviation,

– Volume III, Part I – Digital Data Communications Systems

– Volume III, Part II – Voice Communications Systems

– Volume V, Aeronautical Radio Frequency Spectrum Utilisation

ICAO Document 9718 – Handbook on Radio Frequency Spectrum Requirements for Civil Aviation.

Annex 10 to the Convention on International Civil Aviation does not specify all receiver interference immunity characteristics necessary to fully evaluate the potential for interference to aeronautical safety services from emissions of UWB devices. Due to the safety critical nature of aeronautical systems it is essential that practical testing be undertaken to determine the missing parameters before any final conclusions on the impact on aeronautical systems by UWB are drawn.

Further information on airborne receiver characteristics can be found in the relevant RTCA Eurocae documents, whilst additional information on some ground systems operating within Europe can be found in the relevant European Telecommunication Standardization Institute standards (ETSI).

1.3.1.2.2 System description

Aeronautical mobile (R) systems (AM(R)S) provide a means of two way communication between an aircraft station and either a ground or another aircraft station. The band 117.975-137 MHz is the main communications band for LoS air-ground communications.. HF communications, in various bands between 2.85-22 MHz, provide the main long-distance air-ground communication system in areas where VHF is not practicable, e.g. in oceanic and remote areas. Single sideband amplitude modulation voice is the modulation used. Data transmission over HF frequencies is permissible and has increasing applications.

Basic analogue receiver characteristics

Frequency band	**2.85-22 MHz**		**117.975-137 MHz**	
	HF Comms		**VHF Comms**	
Receiver location	Airborne	Ground	Airborne	Ground
Antenna height above ground	0-13 000 m	30 m (typical)	0-13 000 m	30 m (typical)
Minimum desired signal at the isotropic antenna port			–90 dBm	–94 dBm
Assumed receiver 6 dB bandwidth	3 kHz	3 kHz	16 kHz (25) 5.6 kHz (8.33)	16 kHz (25) 5.6 kHz (8.33)
Intra-system signal to interference ratio(1)	15 dB		20 dB	
Measured maximum tolerable value of UWB interference(2)	Unknown		Unknown	

(1) These values are not necessarily valid for UWB.

(2) The result may be specific to the UWB waveform tested.

Basic digital receiver characteristics

Frequency band	108-137 MHz		117.975-137 MHz	
	VDL mode 4		VDL mode 2 & 3	
Receiver location	Airborne	Ground	Airborne	Ground
Antenna height above ground	0-13 000 m	30 m (typical)	0-13 000 m	30 m (typical)
Minimum desired signal at the isotropic antenna port	–82 dBm	–89 dBm	–82 dBm	–94 dBm
Assumed receiver 6 dB bandwidth	5.56 kHz	6 kHz	16 kHz	8 kHz
Intra-system signal to interference ratio(1)	20 dB			
Measured maximum tolerable value of UWB interference(2)	Unknown			

(1) These values are not necessarily valid for UWB.

(2) The result may be specific to the UWB waveform tested.

1.3.1.3 Aeronautical mobile (OR) service

These allocations are generally used for government purposes. No information has been provided on this service.

1.3.1.4 Aeronautical radionavigation service

1.3.1.4.1 References

Recommendation ITU-R M.1477 – Technical and performance characteristics of current and planned radionavigation-satellite service (space-to-Earth) and aeronautical radionavigation service receivers to be considered in interference studies in the band 1 559-1 610 MHz.

Recommendation ITU-R M.1582 – Method for determining coordination distances, in the 5 GHz band, between the international standard microwave landing system stations operating in the aeronautical radionavigation service and stations of the radionavigation-satellite service (Earth-to-space).

Recommendation ITU-R M.1584 – Methodology for computation of separation distances between earth stations of the radionavigation-satellite service (Earth-to-space) and radars of the radiolocation service and the aeronautical radionavigation service in the frequency band 1 300-1 350 MHz.

ICAO Annex 10 to the Convention on International Civil Aviation,

– Volume I, Radionavigation Aids
– Volume III, Part I – Digital Data Communications Systems
– Volume IV, Surveillance and Collision Avoidance Systems
– Volume V, Aeronautical Radio Frequency Spectrum Utilisation

ICAO Document 9718 – Handbook on Radio Frequency Spectrum Requirements for Civil Aviation

Annex 10 to the Convention on International Civil Aviation does not specify all receiver interference immunity characteristics necessary to fully evaluate the potential for interference to aeronautical safety services from emissions of UWB devices. Due to the safety critical nature of aeronautical systems it is essential that practical testing be undertaken to determine the missing parameters before any final conclusions on the impact on aeronautical systems by UWB are drawn.

Further information on airborne receiver characteristics can be found in the relevant RTCA/Eurocae documents, whilst additional information on ground systems operating within Europe can be found in the relevant ETSI standards.

1.3.1.4.2 System description

1.3.1.4.2.1 LORAN

Long-range hyperbolic navigation for specialized purposes other than flight along national airways and air routes. No information has been provided on this system when used in an aeronautical context. Some information on Loran C can be found in § 2.1.4.

1.3.1.4.2.2 Non-directional beacons (NDB)

NDB are radio beacons for short and medium range navigation that operate in the low and medium frequency bands (190-535 kHz). Automatic direction finder (ADF) equipment is used to measure the relative bearing to the transmitter with respect to the heading of an aircraft. These beacons transmit either a coded or modulated CW signal for station identification. The coded signal is generated by modulating the carrier. The aeronautical beacon accuracy is in the range ±3° to ±10°. NDBs are used over sea or over land routes and to supplement the VOR – DME system for transition from en-route to precision approach facilities and as a non-precision approach aid. NDBs are extensively deployed at aerodromes where it provides an economic and easily installed facility.

Basic NDB receiver characteristics

Frequency band	190-535 kHz
Receiver location	Airborne
Antenna height above ground	100-10 000 m
Minimum desired signal at the isotropic antenna port	–35 dBm
Assumed receiver 6 dB bandwidth	6.0 kHz
Intra-system signal to interference ratio(1)	15 dB
Measured maximum tolerable value of UWB interference(2)	Unknown

(1) These values are not necessarily valid for UWB.

(2) The result may be specific to the UWB waveform tested.

1.3.1.4.2.3 Marker beacon

See § 1.3.1.4.2.4 on ILS for details of this system basic marker beacon receiver characteristics.

Basic marker beacon receiver characteristics

Frequency band	74.8-75.2 MHz
Receiver location	Airborne
Antenna height above ground	100-10 000 m
Minimum desired signal at the isotropic antenna port	–51 dBm
Assumed receiver 6 dB bandwidth	22 kHz
Intra-system signal to interference ratio(1)	20 dB
Measured maximum tolerable value of UWB interference(2)	Unknown

(1) These values are not necessarily valid for UWB.

(2) The result may be specific to the UWB waveform tested.

1.3.1.4.2.4 Instrument landing system (ILS)

The ILS currently operating in the bands 108-112 and 328.6-335.4 MHz are the primary, ICAO approved, precision landing system. An ILS normally consists of two or three marker beacons, a localizer, and a glide slope to provide both vertical and horizontal guidance information. The localizer, operating in the 108-112 MHz band is normally located 1 000 feet beyond the stop end of the runway. The glide slope is normally positioned 1 000 feet beyond the approach end of the runway and operates in the 328.6-335.4 MHz band. Marker beacons operating along the extension of the runway centre line at 75 MHz are used to indicate decision height points for the approach or distance to the threshold of the runway.

Azimuth guidance provided by the localizer is accomplished by use of a 90 Hz modulated left-hand antenna pattern and a 150 Hz modulated right-hand pattern as viewed from the aircraft on approach. A 90 Hz signal detected by the aircraft receiver will cause the vertical course deviation indicator to deviate to the right while a 150 Hz signal will cause the needle to deviate to the left. When the aircraft is on the centre line the vertical course deviation indicator will be centred.

Vertical guidance is provided by the glide-slope facility that is normally located to the side of the approach end of the runway. The carrier radiated in the antenna pattern below the glide slope is amplitude modulated with a 150 Hz signal. The pattern above the glide slope produces a signal with 90 Hz amplitude modulation. When the approaching aircraft is on the glide slope the horizontal course deviation indicator needle will be centreed.

The marker beacon facilities along the course provide vertical fan markers to mark the key progress along the approach. The outer marker is nominally at 7.5 km from the runway threshold, the middle marker at 1 050 m from the threshold and, where installed, the inner marker is located just prior to the threshold. In addition, marker beacons are installed to provide guidance on instrument approaches to some airports in mountain regions. A DME on one of the paired channels with the localizer channels may also be used for indicating position during approach.

Basic ILS receiver characteristics

Frequency band	108-112 MHz	328.6-335.4 MHz
Receiver location	Localizer	Glidepath
Antenna height above ground	0-1 000 m	
Minimum desired signal at the isotropic antenna port	–86 dBm	–89 dBm
Assumed receiver 6 dB bandwidth	50 kHz	150 kHz
Intra-system signal to interference ratio (1)	20 dB	
Measured maximum tolerable value of UWB interference(2)	Unknown	

(1) These values are not necessarily valid for UWB.

(2) The result may be specific to the UWB waveform tested.

1.3.1.4.2.5 Ground-based augmentation system (GBAS)

The GBAS consists of ground and aircraft elements. One ground station can support all the aircraft subsystems within its coverage providing the aircraft with approach data, corrections and integrity information for GNSS satellites in view via a VHF data broadcast (VDB) in the 108-117.975 MHz band. GBAS ground stations, using two or more GNSS reference receivers at surveyed locations, generate and broadcast pseudo-range corrections for all satellites within view as well as monitor quality and integrity of the ranging signals. The aircraft receivers use the corrections for increased accuracy.

Basic GBAS receiver characteristics

Frequency band	108-117.975 MHz
Receiver location	Airborne
Antenna height above ground	30-10 000 m
Minimum desired signal at the isotropic antenna port	–76 dBm
Assumed receiver 6 dB bandwidth	14 kHz
Intra-system signal to interference ratio(1)	26 dB
Measured maximum tolerable value of UWB interference(2)	Unknown

(1) These values are not necessarily valid for UWB.

(2) The result may be specific to the UWB waveform tested.

1.3.1.4.2.6 VHF omnidirectional ranging

A VHF omnidirectional range (VOR) is a ground-based system which provides continuous azimuth bearing information in the form of 360 radials to and from a station. It transmits continuous-wave signals on one of the 50 kHz channels in the 108-117.975 MHz band. A non-directional 30 Hz reference signal with a ±480 Hz frequency modulation on a 9 960 Hz sub-carrier is transmitted along with a carrier radiating from a rotating antenna with a horizontal cardioid pattern. The cardioid antenna pattern rotates at a 30 Hz rate, allowing the airborne receiver to determine its bearing from the station as a function of phase between the reference and the rotating signal. The VOR system has LoS limitations in that at altitudes above 5 000 ft the range is approximately 100 nautical miles and above 20 000 ft the range is approximately 200 nautical miles. The accuracy of the VOR ground station is better than ±1.4°.

