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Planning parameters for terrestrial digital sound broadcasting systems in VHF bands

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REPORT ITU-R BS.2214-3

Planning parameters for terrestrial digital sound broadcasting systems in VHF bands

(Question ITU-R 56/6)

(2011-2015-2016-2019)

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1 Introduction

This Report provides planning parameters for the following digital terrestrial broadcasting systems: system C (also known as HD Radio), system G (also known as DRM+), system A (also known as DAB) and RAVIS system in VHF Bands. DRM+ is designed for use in VHF Bands I, II and III. RAVIS is designed for use in VHF Bands I and II. DAB is designed for use in VHF Band III. HD Radio system is designed for use in VHF Band II.

The Report defines a framework for calculating all relevant network planning parameters that are very similar for the systems.

The system characteristics of digital System A, System C and System G are included in Recommendation ITU-R BS.1114 and the description of RAVIS is contained in Report ITU-R BT.2049.

Framework for evaluation of planning parameters is given in §§ 2 to 3.

Section 4 gives planning parameter for DRM+.

Section 5 gives planning parameter for RAVIS.

Section 6 gives planning parameters for HD Radio.

Section 7 gives planning parameters for DAB.

Normative and technical references are given in Annexes 1 and 2 respectively.

To calculate the relevant planning parameters minimum median field strength and protection ratios, firstly receiver and transmitter characteristics, system parameters as well as transmission aspects as common basis for concrete digital broadcasting transmission network planning are determined. All parameters are either derived or the reference to the source of origin is given. Various typical reception scenarios are taken into account to match as much as possible planning and prediction scenarios.

2 Reception modes

A total of seven reception modes can be distinguished and include fixed, portable and mobile, where portable and mobile receptions are further sub-divided.

Reception availability as addressed by ITU in [15] and [18] considers certain percentile ranges over time and locations but does not attempt to address the practical modes or usage scenario with specific percentile or minimum requirements. Therefore, the analysis derives availability requirements from other related broadcasting areas and broadcasting technologies, and best practices, as broadly recognized.

2.1 Fixed reception

Fixed reception (FX) is defined as reception where a receiving antenna mounted at roof level is used. It is assumed that near-optimal reception conditions (within a relatively small volume on the roof) are found when the antenna is installed. In calculating the field-strength levels for fixed antenna reception, a receiving antenna height of 10 m above ground level is considered to be representative for the broadcasting service [1].

A location probability of 70% is assumed to obtain a good reception situation.

Fixed roof top reception is generally not considered a reception scenario for the planning of DAB networks. DAB networks in most cases are planned for portable or mobile reception and within the service area of the portable or mobile service fixed roof top reception is guaranteed. Therefore, in this Report, fixed roof top reception is not considered for the DAB system.

2.2 Portable reception

In general, portable reception means a reception where a portable receiver with an attached or built-in antenna is used outdoors or indoors at no less than 1.5 m above ground level.

A location probability of 95% is assumed to obtain a good reception situation.

Two receiving locations will be distinguished:

– **Indoor reception** with a reception place in a building.

– **Outdoor reception** with a reception place outside a building.

Within these receiving locations two opposed receiving conditions will be distinguished additionally due to the great variability of portable reception situations with different receiver-/antenna-types and also different reception conditions:

– **Portable reception**: This situation models the reception situation with good reception conditions for both situations indoor and outdoor, resp., and a receiver with an omnidirectional VHF antenna pattern as given in GE06 [1].

– **Portable handheld reception**: This situation models the reception situation with bad reception conditions and a receiver with an external antenna (for example telescopic antennas or the cable of wired headsets) as given in EBU-3317 [2].

2.2.1 Portable indoor reception

Portable indoor (PI) reception is defined by a portable receiver with stationary power supply and a built-in (folded)-antenna or with a plug for an external antenna. The receiver is used indoors at no less than 1.5 m above floor level in rooms on the ground floor and with a window in an external wall. It is assumed that optimal receiving conditions will be found by moving the antenna up to 0.5 m in any direction and the portable receiver is not moved during reception and large objects near the receiver are also not moved [1]. A suburban area is assumed.

2.2.2 Portable outdoor reception

Portable outdoor (PO) reception is defined as reception by a portable receiver with battery supply and an attached or built-in antenna which is used outdoors at no less than 1.5 m above ground level [1]. A suburban area is assumed in this case.

2.2.3 Portable indoor/outdoor handheld reception (PI-H, PO-H)

Portable reception is defined as reception by a portable handheld receiver with battery supply and an external antenna as given in EBU-3317 [2] for both reception situations indoor and outdoor, respectively. An urban area is assumed in this case.

2.3 Mobile reception

Mobile reception (MO) is defined as reception by a receiver in motion, at speeds ranging from approximately two km/h and up to 300 km/h. Speeds in the range of 50 km/h to 60 km/h are of particular interest, as they may represent urban vehicular motion. For this reception category, the antenna is considered matched and situated 1.5 m or more above ground level [1]. While not specifically addressed in [18] but yet allowed along with providing valid guidance for calculations, a reception location probability of 99% is assumed, in order to guarantee ‘good’ reception. Such choice is further supported in [1] and [2].

2.3.1 Mobile handheld reception (MO-H)

This situation corresponds to the reception scenario inside a moving vehicle at no less than 1.5 m above ground level at high speed with a handheld receiver without connection to the external antenna of the vehicle but with its own external antenna (for example, telescopic antennas or the cable of wired headsets). This reception scenario is used in DAB system, mainly because this system is developed for integrated outdoor antennas. The main difference between MO and MO-H reception modes is that in MO mode the receiver can be mounted inside the car and connected to the car antenna, while in MO-H scenario the handheld device is located inside the car but not connected to the car antenna.

In order to cover all of the indicated combinations by using as few cases as possible while providing realistic reception scenarios, only seven reception modes are analysed, as indicated in Table 1.

TABLE 1

Definition of reception modes for performance analysis

Reception mode	**FX**	**MO**	**PO**	**PI**	**PO-H**	**PI-H**	**MO-H**
Antenna type	Fixed	Mounted	External	External	Integrated (see Note 1)	Integrated (see Note 1)	Integrated
Location	Outdoor	Outdoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
Speed [km/h]	0 (static)	2-150	2 (walking)	0 (quasi static)	2 (walking)	0 (quasi static)	2-150
Reception percentage	70%	99%	95%	95%	95%	95%	99%

Note 1: For the DAB system in handheld reception (PO-H, PI-H) it is assumed that a built-in (folded or telescopic) antenna is used.

3 Correction factors for field-strength predictions

Recommendation ITU-R P.1546 [18] forms the basis of a field-strength prediction method applicable for the broadcasting services amongst other services. Predictions can be made from 30 MHz up to 3 000 MHz within a path distance of 1 to 1 000 km, percentage of time of 1 to 50%, and for various transmitting antenna heights. The method draws a distinction between paths over land, cold seas and warm seas, makes due allowance for location variability for land area-service predictions and takes account of local clutter surrounding the