Distance measuring equipments (DMEs) are often collocated with the VOR stations to provide ranging information. The military in a number of countries collocate TACAN (Tactical air navigation), their equivalent of DME, with VORs.

Basic VOR receiver characteristics

Frequency band	108-117.975 MHz
Receiver location	Airborne
Antenna height above ground	300-10 000 m
Minimum desired signal at the isotropic antenna port	–79 dBm
Assumed receiver 6 dB bandwidth	50 kHz
Intra-system signal to interference ratio(1)	20 dB
Measured maximum tolerable value of UWB interference(2)	Unknown

(1) These values are not necessarily valid for UWB.

(2) The result may be specific to the UWB waveform tested.

1.3.1.4.2.7 Distance measuring equipment (DME)

The airborne equipment (interrogator) generates a pulse signal that is recognized by the ground equipment (transponder); the transponder then transmits a reply that is identified by the tracking circuit in the interrogator. The distance is computed by measuring the total round trip time of interrogation, reply and fixed delay introduced by the ground transponder. The airborne interrogator transmits pulse pairs per second on one of the channels between 1 025 and 1 150 MHz. The ground transponder replies on the paired response channels in the 962 to 1 024 MHz band or 1 151 to 1 213 MHz band.

Basic DME receiver characteristics

Frequency band	960-1 215 MHz	
Receiver location	Airborne	Ground
Antenna height above ground	500-10 000 m	
Minimum desired signal at the isotropic antenna port	–82 dBm	–96 dBm
Assumed receiver 6 dB bandwidth	6 MHz	6 MHz
Intra-system signal to interference ratio(1)	8 dB	
Measured maximum tolerable value of UWB interference(2)	Unknown	

(1) These values are not necessarily valid for UWB.

(2) The result may be specific to the UWB waveform tested.

1.3.1.4.2.8 TACAN (Tactical air navigation)

Tactical air navigation is used primarily by the military for en route, non-precision approaches and other military applications. The TACAN system provides both omni-bearing and distance-measuring capability. The rotating directional horizontal-plane radiation pattern produces the azimuth signal, which contains a coarse (15 Hz) and a fine (135 Hz) azimuth element. The rotation of the pattern at 15 Hz results in a modulation of the carrier with a composite 15 Hz sine wave. Reference signals are transmitted by coded pulse trains to provide the phase reference. Bearing is obtained by the airborne receiver by comparing the 15 Hz and the 135 Hz sine waves with the reference pulse groups. The TACAN system operates in the 960 to 1 215 MHz band with 1 MHz channel separations.

Basic TACAN receiver characteristics

Frequency band	960-1 215 MHz	
Receiver location	Airborne	Ground
Antenna height above ground	50-10 000 m	
Assumed receiver 6 dB bandwidth	6 MHz	6 MHz
Intra-system signal to interference ratio(1)	8 dB	
Measured maximum tolerable value of UWB interference(2)	Unknown	

(1) These values are not necessarily valid for UWB.

(2) The result may be specific to the UWB waveform tested.

1.3.1.4.2.9 Secondary surveillance radar (SSR)

The SSR ground interrogator transmits at 1 030 MHz with a rotating directional antenna pattern. The interrogator transmits approximately 400 pulse pairs per second and receives replies from aircraft transponders that are within the beam of the antenna pattern. The airborne transponder will reply at 1 090 MHz with one of the 4 096 (Mode A), 2 048 (Mode C) or 16 500 000 (Mode S) pulse codes available. The decoded replies are displayed on the surveillance radar display along with primary radar returns. An omnidirectional pulsed pattern is also radiated from the ground to suppress unwanted side-lobe replies.

Basic SSR receiver characteristics

Frequency band	1 030 MHz	1 090 MHz
Receiver location	Airborne transponder	Ground interrogator
Antenna height above ground	0-10 000 m	30 m
Minimum desired signal at the isotropic antenna port	–74 dBm	–103 dBm
Assumed receiver 6 dB bandwidth	9 MHz	5.5 MHz
Intra-system signal to interference ratio(1)	12 dB	
Measured maximum tolerable value of UWB interference(2)	Unknown	

(1) These values are not necessarily valid for UWB.

(2) The result may be specific to the UWB waveform tested.

1.3.1.4.2.10 Airborne collision avoidance system (ACAS)

No information has been provided on this system.

1.3.1.4.2.11 Ground-based primary radar

Radar operates by transmitting a known waveform, usually a series of narrow pulses, and observing the nature of the signal reflected by the target back to the radar. In addition to determining the presence of targets within its coverage, the basic measurements made by radar are range and angular location. The Doppler frequency shift of the reflected signal from a moving target is sometimes extracted as a measure of the relative velocity. The Doppler shift is also important in continuous wave, moving target indication and pulse Doppler radars for separating desired moving targets, such as aircraft, from large undesired fixed echoes such as ground clutter.

Radars operating in the band 590-598 MHz are used for long range detection although they are being phased out in favour of Radars operating in the band 1 215-1 350 MHz. Radars operating in the 1 215-1 350 MHz band are now the norm for the provision of en-route long-range radar coverage (typically 200+ nautical miles). Radars operating in the 2 700-3 100 MHz band are generally used for the provision of airport approach coverage (typically up to 80 nautical miles). Radars operating in the 9 000-9 500 MHz band are generally used for the provision of coverage of the aerodrome surface.

Basic ground-based radar receiver characteristics

Frequency band (MHz)	590-598[(1)]	1 215-1 400	2 700-3 400	9 000-9 500[(1)]
Receiver location	Ground			
Antenna height above ground	15 m (typical)			
Receiver noise level *N* (in the receiver bandwidth) (dBm)	–107.2	–113.6	–111.1	–102.0
I/*N* Criteria (dB)	–6	–6	–10	–6
Maximum antenna gain (dBi)	28	39	35	38
Assumed azimuthal beamwidth (degrees)	1.4	1.4	1.4	1.4
Typical receiver 6 dB bandwidth (MHz)	3	0.69	1.2	10[(2)]
Feeder loss (dB)	3	2	2	3

(1) These values are taken from the performance of United Kingdom radars in the appropriate band.

(2) It should be noted that in addition, there are 60 MHz bandwidth radars.

1.3.1.4.2.12 Radio altimeters

Aircraft use radio altimeters to provide altitude estimation accuracy and an independent altitude reference near the ground. These devices send signals towards, the ground, and then measure the time required for the reflected signal to return to the aircraft to determine height- above-terrain.

Radio altimeters are used during landing and form an integral part of the ground proximity warning systems on-board an aircraft.

Basic radio altimeter receiver characteristics

Frequency band	4 200-4 400 MHz
Receiver location	Airborne
Antenna height above ground	0-10 000 m
Assumed receiver 6 dB bandwidth	30 MHz
Intra-system signal to interference ratio[(1)]	6 dB
Measured maximum tolerable value of UWB interference[(2)]	Unknown

(1) These values are not necessarily valid for UWB.

(2) The result may be specific to the UWB waveform tested.

1.3.1.4.2.13 Microwave landing system (MLS)

The MLS is an ICAO standardized system and designed to provide precise navigation guidance in the form of azimuth alignment and vertical descent information to aircraft on approach to and landing on a runway. The MLS system is based on time-referenced scanning beams, referenced to the runway, that enable the airborne unit to determine precise azimuth angle and elevation angle. The angular position of the aircraft is determined by measuring the time intervals between the "TO and FROM" azimuth antenna beam scan and the UP and DOWN scan of the elevation antenna pattern. The time interval represents a unique position either in the range of the scanning beams. The azimuth scan is typically 60° either side of the runway centreline, and the elevation scan is from 0 to 30°. The signal format provides for 360° azimuth coverage from future implementation. The azimuth and elevation angle functions are provided by 200 channels in the 5 030 to 5 150 MHz band. The MLS also includes, as an integral part of the installation, range guidance which is provided by DMEs operating in the 960 to 1 215 MHz band.

Basic MLS receiver characteristics used

Frequency band	5 030-5 150 MHz
Receiver location	Airborne
Antenna height above ground	0-3 000 m
Minimum desired signal at the isotropic antenna port	–95 dBm
Assumed receiver 6 dB bandwidth	150 kHz
Intra-system signal to interference ratio(1)	25 dB
Measured maximum tolerable value of UWB interference(2)	Unknown

(1) These values are not necessarily valid for UWB.

(2) The result may be specific to the UWB waveform tested.

1.3.1.4.2.14 Airborne radars

No information has been provided however it should be noted that these radars operate in the 5 and 9 GHz bands.

1.3.1.4.2.15 Airport surface detection system

No information has been provided on these systems.

1.4 Terrestrial IMT-2000 and systems beyond

General information can be found in Report ITU-R M.2039 – Characteristics of terrestrial IMT-2000 systems for frequency sharing /interference analyses.

The following frequency bands are identified for terrestrial IMT-2000:

806-960 MHz, 1 710-1 885 MHz, 1 885-2 025 MHz, 2 110-2 170 MHz, 2 500-2 690 MHz.

The protection criterion used with regard to IMT-2000 mobile and base stations is given in the table below.

Reference	*I*/*N* (dB)	Comment
Report ITU-R M.2039	–6	Criterion used with regard to IMT-2000 mobile and base stations, in the case of scenarios involving different IMT-2000 networks or when a limited number of IMT-2000 cells are affected by another type of co-primary service or system
Report ITU-R M.2039	–10	Criterion used with regard to IMT-2000 mobile and base stations, in the case of scenarios involving co-primary satellite systems (e.g. BSS(sound)) interfering into IMT-2000 networks

The tolerable UWB interference at the base station is −122 dBm/MHz, −124.5 dBm/MHz and −126.5 dBm/MHz in the urban area highly loaded case (75% load), the suburban area case with 50% load and the rural area case with load close to zero, respectively. Additional details are given in § 4.4.2 of Annex 1.

Radiocommunication WP 8F has provided protection criteria for interference from devices using UWB technology, in terms of *I*/*N* as summarized in the following table.

Protection criteria for terrestrial IMT-2000 *I*/*N* (dB)

Area class	Urban areas	Sub-urban areas	Rural areas
Load	75%	50%	Close to 0
I/*N* ratio (dB)	−13	−15.5	−17.5

The proposed *I*/*N* ratios assume that interference at the corresponding value is tolerable concurrently in each cell. In reality, UWB interference will vary in time and between cells. The above *I*/*N* criteria are understood as being relevant for long-term protection criteria and may be exceeded only for a small percentage of time or cells.

1.5 Wireless access systems, including radio local area networks (WAS/RLAN), operating in the mobile service in the bands 5 150-5 250 MHz, 5 250-5 350 MHz and 5 470-5 725 MHz

In Recommendation ITU-R M.1739, it is recommended that, for the purposes of conducting compatibility studies with respect to services or applications from which WAS/RLAN systems are entitled to protection, the protection criteria for WAS/RLAN systems operating in the mobile service under the provisions of Resolution 229 (WRC-03) should be as follows:

– the *I*/*N* ratio at the WAS/RLAN receiver should not exceed –6 dB, assuring that degradation to a WAS/RLAN receiver's sensitivity will not exceed approximately 1.0 dB.

That means the tolerable reduction (degradation) of the SINR is assumed to be 1 dB. For information the required *S*/*N* for the various data rates are listed below.

Data rate vs. required *S*/*N* (without interference)

Data rate (Mbits/s)	Required *S*/*N* (dB)
54	25
48	22
36	19
24	16
18	13
12	10
9	8
6	5

F-series Recommendations on fixed wireless access (FWA) systems

Recommendation ITU-R	Title
F.757	Basic system requirements and performance objectives for fixed wireless access using mobile-derived technologies offering telephony and data communication services
F.1399	Vocabulary of terms for wireless access
F.1400	Performance and availability requirements and objectives for fixed wireless access to public switched telephone network
F.1401	Considerations for the identification of possible frequency bands for fixed wireless access and related sharing studies
F.1402	Frequency sharing criteria between a land mobile wireless access system and a fixed wireless access system using the same equipment type as the mobile wireless access system
F.1488	Frequency block arrangements for fixed wireless access systems in the range 3 400 3 800 MHz
F.1489	A methodology for assessing the level of operational compatibility between fixed wireless access and radiolocation systems when sharing the band 3.4-3.7 GHz
F.1490	Generic requirements for fixed wireless access systems
F.1499	Radio transmission systems for fixed broadband wireless access based on cable modem standards
F.1518	Spectrum requirement methodology for fixed wireless access and mobile wireless access networks using the same type of equipment when coexisting in the same frequency band
F.1613	Operational and deployment restrictions for fixed wireless access systems in the fixed service in Region 3 to ensure the protection of systems in the Earth exploration-satellite service (active) and the space research service (active) in the band 5 250 5 350 MHz

ITU-R Recommendations and Report on RLANs

Recommendation ITU-R	Title
M.1450	Characteristics of broadband radio local area networks
M.1454	e.i.r.p. density limit and operational restrictions for RLANs or other wireless access transmitters in order to ensure the protection of feeder links of non-geostationary systems in the mobile-satellite service in the frequency band 5 150-5 250 MHz
M.1651	A method for assessing the required spectrum for broadband nomadic wireless access systems including radio local area networks using the 5 GHz band
M.1652	Dynamic frequency selection (DFS) in wireless access systems including radio local area networks for the purpose of protecting the radiodetermination service in the 5 GHz band
M.1653	Operational and deployment requirements for wireless access systems including radio local area networks in the MS to facilitate sharing between these systems and systems in the EESS (active) and the space research service (active) in the band 5 470-5 570 MHz within the 5 460-5 725 MHz range
F.1613	Operational and deployment restrictions for fixed wireless access systems in the fixed service in Region 3 to ensure the protection of systems in the Earth exploration-satellite service (active) and the space research service (active) in the band 5 250-5 350 MHz
M.1739	Protection criteria for wireless access systems, including radio local area networks, operating in the mobile service in the bands 5150- 5250 MHz, 5250-5350 MHz and 5470-5725 MHz
SA.1632	Sharing in the band 5 250-5 350 MHz between the Earth exploration-satellite service (active) and wireless access systems (including radio local area networks) in the mobile service
Report ITU-R M.2034	Impact of radar detection requirements of dynamic frequency selection on 5 GHz wireless access system receivers

1.6 Amateur and amateur-satellite services

Amateur and amateur-satellite stations perform a variety of functions, such as:

– training, intercommunication between amateur stations and technical investigations by duly authorized persons interested in radio technique solely with a personal aim and without pecuniary interest (RR Nos. 1.56, 1.57);

– disaster relief communications as elaborated in Recommendation ITU-R M.1042.

The text below is based on Recommendation ITU-R M.1732.

1.6.1 Operational characteristics

Amateur stations and amateur-satellite earth stations generally do not have assigned frequencies but dynamically select frequencies within an allocated band using listen-before-talk techniques. Terrestrial repeaters, digital relay stations and amateur satellites use frequencies selected on the basis of voluntary coordination within the amateur services. Some amateur frequency allocations are exclusive to the amateur and amateur-satellite services. Many of the allocations are shared with other radio services and amateur operators are aware of the sharing limitations.

Operating protocols vary according to communication requirements and propagation. MF and HF bands are used for near-vertical-incidence-sky wave to global paths. VHF, UHF and SHF bands are used for short-range communications. Amateur satellites afford an opportunity to use frequencies above HF for long-distance communications.

1.6.2 Technical characteristics

Tables 311-316 contain technical characteristics of representative systems operating in the amateur and amateur-satellite services. This information is sufficient for general calculation to assess the compatibility between these systems and systems operating in other services. The upper frequency boundaries shown in Tables 311 to 316 represent the state of current amateur system deployment, which is expected to extend to higher frequencies over time.

TABLE 311

Characteristics of amateur systems for Morse on-off keying

Parameter	Value							
Mode of operation	CW Morse 10-50 baud				CW Morse < 20 baud (Earth-moon-Earth)			Slow Morse ≤ 1 baud CW
Frequency band (MHz)[(1)]	1.8-7.3	10.1-29.7	50-450	902-47 200	144	432	1 296	0.136
Necessary bandwidth and class of emission (emission designator)	150HA1A 150HJ2A	150HA1A 150HJ2A	150HA1A 150HJ2A	150HA1A 150HJ2A	50H0A1A 50H0J2A	50H0A1A 50H0J2A	50H0A1A 50H0J2A	1H00A1B 1H00J2B
Transmitter power (dBW)[(2)]	3-31.7	3-31.7	3-31.7	3-31.7	3-31.7	3-31.7	17-31.7	23
Transmitter line loss (dB)	0.2	0.3-0.9	1-2	0-10	1-2	1-2	1-4	0.0
Transmitting antenna gain (dBi)	–20 to 15	–10 to 21	0-26	10-40	20-26	20-26	25-40	–22
Typical e.i.r.p. (dBW)	–17.2 to 46.5	–7.3 to 52.4	2-55	1-45	38-55	38-55	68	1
Antenna polarization	Horizontal, vertical	Horizontal, vertical	Horizontal	Horizontal, vertical	Horizontal	Horizontal, vertical, LHCP, RHCP	Horizontal, vertical, LHCP, RHCP	Vertical
Receiver IF bandwidth (kHz)	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Receiver noise figure (dB)[(3)]	13	7-13	0.5-2	1-7	1	1	1	13

(1) With the exception of the band around 0.136 MHz, the amateur bands within the frequency ranges shown conform to RR Article 5.

(2) Maximum powers are determined by each administration.

(3) Receiver noise figures for bands above 50 MHz assume the use of low-noise preamplifiers.

TABLE 312

Characteristics of amateur systems for narrow-band direct printing telegraphy and data

Parameter	Value					
Mode of operation (see Note 1)	PSK31 31 baud	NBDP 50 baud	PACTOR 2	PACTOR 3	CLOVER 2000	MFSK16
Frequency band (MHz)(1)	1.8-29.7	1.8-29.7	1.8-29.7	1.8-29.7	1.8-29.7	1.8-29.7
Necessary bandwidth and class of emission (emission designator)	60H0J2B	250HF1B	375HJ2D	2K20J2D	2K00J2D 2K00J2B	316HJ2D 316HJ2B
Transmitter power (dBW)(2)	3-31.7	3-31.7	3-31.7	3-31.7	3-31.7	3-31.7
Feeder loss (dB)	0.2-0.9	0.2-0.9	0.2-0.9	0.2-0.9	0.2-0.9	0.2-0.9
Transmitting antenna gain (dBi)	–20 to 21	–20 to 21	–20 to 21	–20 to 21	–20 to 21	–20 to 21
Typical e.i.r.p. (dBW)	–17.2 to 52.5	–17.2 to 52.5	–17.2 to 52.5	–17.2 to 52.5	–17.2 to 52.5	–17.2 to 52.5
Antenna polarization	Horizontal, vertical	Horizontal, vertical	Horizontal, vertical	Horizontal, vertical	Horizontal, vertical	Horizontal, vertical
Receiver IF bandwidth (kHz)	0.5	0.5	0.5	2.7	2.4	0.5
Receiver noise figure (dB)(3)	7-13	7-13	7-13	7-13	7-13	7-13

NOTE 1 – PSK31 is a data system using PSK at 31.1 bauds. PACTOR 2 is a data system using DPSK modulation with rates varying according to conditions. PACTOR 3 is a data system with a potential throughput of up to 5.2 kbit/s. CLOVER 200 is a digital data system capable of rates up to 5.2 kbit/s. MFSK16 is a data system using 16-tone FSK and forward error correction.

Further information about these modes of operation can be obtained from the "ARRL HF Digital Handbook", American Radio Relay League, ISBN: 0-87259-915-9, published 2003.

(1) Amateur bands within the frequency ranges shown conform to RR Article 5.

(2) Maximum powers are determined by each administration.

(3) Receiver noise figures for bands above 50 MHz assume the use of low-noise preamplifiers.

TABLE 313

Characteristics of amateur analogue voice systems

Parameter	Value					
Mode of operation	SSB voice				FM voice	
Frequency band (MHz)(1)	1.8-7.3	10.1-29.7	50-450	902-47 200	50-450	902-47 200
Necessary bandwidth and class of emission (emission designator)	2K70J3E	2K70J3E	2K70J3E	2K70J3E	11K0F3E 16K0F3E 20K0F3E	11K0F3E 16K0F3E 20K0F3E
Transmitter power (dBW)(2)	3-31.7	3-31.7	3-31.7	3-31.7	3-31.7	3-31.7
Feeder loss (dB)	0.2	0.3-0.9	1-2	0-10	1-2	0-10
Transmitting antenna gain (dBi)	–20 to 15	–10 to 21	0-23	0-40	0-26	0-40
Typical e.i.r.p. (dBW)	–16.8 to 46.5	–7.3 to 52.4	2-53.7	1-45	2-55	1-45
Antenna polarization	Horizontal, vertical	Horizontal, vertical	Horizontal, vertical	Horizontal, vertical	Horizontal, vertical	Horizontal, vertical
Receiver IF bandwidth (kHz)	2.7	2.7	2.7	2.7	9 15	9 15
Receiver noise figure (dB)(3)	13	7-13	0.5-2	1-7	0.5-2	1-7

(1) Amateur bands within the frequency ranges shown conform to RR Article 5.

(2) Maximum powers are determined by each administration.

(3) Receiver noise figures for bands above 50 MHz assume the use of low-noise preamplifiers.

TABLE 314

Characteristics of amateur digital voice and multimedia systems

Parameter	Value				
Mode of operation	Digital voice			Digital voice and multimedia	
Frequency band (MHz)[(1)]	1.8-7.3	10.1-29.7	50-450	1 240-1 300	5 650-10 500
Necessary bandwidth and class of emission (emission designator)	2K70J2E	2K70J2E	2K70J2E 5k76G1E 8K10F1E	2K70G1D 6K00F7D 16K0D1D 150KF1W	2K70G1D 6K00F7D 16K0D1D 150KF1W 10M5F7W
Transmitter power (dBW)[(2)]	3-31.7	3-31.7	3-31.7	1-10	3
Feeder loss (dB)	0.2	0.3-0.9	1-2	1-3	1-6
Transmitting antenna gain (dBi)	–20 to 15	–10 to 21	0-26	30	36
Typical e.i.r.p. (dBW)	–16.8 to 46.5	–7.3 to 52.4	2-55	39	38
Antenna polarization	Horizontal, vertical	Horizontal, vertical	Horizontal	Horizontal, vertical	Horizontal, vertical
Receiver IF bandwidth (kHz)	2.7	2.7	2.7 5.76 8.1	2.7, 6, 16, 130	2.7, 6, 16, 130, 10 500
Receiver noise figure (dB)[(3)]	13	7-13	1	2	2

(1) Amateur bands within the frequency ranges shown conform to RR Article 5.

(2) Maximum powers are determined by each administration.

(3) Receiver noise figures for bands above 50 MHz assume the use of low-noise preamplifiers.

TABLE 315

Characteristics of amateur-satellite systems in the Earth-to-space direction

Mode of operation	CW Morse, 10-50 baud			SSB voice, digital voice, FM voice, data		
Frequency band (MHz)[(1)]	28	144-5 670	10 450-24 050	28	144-5 670	10 450-24 050
Necessary bandwidth and class of emission (emission designator)	150HA1A 150HJ2A	150HA1A 150HJ2A	150HA1A 150HJ2A	2K70J3E 2K70J2E 16K0F3E	2K70J3E 16K0F3E 44K2F1D 88K3F1D	2K70J3E 16K0F3E 44K2F1D 88K3F1D
Transmitter power (dBW)[(2)]	0-20	0-20	0-13	0-20	0-20	0-13
Feeder loss (dB)	0.2-1.5	0.2-3	0.2-3	0.2-1.5	0.2-3	0.2-3
Transmitting antenna gain (dBi)	–2 to 10	–2 to 27	–2 to 31	–2 to 10	–2 to 27	–2 to 31
Typical e.i.r.p. (dBW)	10-29	10-45	10-42	10-29	10-45	10-42
Antenna polarization	Horizontal, vertical, RHCP, LHCP	Horizontal, vertical, RHCP, LHCP	Horizontal, vertical, RHCP, LHCP	Horizontal, vertical, RHCP, LHCP	Horizontal, vertical, RHCP, LHCP	Horizontal, vertical, RHCP, LHCP
Receiver IF bandwidth (kHz)	0.4	0.4	0.4	2.7 16	2.7, 16, 50, 100	2. 7, 16, 50, 100
Receiver noise figure (dB)[(3)]	3-10	1-3	1-7	3-10	1-3	1-7

(1) Amateur bands within the frequency ranges shown conform to RR Article 5.

(2) Maximum powers are determined by each administration.

(3) Receiver noise figures for bands above 50 MHz assume the use of low-noise preamplifiers.

TABLE 316

Characteristics of amateur-satellite systems in the space-to Earth direction

Mode of operation	CW Morse, 10-50 baud			SSB voice, digital voice, FM voice, data		
Frequency band (MHz)[(1)]	28	144-5 850	10 450-24 050	28	144-5 850	10 450-24 050
Necessary bandwidth and class of emission (emission designator)	150HA1A 150HJ2A	150HA1A 150HJ2A	150HA1A 150HJ2A	2K70J3E 2K70J2E 16K0F3E	2K70J3E 16K0F3E 44K2F1D 88K3F1D	2K70J3E 16K0F3E 44K2F1D 88K3F1D
Transmitter power (dBW)[(2)]	10	10	10	10	10	0-10
Feeder loss (dB)	0.2-1	0.2-1	0.2-1	0.2-1	0.2-1	0.2-1
Transmitting antenna gain (dBi)	0	0-6	0-6	0	0	0-6
Typical e.i.r.p. (dBW)	9	9-15	9-15	9	9-15	9-15
Antenna polarization	Horizontal, vertical, RHCP, LHCP	Horizontal, vertical, RHCP, LHCP	Horizontal, vertical, RHCP, LHCP	Horizontal, vertical, RHCP, LHCP	Horizontal, vertical, RHCP, LHCP	Horizontal, vertical, RHCP, LHCP
Receiver IF bandwidth (kHz)	0.4	0.4	0.4	2.7, 16	2.7, 16, 50, 100	2.7, 16, 50, 100
Receiver noise figure (dB)[(3)]	3-10	1-3	1-7	3-10	1-3	1-7

(1) Amateur bands within the frequency ranges shown conform to RR Article 5.

(2) While total transmitter power of 20 dB is assumed, 10 dBW is used as power is shared among signals in pass-band.

(3) Receiver noise figures for bands above 50 MHz assume the use of low-noise preamplifiers.

1.7 Meteorological radars

The ITU-R Recommendations relevant to UWB interference analysis with the radio determination service include:

Rec. ITU-R M.1462 – Characteristics of and protection criteria for radars operating in the radiolocation service in the frequency range 420-450 MHz

Rec. ITU-R M.1463 – Characteristics of and protection criteria for radars operating in the radiodetermination service in the frequency band 1 215-1 400 MHz

Rec. ITU-R M.1464 – Characteristics of radiolocation radars, and characteristics and protection criteria for sharing studies for aeronautical radionavigation and meteorological radars in the radiodetermination service operating in the frequency band 2 700-2 900 MHz

Rec. ITU-R M.1465 – Characteristics of and protection criteria for radars operating in the radiodetermination service in the frequency band 3 100-3 700 MHz

Rec. ITU-R M.1466 – Characteristics of and protection criteria for radars operating in the radionavigation service in the frequency band 31.8-33.4 GHz

For other characteristics and protection criteria used in the study see Annex 1, § 7.

2 Fixed service

Interference analyses between devices using UWB technology and the FS require knowledge of the protection criteria of potentially affected systems. Several ITU-R Recommendations exist which provide such information: The following ITU-R Recommendations exist which provide protection criteria and system characteristics of for FS. This section also includes text from input contributions to Radiocommunication TG 1/8.

Rec. ITU-R F.699 – Reference radiation patterns for fixed wireless system antennas for use in coordination studies and interference assessment in the frequency range from 100 MHz to about 70 GHz

Rec. ITU-R F.758 – Considerations in the development of criteria for sharing between the fixed service and other services

Rec. ITU-R F.1094 – Maximum allowable error performance and availability degradations to digital radio-relay systems arising from interference from emissions and radiations from other sources

Rec. ITU-R F.1336 – Reference radiation patterns of omnidirectional sectoral and other antennas in point-to-multipoint systems for use in sharing studies in the frequency range from 1 GHz to about 70 GHz.

The maximum acceptable interference is summarized in Table 317 for the assumed FWA and P-P representative cases.

Values in Table 317 and 318 are referenced to the antenna input and take into account feeder losses, when applicable, between the antenna and the receiver input. They are based on an $I/N = -20$ dB protection criteria for the average (r.m.s.) objective and on a preliminary $I/N = +5$ dB for the peak objectives.

TABLE 317

Summary of UWB aggregate interference objectives for protection of FS

		Average power density of aggregate interference (dBm/MHz)				Peak power wide-band density of aggregate interference (dBm/50 MHz)			
		Bands 3 to 6 GHz	**Bands 7 and 8 GHz**	**Band 10.5 GHz**	**Bands 23 and 26 GHz**	**Bands 3 to 6 GHz**	**Bands 7 and 8 GHz**	**Band 10.5 GHz**	**Bands 23 and 26 GHz**
FWA CS and TS (wide-band BW = 50 MHz)	CS and outdoor TS	≤ – 129	Not available	≤ – 127	≤ – 128	≤ – 87	Not available	≤ – 85	≤ – 86
	Indoor TS	≤ – 121.5	Not available	Not available	Not available	Not available	Not available	Not available	Not available
High capacity P-P (BW = 50 MHz)		≤ – 127	≤ – 128	≤ – 127	≤ – 128	≤ – 85	≤ – 86	≤ – 85	≤ – 86

TABLE 318

UWB aggregate interference objectives for protection of FWA TS that are close to the CS

	Average power density of aggregate interference (dBm/MHz)		Peak power wide-band density of aggregate interference (dBm/50 MHz)	
	3.5 GHz band	**10.5 GHz band**	**3.5 GHz**	**10.5 GHz**
FWA TS (wideband W = 50 MHz)	≤ –104	≤ –102	≤ –74	≤ –72

F-series Recommendations on FWA systems

Recommendation ITU-R	Title
F.757	Basic system requirements and performance objectives for fixed wireless access using mobile-derived technologies offering telephony and data communication services
F.1399	Vocabulary of terms for wireless access
F.1400	Performance and availability requirements and objectives for fixed wireless access to public switched telephone network
F.1401	Considerations for the indentification of possible frequency bands for fixed wireless access and related sharing studies
F.1402	Frequency sharing criteria between a land mobile wireless access system and a fixed wireless access system using the same equipment type as the mobile wireless access system
F.1488	Frequency block arrangements for fixed wireless access systems in the range 3 400-3 800 MHz
F.1489	A methodology for assessing the level of operational compatibility between fixed wireless access and radiolocation systems when sharing the band 3.4-3.7 GHz
F.1490	Generic requirements for fixed wireless access systems

Recommendation ITU-R	Title
F.1499	Radio transmission systems for fixed broadband wireless access based on cable modem standards
F.1518	Spectrum requirement methodology for fixed wireless access and mobile wireless access networks using the same type of equipment, when coexisting in the same frequency band
F.1613	Operational and deployment restrictions for fixed wireless access systems in the fixed service in Region 3 to ensure the protection of systems in the Earth exploration-satellite service (active) and the space research service (active) in the band 5 250-5 350 MHz

3 Fixed satellite service

Characteristics of the FSS have been identified as follows:

TABLE 319

Typical downlink FSS parameters in the 4 GHz band

Parameter	Typical value						
Range of operating frequencies	3 400-4 200 MHz, 4 500-4 800 MHz						
Earth station off-axis gain towards the local horizon (dBi)(1)	Elevation angle(2)	5°	10°	20°	30°	48°	> 85°
	Off-axis gain	14.5	7.0	–0.5	–4.9	–10	0
Range of emission bandwidths	40 kHz – 72 MHz						
Noise temperature of Earth station receiver (K)	100						
Earth station deployment	All regions, in all locations (rural, semi-urban, urban)(3)						

(1) The values were derived by assuming a local horizon at 0° of elevation.

(2) 5° is considered as the minimum operational elevation angle.

(3) FSS antennas in this band may be deployed in a variety of environments. Smaller antennas (1.8-3.8 m) are commonly deployed on the roofs of buildings or on the ground in urban, semi-urban or rural locations, whereas larger antennas are typically mounted on the ground and deployed in semi-urban or rural locations.

TABLE 320

Typical FSS parameters at 7 GHz band

Downlink bands	7 250-7 750 MHz					
Earth station off-axis gain towards the local horizon (dBi)	Elevation angle	5°[(1)]	10°	20°	30°	≥ 48°
	Off-axis gain	21.6	16.8	9.6	5.2	0.1
Bandwidths (range)	19.2 kHz – 40 MHz					
Polarization	Circular					
Noise temperature of Earth station receiver system (K)	195					
Deployment	All regions, in all locations (rural, semi-urban and ocean)					

(1) 5° is considered as the minimum operational elevation angle.

TABLE 321

Typical uplink FSS parameters in the 6 GHz and 8 GHz bands

Parameter	Typical value in 6 GHz band	Typical value in 8 GHz band
Uplink band (GHz)	5 725-7 075	7 900-8 400
Free-space loss (dB)	199.5	201
Clear-air loss (dB)	0.1	0.1
Satellite antenna gain (dBi)	35	19.1-36
Noise temperature (K)	600	634

TABLE 322

Typical MSS feeder link receiving earth station parameters in the 3 and 7 GHz bands

Parameter	System 1 Feeder link earth station	System 2 Feeder link earth station	System 3 (non-GSO) Feeder link earth station
Range of operating frequencies (MHz)	3 550-3 700	3 550-3 700	6 875-7 055
Antenna reference pattern	AP 7	AP 7	Rec. ITU-R S.465
System noise temperature (T_S) (K)	71	52.5	128
IF bandwidth (B_{IF}) (MHz)	40	40	16.5

TABLE 323

Typical MSS feeder link receiving satellite parameters in the 5 and 6 GHz bands

Parameter	System 1	System 2	System 3 (non-GSO)
Coverage area of beam	Global	Global	Global(1)
Range of operating frequencies (MHz)	6 425-6 575	6 425-6 725	5 091-5 250
System noise temperature (K)	891	501	550
Bandwidth (MHz)	32.7	150	159

(1) The feeder link receive antenna covers the full field of view of the Earth, but since the satellite is at a lower altitude than that of the GSO, the coverage area is smaller than that of a GSO satellite.

TABLE 324

Typical downlink FSS parameters in the 11 and 12 GHz bands

Parameter	Typical value						
Range of operating frequencies	10.7-12.75 GHz						
Earth station off-axis gain towards the local horizon (dBi)(1)	Elevation angle(2)	5°	10°	20°	30°	48°	>85°
	Off-axis gain	14.5	7.0	–0.5	–4.9	–10	0
Range of emission bandwidths	40 kHz – 72 MHz						
Noise temperature of Earth station receiver (K)	90						
Earth station deployment	All regions, in all locations (rural, semi-urban, urban)(3)						

(1) The values were derived by assuming a local horizon at 0° of elevation.

(2) 5° is considered as the minimum operational elevation angle.

(3) FSS antennas in this band may be deployed in a variety of environments. Smaller antennas (0.45-2.4 m) are commonly deployed on the roofs of buildings or on the ground in urban, semi-urban or rural locations, whereas larger antennas are typically mounted on the ground and deployed in semi-urban or rural locations.

TABLE 325

Typical uplink FSS parameters in the 14 GHz band

Parameter	Typical value
Range of operating frequencies (GHz)	13.75-14.50
Free-space loss (dB)	207.5
Clear-air loss (dB)	0.1
Satellite antenna gain (dBi)	39
Earth station system noise temperature (K)	550

TABLE 326

Typical downlink FSS parameters in the 17.3-20.2 GHz band

Parameter	Typical value						
Range of operating frequencies	17.3-20.2 GHz						
Earth station off-axis gain towards the local horizon (dBi)(1)	Elevation angle(2)	5°	10°	20°	30°	48°	> 85°
	Off-axis gain	14.5	7.0	−0.5	−4.9	−10	0
Range of emission bandwidths	40 kHz – 500 MHz						
Noise temperature of Earth station receiver (K)	150						
Earth station deployment	All regions, in all locations (rural, semi-urban, urban)(3)						

(1) The values were derived by assuming a local horizon at 0° of elevation.

(2) 5° is considered as the minimum operational elevation angle.

(3) FSS antennas in this band may be deployed in a variety of environments. Smaller antennas (0.45-2.4 m) are commonly deployed on the roofs of buildings or on the ground in urban, semi-urban or rural locations, whereas larger antennas are typically mounted on the ground and deployed in semi-urban or rural locations.

TABLE 327

Typical downlink FSS parameters in the 20.2-21.2 GHz band

Downlink bands	20.2-21.2 GHz					
Earth station off-axis gain towards the local horizon (dBi)	Elevation angle	5°(1)	10°	20°	30°	≥ 48°
	Off-axis gain	19.3	11.7	4.2	–0.2	–5.3
Bandwidths (range)	19.2 kHz – 2.048 MHz					
Polarization	Circular					
Noise temperature of earth station receiver system (K)	360					
Deployment	All regions, in all locations (rural, semi-urban and urban)					

(1) 5° is considered as the minimum operational elevation angle.

TABLE 328

Typical uplink FSS parameters in the 30 GHz band

Parameter	Typical value	Typical value
Range of operating frequencies (GHz)	27-30	30-31
Free-space loss (dB)	213	213
Clear-air loss (dB)	0.4	0.4
Satellite antenna gain (dBi)	40-51	22-38
Earth station system noise temperature (K)	500	729-794

Recommendation ITU-R S.1432 contains the allowable degradations to the FSS systems below 15 GHz. This Recommendation states that for all sources of long-term interference that is neither from FSS systems, nor from systems having co-primary status, the allowable interference noise contribution is 1%. This Recommendation was also used as the protection criteria of MSS feeder links operating in the 6/4 GHz bands.

For ease of calculation, 1% can be assumed on the uplink and 1% can be assumed on the downlink when assessing the long-term interference.

It should be noted that this 1% value is the total of all sources of interference that are not FSS or co-primary and only a portion of the total of 1% should be apportioned to UWB. The short-term interference effects have not been considered.

4 Mobile satellite service and radionavigation satellite service

Rec. ITU-R M.1088 – Considerations for sharing with systems of other services operating in the bands allocated to the radionavigation satellite service

Rec. ITU-R M.1184 – Technical characteristics of mobile satellite systems in the frequency bands below 3 GHz for use in developing criteria for sharing between the mobile-satellite service (MSS) and other services

Rec. ITU-R M.1234 – Permissible level of interference in a digital channel of a geostationary satellite network in the aeronautical mobile-satellite (R) service (AMS(R)S) in the bands 1 545 to 1 555 MHz and 1 646.5 to 1 656.5 MHz and its associated feeder links caused by other networks of this service and the fixed-satellite service

Rec. ITU-R M.1317 – Considerations for sharing between systems of other services operating in bands allocated to the radionavigation-satellite and aeronautical radionavigation services and the Global Navigation Satellite System (GLONASS-M)

Rec. ITU-R M.1318 – Interference protection evaluation model for the radionavigation-satellite service in the 1 559-1 610 MHz band

Rec. ITU-R M.1477 – Technical and performance characteristics of current and planned radionavigation-satellite service (space-to-Earth) and aeronautical radionavigation service receivers to be considered in interference studies in the band 1 559-1 610 MHz

Rec. ITU-R M.1478 – Protection criteria for Cospas-Sarsat search and rescue instruments in the band 406-406.1 MHz

Rec. ITU-R M.1479 – Technical characteristics and performance requirements of current and planned radionavigation-satellite service (space-to-space) receivers to be considered in interference studies in the frequency bands 1 215-1 260 MHz and 1 559-1 610 MHz

Rec. ITU-R M.1731 – Protection criteria for Cospas-Sarsat local user terminals in the band 1 544-1 545 MHz

4.1 MSS systems

Search and rescue systems

For MSS search and rescue in 1 544-1 545 MHz (space-to-Earth), the Cospas/Sarsat (C/S) system provides distress alert and location information to appropriate public safety rescue authorities for maritime, aviation and land users in distress. In the LEO case, the psd that must not be exceeded at the ground station level is –203.2 dBW/Hz. For the GSO case, the limit is much more stringent (because of a lower signal-to-noise ratio) and becomes –223.5 dBW/Hz. In both cases, the psd is valid after the ground station antenna. Therefore, in the calculations, the ground antenna gain has to be taken into account.

The band 406-406.1 MHz is an uplink band (Earth-to-space) for Emergency Power Indicator Radio Beacon (EPIRB) or distress beacons that are active when somebody is in a distress situation. The signal is relayed by LEO satellites (850 km) and also by GSO satellites. On board the LEO satellite, the maximum spfd due to out of band emissions or other emissions than distress beacons must not exceed −198.6 dBw/(m^2·Hz) (Recommendation ITU-R M.1478, which takes into account an antenna gain of 3.9 dBi). This spfd is equivalent to a maximum admissible noise density of −210.1 dBW/Hz or −120.1 dBm/MHz.

According to Recommendation ITU-R M.1731 (2005), the protection criteria for Cospas-Sarsat local user terminals in the band 1 544-1 545 MHz concerning the LEO satellites is –207.5 dB(W/Hz) for one type of satellite channel and –204.7 dB(W/Hz) for another type of satellite channel. Concerning the GSO satellites, the corresponding protection criteria is –209.7 dB(W/Hz).

MSS feeder-link earth station characteristics in the 4/6 GHz band

Representative MSS feeder-link earth station parameters of GSO MSS systems in the 4 GHz are given in § 3.

MSS service link satellite receiver characteristics in the 1 626.5-1 660.5 MHz band

Table 329 contains the representative MSS service link satellite receiver parameters of GSO MSS systems in the 1.6 GHz band that should be used in the evaluation of the UWB interference into an MSS feeder-link satellite receiver.

TABLE 329

Typical MSS service link satellite parameters of GSO MSS systems

Parameter	System-1	System-1	System-2	System-2
Beam	Global	Spot	Global	Narrow spot
System noise temperature (K)	562	708	501	501
Bandwidth (MHz)	34	34	34	34
Satellite receiver antenna gain (EoC) (dBi)	16	23	17	37

MSS service link MES terminal receiver characteristics in the 1 525-1 559 MHz band

TABLE 330

Typical MES terminal receiver parameters

Parameter	Symbol	Type-1 terminal	Type-2 terminal
System noise temp (K)	T_S	355	316
IF bandwidth (kHz)	B_{IF}	200	60

The following antenna radiation patterns are used to determine t the victim Mobile Earth Station (MES) terminal antenna gain towards the UWB transmitter (Tables 331 and 332).

TABLE 331

Type-1 MES terminal antenna radiation pattern

Gain pattern (dB)	**Off-axis angle (degrees)**
17	$\theta \leq 13$
14	$13 < \theta \leq 21$
$G = 44 – 25 \log \theta$	$21 < \theta \leq 76$
$G = –3$ dBi	$\theta > 76$

TABLE 332

Type-2 MES terminal antenna radiation pattern

Gain pattern (dB)	**Off-axis angle (degrees)**
18.0	$0 < \theta \leq 30$
$41 – 25 \log(\theta)$	$30 < \theta \leq 63$
–4.0	$\theta > 63$

MSS service link satellite receiver characteristics in the 1 980-2 010 MHz band

Table 333 contains the representative MSS service link satellite receiver parameters from Report ITU-R M.2041.

TABLE 333

Typical MSS service link satellite parameters of GSO MSS systems

Parameter	**S-DMB**
Beam	Spot
System noise temperature (K)	550
Bandwidth (MHz)	4.84
Satellite receiver antenna gain (EoC) (dBi)	40

MSS service link MES terminal receiver characteristics in the 2 170-2 200 MHz band

Table 334 contains the MSS terminal receiver parameters in the 2.2 GHz band extracted from Report ITU-R M.2041.

TABLE 334

Typical MES terminal receiver parameters

Parameter	Symbol	S-DMB handheld terminal	S-DMB transportable terminal
Noise figure (dB)	T_S	9	9
Rx bandwidth (MHz)	B	4.84	4.84
Maximum antenna gain (dBi)	G_{max}	0	14

Parameters of non-GSO MSS systems in 2 GHz frequency band

Table 335 contains parameters of MES terminals of non-GSO MSS systems in the 2.2 GHz band.

TABLE 335

Maximum permissible interference level for the compatibility analysis

Parameter	Earth station	Earth station
Frequency band (MHz)	2 170-2 200 (downlink)	2 170-2 200 (downlink)
System noise temp (K)	158	158
Reference bandwidth (kHz)	30 000 (maximum)	1.4 (minimum)

Typical characteristics of GSO MSS systems in 8/7 GHz band

Tables 336 and 337 contain characteristics of GSO MSS Systems in 8/7 GHz frequency bands.

TABLE 336

Typical MSS(1) parameters at 7 GHz band (downlink), 0.4 m dish size

Downlink bands	7 250-7 375 MHz					
Antenna reference pattern	App. 8					
Earth station off-axis gain towards the local horizon (dBi)	Elevation angle	5°(2)	10°	20°	30°	≥ 48°
	Off-axis gain	21.6	16.8	9.6	5.2	0.1
Bandwidths (range)	19.2 kHz to 2 048 MHz					
Polarization	Circular					
Noise temperature of ES receiver system (K)	195					
Deployment	All Regions, in all locations (rural, urban and ocean)					

(1) The band 7 250-7 375 MHz (space-to-Earth) and 7 900-8 025 MHz (Earth-to-space) is also allocated to the MSS on a primary basis (refer to RR No. 5.461).

(2) 5° is considered as the minimum operational elevation angle.

TABLE 337

Typical MSS parameters at 7/8 GHz (uplink)

Parameter	Typical geostationary satellite system
Uplink band (MHz)	7 900-8 025
Free-space loss (dB)	201
Satellite antenna gain (dBi)	19.1-36
Noise temperature (K)	634

Typical characteristics of GSO MSS systems in 30/20 GHz band

Tables 338 and 339 contain characteristics of GSO MSS systems in 30/20 GHz frequency bands.

TABLE 338

Typical MSS parameters at 20 GHz band (downlink), 0.5 m dish size

<table>
<tr><td>Downlink bands</td><td colspan="6">20.2-21.2 GHz</td></tr>
<tr><td>Antenna reference pattern</td><td colspan="6">App. 8</td></tr>
<tr><td rowspan="2">Earth station off-axis gain towards the local horizon (dBi)</td><td>Elevation angle</td><td>5°(1)</td><td>10°</td><td>20°</td><td>30°</td><td>≥ 48°</td></tr>
<tr><td>Off-axis gain</td><td>19.3</td><td>11.7</td><td>4.2</td><td>–0.2</td><td>–5.3</td></tr>
<tr><td>Bandwidths (range)</td><td colspan="6">19.2 kHz – 2 048 MHz</td></tr>
<tr><td>Polarization</td><td colspan="6">Circular</td></tr>
<tr><td>Noise temperature of Earth station receiver system (K)</td><td colspan="6">360</td></tr>
<tr><td>Deployment</td><td colspan="6">All Regions, in all locations (rural, semi-urban, urban)</td></tr>
</table>

(1) 5° is considered as the minimum operational elevation angle.

TABLE 339

Typical MSS parameters at 30 GHz (uplink)

Parameter	Typical geostationary satellite system
Uplink band (GHz)	30-31
Free-space loss (dB)	213
Satellite antenna gain (dBi)	22-38
Noise temperature (K)	729-794

Scenarios of interference from UWB systems into GSO MSS systems

There are two scenarios of interference to be considered from UWB systems into service links of GSO MSS systems. These are as follows.

Scenario-A (1.5 GHz/2 185 GHz) service downlink

Single UWB emitter interference into a single MES terminal and aggregate interference into aeronautical MES terminals (1.5 GHz) from multiple UWB emitters.

Scenario-B (1.6 GHz) service uplink

Aggregate interference into satellite receiver from multiple UWB emitters

Maximum permissible interference levels

A criterion of 1% is assumed for the analysis. The maximum permissible interference levels into two typical GSO MES terminals in the downlink direction (Scenario-A) are given in Table 340.

TABLE 340

Maximum permissible interference levels for Scenario-A (1.5 GHz) compatibility analysis (All MES terminals including Aeronautical MES terminals)

Parameter	Symbol	Type-1 Terminal	Type-2 Terminal
System noise temp (K)	T_S	355	316
IF bandwidth (kHz)	B_{IF}	200	60
Max permissible interference level (dBm)	I_{MAX}	–140.09	–145.82

The maximum permissible interference levels into satellite receivers of GSO MSS systems operating in 1.6 GHz band in the uplink direction (Scenario-B) are given in Table 341.

TABLE 341

Maximum permissible interference levels into GSO MSS satellite receivers satellites for Scenario-B compatibility analysis (1.6 GHz)

Parameter	System-1	System-1	System-2	System-2
Beam	Global	Spot	Global	Narrow Spot
System noise temperature (K)	562	708	501	501
Bandwidth (MHz)	34	34	34	34
Max permissible interference level (dBm)	–115.79	–114.78	–116.29	–116.29

The maximum permissible interference levels into MES terminals of non-GSO MSS systems operating in 2.2 GHz band in the downlink direction are given in Table 342.

TABLE 342

Maximum permissible level for the interference analysis

Parameter	Earth station	Earth station
System noise temp (K)	158	158
Reference bandwidth (kHz)	30 000 (maximum)	1.4 (minimum)
Max permissible level in terms of the average UWB emission	–121.9 (dBm/30 MHz)	–165.2 (dBm/1.4 kHz)
Max permissible level in terms of the peak UWB emission	–99.1 (dBm/30 MHz)	Not available

4.2 Radionavigation satellite services

The radionavigation satellite services include those defined in § 1.9, 1.10, 1.40, 1.41, 1.42 and 1.43 of Article 1 of the RR.

4.2.1 GPS protection criteria

4.2.1.1 GPS noise-like signal protection criteria

The criteria for GPS protection from noise-like UWB radiated emissions were specified as an rms average interference-to-noise ratio (*I*/*N*) of −3 dB in a 1 MHz measurement bandwidth. The thermal noise density of a typical GPS receiver is −111.5 dBm as expressed in a nominal receiver bandwidth of 1 MHz. Thus, an *I*/*N* criteria of −3 dB yields a required protection threshold of −114.5 dBm/MHz.

4.2.1.2 GPS CW protection criteria

In addition to the rms average emissions limit, a spectral line emissions limit was also adopted for GPS. The spectral line limit is intended to protect GPS receivers from potential interference interactions involving un-modulated UWB waveforms. This limit is specified as 10 dB below the average limit when measured with a resolution bandwidth no less than 1 kHz. The spectral line emissions limit is applicable to the 1 164-1 240 MHz (L5 and L2C) and the 1 559-1 610 MHz (L1) frequency bands.

4.2.2 Galileo protection criteria

4.2.2.1 Galileo noise-like signal protection criteria

4.2.2.1.1 Safety of life application

The criteria for GALILEO protection from UWB radiated emissions were specified as an interference-to-noise ratio (*I*/*N*) of −20 dB.

For Galileo receivers, the admissible increment of its noise temperature caused by the UWB single or aggregated emissions and all other sources of interference is equal to 1%. The thermal noise density of an aeronautical (acquisition mode) GALILEO receiver is −111.3 dBm as expressed in a nominal receiver bandwidth of 1 MHz. Thus, an *I*/*N* criteria of −20 dB yields a required protection threshold of −131.3 dBm/MHz.

4.2.2.1.2 Non safety of life applications

The requirement for GALILEO protection from UWB radiated emissions were specified as an interference-to-noise ratio (*I*/*N*) of −6 dB. For Galileo receivers, the admissible increment of its noise temperature caused by the UWB single or aggregated emissions and all other sources of interference is equal to 25%[69]. The thermal noise density of a (acquisition mode) GALILEO receiver is −111.3 dBm as expressed in a nominal receiver bandwidth of 1 MHz. Thus, an *I*/*N* criteria of −6 dB yields a required protection threshold of −117.3 dBm/MHz.

4.2.2.1.3 Galileo protection criteria from non-noise-like interference including CW

In addition to the rms average emissions limit, a spectral line emissions limit was also adopted for GALILEO. The spectral line limit is intended to protect GALILEO receivers from potential interference interactions involving un-modulated UWB waveforms. This limit is specified as 18 dB below the average limit when measured with a resolution bandwidth no less than 1 kHz.

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[69] This value of 1% is not derived from any existing ITU-R Recommendations. However, an FSS Recommendation, ITU-R S.1432, uses 1% as the value for all other interferers. No determination has been made on what part of this 1% will be attributed to UWB.

4.2.3 GLONASS protection criteria

4.2.3.1 Non-CW protection criterion (single or aggregate interference)

For GLONASS receivers, the admissible increment of its noise temperature caused by the UWB single or aggregated emissions is equal to 1%. Since the nominal value of the GLONASS receiver noise temperature is 400°K, the effect of interference should not lead to increasing this temperature for more than 4°K. Such an increment in noise temperature is equivalent to impact of interference with a spectral power density of –162 dBW/MHz at input of the GLONASS receiver.

4.2.3.2 CW protection criterion (single or aggregate interference)

Criterion of narrowband interference is defined in that the spectral power density of interference should not exceed a specified value. Normally, the value specified is in dBW/kHz. For GLONASS spectral power density of interference should not exceed –155 dBW/kHz.

4.2.4 RNSS signal characteristics

4.2.4.1 GPS signal characteristics

The following provides a brief description of the existing and future GPS signals available for use in civil-based GPS applications.

GPS L1

The GPS L1 signal is centred on a frequency of 1 575.42 MHz with a registered bandwidth of 24 MHz (1 575.42 ± 12 MHz). As such, the L1 signal is completely contained within the 1 559-1 610 MHz frequency band allocated on a co-primary basis to the ARNS and the RNSS.

The GPS L1 signal provides a standard positioning service (SPS), a precise positioning service (PPS), and a navigation message. The L1 carrier is modulated with a coarse acquisition (C/A) code to provide the SPS and is the only signal presently guaranteed to be available to civil users of GPS. The L1 carrier is also modulated with a longer precision (P) code, in phase-quadrature with the C/A-code, to provide the PPS. The minimum signal level at the surface of the Earth is specified as −130 dBm for the GPS L1 C/A-code signal.

GPS L2

The GPS L2 signal is transmitted on a centre frequency of 1 227.60 MHz with a registered bandwidth of 24 MHz (1 227.60 ± 12 MHz). Currently, only the P-code (unencrypted) or Y-code (encrypted) is modulated onto the GPS L2 carrier. Ongoing GPS modernization efforts include the addition of a new civil signal (L2C) in phase-quadrature with the GPS L2 carrier, providing an additional channel for civil utilization of the SPS.

GPS L5

The implementation of a new GPS signal, denoted L5, is also part of the ongoing GPS modernization effort. WRC-2000 provided a co-primary allocation to RNSS in the 1 164-1 215 MHz segment of the 960-1 215 MHz ARNS frequency band. GPS L5 will be transmitted on 1 176.45 MHz with a registered bandwidth of 24 MHz (1 176.45 ± 12 MHz). The new GPS L5 signal has been specifically designed to support aviation applications. However, based on the observed escalation of communications applications utilizing GPS L1, it can be anticipated that similar applications will also develop utilizing the L5 signal, once it becomes available.

4.2.4.2 Galileo signal characteristics

The following provides a brief description of the future Galileo signals available for use in Galileo applications.

Galileo L1

The Galileo L1 signal is centred on a frequency of 1 575.42 MHz. The Galileo L1 signal provides an open service (OS), a public regulated service (PRS), which both include a navigation message. Moreover an integrity message is included in the OS signal for safety application service (SAS). The L1 carrier is modulated with a BOC (1,1) code to provide the OS. The L1 carrier is also modulated with a BOC cosine (15,2.5) code, to provide the PRS. The minimum signal level at the surface of the Earth is specified as −127 dBm.

Galileo E6

The Galileo E6 signal is transmitted on a centre frequency of 1 278.75 MHz with a registered bandwidth of 40 MHz.

The Galileo E6 signal provides a commercial service (CS), a public regulated service (PRS), which both include a navigation message. The E6 carrier is modulated with a BPSK(5) code to provide the CS. The E6 carrier is also modulated with a BOC (10,5) code, to provide the PRS. The minimum signal level at the surface of the Earth is specified as −125 dBmGalileo E5.

The Galileo E5a signal is centred on a frequency of 1 176.45 MHz with a registered bandwidth of 24 MHz The Galileo E5a signal provides an open service (OS), a safety application service (SAS), which both includes a navigation message. The E5a carrier is modulated with a BPSK(10) code to provide both OS and SAS.

The Galileo E5b signal is centred on a frequency of 1 207.14 MHz with a registered bandwidth of 24 MHz. The Galileo E5b signal provides a safety application service (SAS), which includes a navigation message and an integrity message. The E5b carrier is modulated with a BPSK(10) code to provide SAS.

The minimum signal level at the surface of the Earth is specified as −125 dBm.

4.2.4.3 GLONASS signal characteristics

The GLONASS system operates with four types of BPSK signals: 16M4G7X, 4M01G7X, 1M02G7X, 10M2G7X. Characteristics of the signals are given in Table 343.

TABLE 343

Characteristics of signals

Signal	Frequency (MHz)	Transmitted bandwidth (MHz)	Code rate (Mchip/s)	Symbol rate (Symbol/s)	Type	
16M4G7X	1 201.5	16.4	8.191	200	BPSK(16)	data
4M10G7X		4.1	2.047	200	BPSK(8)	data
10M2G7X	1 246.00	10.2	5.11	50	BPSK(10)	data
1M02G7X		1.02	0.511	50	BPSK(1)	data
10M2G7X	1 602.00	10.2	5.11	50	BPSK(10)	data
1M02G7X		1.02	0.511	50	BPSK(1)	data

4.2.5 RNSS systems parameters

4.2.5.1 GPS parameters

Table 344 presents the parameters included in the link budget analysis performed to determine the protection necessary to the GPS component associated with the E-911 operational scenario.

TABLE 344

Link budget analysis for GPS-enabled E-911 indoor operation

Parameter	Value
GPS protection criteria relative to UWB transmissions ($I/N = -3$ dB)	−114.5 dBm/MHz
GPS antenna gain in direction of UWB source	0 dBi
Propagation path loss @ 2 m	42.4 dB
UWB uncertainty factor	−3.0 dB
E-911 protection criteria	−75.1 dBm/MHz

4.2.5.1.1 GPS antenna gain in direction of UWB source

The antenna subsystem utilized in this type of GPS application is often implemented as a silicone patch. The antenna typically produces an upper hemispherical pattern, with the gain maximized in the direction of the satellites in space. Table 345 defines the model used to determine the GPS antenna gain in the direction of an assumed UWB source. Emissions from UWB transmitters were assumed incident in the side lobe (−10º to 10º) region of the GPS receive antenna in this scenario.

TABLE 345

GPS receive antenna model

Off-axis angle (degrees relative to horizon)	GPS antenna gain (dBi)
10 to 90	3
−10 to 10	0
−90 to −10	−4.5

4.2.5.2 Galileo

4.2.5.2.1 Noise-like effects (by single UWB interference)

Protection levels have been defined in 1 MHz band to take into account the noise like effect.

4.2.5.2.2 Non noise-like effects including CWA (by aggregate UWB interference)

Protection levels have been defined in a 1 kHz bandwidth to take into account non noise like effects (including CW).

4.2.5.2.3 Galileo antenna gain in direction of UWB source

The antenna subsystem utilized in almost all mobile applications is often implemented as a silicone patch. The antenna typically produces an upper hemispherical pattern, with the gain maximized in the direction of the satellites in space. Table 346 defines the model used to determine the Galileo antenna gain in the direction of an assumed UWB source. Emissions from UWB transmitters were assumed incident in the side lobe (−10º to 10º) region of the Galileo receive antenna in this scenario.

TABLE 346

Galileo receive antenna model

Off-axis angle (degrees relative to horizon)	Galileo antenna gain (dBi)
10 to 90	3
−10 to 10	0
−90 to −10	−4.5

4.2.5.3 GLONASS

4.2.5.3.1 GLONASS parameters

Protection levels have been defined in 1 MHz band to take into account the wide-band interference and in 1 kHz band to take into account the narrow-band interference.

There are two main types of navigation receivers:

– an airborne GLONASS navigation receiver designed for aircraft navigation (an airborne receiver);

– a low-cost commercial general-purpose GLONASS receiver.

The protection of the GLONASS safety-of-life and non-safety-of-life applications from wide-band interference and narrow-band interference of a single UWB device was obtained, assuming a 1 m and 30 m protection distance.

The protection of the GLONASS safety-of-life application from wide-band interference and narrow-band interference of a multiple UWB device was obtained, assuming a 30 m protection distance.

Table 347 presents the parameters included in the link budget analysis performed to determine the protection necessary to the GLONASS receivers.

TABLE 347

GLONASS receiver parameter

Parameter	Airborne GLONASS receiver	Commercial GLONASS receiver
Navigation receiver antenna gain in direction of UWB source (dBi)	5	3
Interference-to-noise ratio (dB)	–20	–6
Margin for system safety (dB)	–5.6	0
GLONASS receiver protection criteria from wide-band interference (dBm/MHz)	–132	–118
GLONASS receivers protection criteria from narrow-band interference (dBm/MHz)	–147	–133

4.2.5.3.2 GLONASS receiver antenna gain

Estimation of airborne receiver protection criteria assumed its antenna gain of 5 dB.

Antenna gain of 3 dB was assumed for a commercial receiver in the direction to an interfering source.

5 Broadcasting

5.1 Characteristics

The following ITU-R Recommendations provide system characteristics of broadcasting services:

Rec. ITU-R BS.450 – Transmission standards for FM sound broadcasting at VHF

Rec. ITU-R BS.1114 – Systems for terrestrial digital sound broadcasting to vehicular, portable and fixed receivers in the frequency range 30-3 000 MHz

Rec. ITU-R BT.419 – Directivity and polarization discrimination of antennas in the reception of television broadcasting

Rec. ITU-R BT.470 – Conventional analogue television systems

Rec. ITU-R BT.1306 – Error-correction, data framing, modulation and emission methods for digital terrestrial television broadcasting

Rec. ITU-R BT.1368 – Planning criteria for digital terrestrial television services in the UHF/VHF bands

5.2 Interference criteria for broadcasting

Impact analyses between UWB devices and broadcasting require knowledge of the protection requirement level of potentially affected systems.

The total interference to systems operating in the broadcasting service frequency bands, from devices with no corresponding frequency allocations in the RR, should not exceed 1%[70] (which corresponds to I/N = –20 dB) of the total system noise at all times.

Table 348 lists the protection criteria on interference from devices using UWB technology to broadcasting services.

TABLE 348

Criteria on interference from devices using UWB technology to broadcasting services

Service/application	Frequency bands	Service protection requirement
Broadcasting LF	148.5-283.5 kHz	I/N = –20 dB
Broadcasting MF	525-1 705 kHz	I/N = –20 dB
Broadcasting HF	2 300-2 498 kHz 3 200-3 400 kHz 3 900-4 000 kHz 4 750-4 995 kHz 5 005-5 060 kHz 5 900-6 200 kHz 7 100-7 350 kHz 9 400-9 900 kHz 11 600-12 100 kHz 13 570-13 870 kHz 15 100-15 800 kHz 17 480-17 900 kHz 18 900-19 020 kHz 21 450-21 850 kHz 25 670-26 100 kHz	I/N = –20 dB
Broadcasting Band I	47-72 MHz	I/N = –20 dB
Broadcasting Band I	76-88 MHz	I/N = –20 dB
Broadcasting Band II	88-108 MHz	I/N = –20 dB
Broadcasting Band III	174-230 MHz	I/N = –20 dB
Broadcasting Band IV/V	470-960 MHz	I/N = –20 dB
Broadcasting Band L	1452-1492 MHz	I/N = –20 dB

Additional national allocations also apply. Refer to RR Article 5.

In the impact studies on UWB/DVB-T and UWB/T-DAB presented in this report, a protection criterion of I/N = 0 dB (C/N = C/I) was used. This was motivated by the fact that UWB is a technology and not a radiocommunication service and UWB applications are intended for short-range communication.

However, it should be noted that a concession has been made in the presence of single UWB interference by using the protection criterion I/N = 0 dB. The use of this criterion may not adequately protect all the existing broadcasting services. Consequently, in case of interference from devices using UWB technology to a broadcasting service, to ensure an adequate protection corresponding maximum interference level has to be developed by using the protection criterion given in Table 348.

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[70] See also § 2.0 in Attachment 5.

5.3 Broadcasting-satellite service

Typical BSS (television) parameters in the 620-790 MHz band

Parameter	Typical value						
Range of operating frequencies	620-790 MHz						
Earth station off-axis gain towards the local horizon (dBi)(1)	Elevation angle(2)	5°	10°	20°	30°	48°	> 85°
	Off-axis gain	19.4	19.0	11.5	7.1	2.0	–4.2
Earth station off-axis gain towards the local horizon (dBi)(3)	2.0 dBi for all elevation angles						
Range of emission bandwidths	8 to 170 MHz						
Noise temperature of Earth station receiver	100 K						
Earth station deployment	All Regions, in all locations (rural, semi-urban, urban)(4)						

(1) The antenna represented in this row has a directional beam. The values were derived by assuming a local horizon at 0° of elevation.

(2) 5° is considered as the minimum operational elevation angle.

(3) The antenna represented in this row is omnidirectional. The values were derived by assuming a local horizon at 0° of elevation.

(4) Mobile (vehicular) reception, portable and fixed reception.

Typical BSS (sound) parameters

Parameter	Typical value
Range of operating frequencies(1)	1 452-1 492 MHz, 2 310-2 360 MHz, 2 535-2 655 MHz
Earth station off-axis gain towards the local horizon (dBi)(2)	5 dBi for all elevation angles
Range of emission bandwidths(1)	40 kHz – 25 MHz
Noise temperature of Earth station receiver	100 K
Earth station deployment	All Regions, in all locations (rural, semi-urban, urban)(3)

(1) See the RR for details in the frequency allocation.

(2) The values were derived by assuming an omnidirectional antenna.

(3) BSS antennas in this band may be deployed in a variety of applications (mobile (vehicular) reception, portable and fixed reception). See the relevant footnotes in the RR for specific usage in each band.

Typical BSS (television) parameters in the 2 520-2 670 MHz band*

Parameter	Typical value						
Range of operating frequencies	2 520-2 670 MHz						
Earth station off-axis gain towards the local horizon (dBi)(1)	Elevation angle(2)	5°	10°	20°	30°	48°	> 85°
	Off-axis gain	22	21	19	10	3	0
Range of emission bandwidths	22 MHz – 27 MHz						
Noise temperature of Earth station receiver	100 K						
Earth station deployment	All Regions, in all locations (rural, semi-urban, urban)(3)						

* BSS Community reception, in accordance with RR No. 5.416.

(1) The values were derived by assuming a local horizon at 0° of elevation.

(2) 5° is considered as the minimum operational elevation angle.

(1) BSS antennas in this band may be deployed in a variety of applications, including at fixed locations and in mobile applications.

Typical BSS (television) parameters in the 12 GHz band

Parameter	Typical value					
Range of operating frequencies	11.7-12.5 GHz (R1),12.2-12.7 GHz (R2),11.7-12.2 GHz and 12.5-12.75 GHz (R3)					
Earth station off-axis gain towards the local horizon (dBi)(1) (D = 60 cm)	Elevation angle(2)	5°	10°	20°	30-70°	> 70°
	Off-axis gain	11.5	4.0	–3.5	–5.0	0.0
Range of emission bandwidths	24 MHz (R2) or 27 MHz (R1, R3)					
Noise temperature of Earth station receiver	110 K					
Earth station deployment(3)	All Regions, in all locations (rural, semi-urban, urban)					

(1) The values were derived by assuming a local horizon elevation angle of 0° and an antenna pattern as described in Recommendation ITU-R BO.1213.

(2) 5° is considered as the minimum operational elevation angle.

(3) BSS antennas in these bands can be deployed in urban, sub-urban, rural and remote environments. BSS individual reception antennas are commonly deployed near the ground, on roofs and chimneys of individual dwellings and on balconies of multiple dwellings (apartments). Community reception antennas are typically deployed on the ground or roofs of multiple dwelling units (apartments).

Typical BSS (television) parameters in the 17/21 GHz band

Parameter	Typical value						
Range of operating frequencies	17.3-17.8 GHz (R2), 21.4-22 GHz (R1, R3)						
Earth station off-axis gain towards the local horizon (dBi)[1] (D = 45 cm)	Elevation angle[2]	5°	10°	20°	30°	40°	> 70°
	Off-axis gain	11.5	4.0	–3.5	–5.0	–5.0	0.0
Range of emission bandwidths	27-600 MHz						
Noise temperature of Earth station receiver	160 K						
Earth station deployment	In all locations within the relevant Regions (rural, semi-urban, urban)						

(1) The values were derived by assuming a local horizon elevation angle of 0° and an antenna pattern as described in Recommendation ITU-R BO.1213.

(2) 5° is considered as the minimum operational elevation angle.

With regard to protection criteria, an appropriate interference protection criteria for the protection of the BSS in all cases under consideration is an aggregate interference value of $\Delta T/T$ of 1%, applicable to all interference sources not having primary status in the band. This criterion is identical to the value of 1% contained in Recommendation ITU-R S.1432, which is applicable to the feeder links associated with the BSS downlink.

6 Earth exploration-satellite service and radioastronomy

6.1 Earth exploration-satellite service

Rec. ITU-R SA. 1026 – Interference criteria for space-to-earth data transmission systems operating in the Earth exploration-satellite and meteorological-satellite satellites in low earth orbit.

Rec. ITU-R SA.1028 – Performance criteria for satellite passive remote sensing

Rec. ITU-R SA.1029 – Interference criteria for satellite passive remote sensing

Radiocommunication WP 7C has provided in liaison statements information regarding apportionment of interference criteria to apply to interference from devices using UWB technology that would be necessary to protect the EESS (passive).

In purely passive bands protected by footnote RR No. 5.340, the interference criteria should be based on an apportionment of 1% to 5% of the total interference criteria given in Recommendation ITU-R SA.1029.

For bands shared between passive and active services, the interference criteria to be used represents 5% of the total interference criteria given in Recommendation ITU-R SA.1029.

For the EESS (active) spaceborne radar altimeter, which provides measurements mainly over oceans, allocated in 5 250 MHz to 5 460 MHz (210 MHz bandwidth), the interference threshold is –88 dBm in the EESS reference bandwidth of 210 MHz or –111 dBm per MHz.

For the EESS (active) synthetic aperture radar (SAR) in 5 250 MHz to 5 460 MHz (210 MHz bandwidth), the SAR interference threshold is –115.3 dBm per MHz.

6.2 Space research (including deep space) and space operation services

There are a number of space research (including deep space) and space operation service systems operating or planned for operation in bands that span the spectrum of frequencies from less than 1 GHz to frequencies above about 40 GHz.

Frequency Band	Service	Protection criteria	ITU-R Recommendation
2 200-2 290 MHz	SRS	–216 dB(W/Hz)	SA.609
2 290-2 300 MHz	SRS (deep space)	–222 dB(W/Hz)	SA.1157
5 650-5 725 MHz	SRS	–216 dB(W/Hz)	SA.609
7 190-7 235 MHz	SRS	–177 dB(W/kHz)	SA.609
8 400-8 450 MHz	SRS (deep space)	–220 dB(W/Hz)	SA.1157
8 450-8 500 MHz	SRS	–216 dB(W/Hz)	SA.609
12.75-13.25 GHz	SRS (deep space)	–220 dB(W/Hz)	SA.1157
13.75-14.3 GHz	SRS	–176 dB(W/kHz)	SA.1155
14.5-15.35 GHz	SRS	–179 dB(W/kHz)	SA.1155
22.55-23.55 GHz	Inter-satellite service allocation used by the SRS and other services	–181 dB(W/kHz)	SA.1155
25.5-27.0 GHz	SRS	–156 dB(W/MHz)	SA.609
31.8-32.3 GHz	SRS (deep space)	–216 dB(W/Hz)	SA.1157
37.0-38.0 GHz	SRS	–217 dB(W/Hz)	SA.1396

Radiocommunication WP 7B has studied the apportionment of degradation for space research and space operation service systems for the following categories of emissions:

– emissions from other SRS and SOS networks sharing the same band;

– emissions from networks of other services with equal status sharing the same band;

– emissions from all other sources.

It is noted that interference from the emissions of devices using UWB technology is in the third category. It is currently considered that the aggregate interference from the third category of sources of interference should constitute on the order of 1% of the total degradation. Radiocommunication SG 7 is currently developing a Recommendation on this issue.

Interference analyses between devices using UWB technology and the SRS require consideration of the protection levels of allocated services and the fractional amount that may be attributed to interference from sources such as UWB. The protection level criteria are addressed in the following ITU-R Recommendations:

Space research service

Rec. ITU-R SA.609 – Protection criteria for telecommunication links for manned and unmanned near-Earth research satellites

Rec. ITU-R SA.1155 – Protection criteria related to the operation of data relay satellite systems

Rec. ITU-R SA.1396 – Protection criteria for the space research service in the 37-38 GHz and 40 40.5 GHz bands

Rec. ITU-R SA.1414 – Characteristics of data relay satellite systems

Space research service (deep space)

Rec. ITU-R SA.1016 – Sharing considerations relating to deep-space research

Rec. ITU-R SA.1157 – Protection criteria for deep-space research

Space operation service

Rec. ITU-R SA.363 – Space operation systems. Frequencies, bandwidths and protection criteria

6.3 Radioastronomy

Rec. ITU-R RA.769 – Protection criteria used for radio astronomical measurements

Rec. ITU-R RA.1513 – Levels of data loss to radio astronomy observations and percentage-of-time criteria resulting from degradation by interference for frequency bands allocated to the radio astronomy on a primary basis.

The threshold levels of interference detrimental to radio astronomy observations, representing an increase in the measurement error by 10%, are given in Recommendation ITU-R RA.769. Single-dish spectral line observations are usually made using a channel bandwidth (one of the spectrometer channels) of 20 kHz. Single-dish continuum observations are made using the entire allocated radio astronomy bandwidth. For VLBI observations, signals from widely spaced antennas are recorded and correlated after the observations.

The threshold pfd values for detrimental interference are given in Table 349 for single-dish observations, which represents the worst case.

TABLE 349

Threshold pfd levels for detrimental interference for radio astronomical observations

Frequency band (MHz)	Detrimental spfd (Rec. ITU-R RA.769) (dB(W/(m^{-2} Hz^{-1})))
608-614(1)	–253(2)
1 330.0-1 400.0(1)	–239(3), –255(2)
1 400.0-1 427.0(4)	–239[1], –255(2)
1 610.6-1 613.8(1)	–238(3)
1 660.0-1 670.0(1)	–237(3), –251(2)
1 718.8-1 722.2(1)	–237(3)
2 655.0-2 690.0(1)	–247(2)
2 690.0-2 700.0(4)	–247(2)
3 260.0-3 267.0(1)	–230(3)
3 332.0-3 339.0(1)	–230(3)
3 345.8-3 352.5(1)	–230(3)
4 800.0-4 990.0(1)	–230(3), –241(2)
4 990.0-5 000.0(1)	–241[2]
6 650.0-6 675.2(1)	–230(3)
22 010-22 210(1)	–216(3)

TABLE 349 (*end*)

Frequency band (MHz)	**Detrimental spfd (Rec. ITU-R RA.769) (dB(W/(m^{-2} Hz^{-1})))**
22 210-22 500(1)	–216(3)
22 810-22 860(1)	–216[1](3)
23 070-23 120[3](1)	–215(3)
23 600-24 000(4)	–215(3), –233(2)
76 000-77 500 (1)	–205(3), –221(2)
77 500-78 000(1)	–205(3), –218(2)
78 000-79 000(1)	–205(3), –220(2)
79 000-81 000(1)	–205(3), –221(2)
81 000-84 000(1)	–204(3), –222(2)

(1) RR No. 5.149 applies.

(2) Continuum observations (broadband).

(3) Spectral line observations (narrow-band).

(4) RR No. 5.3.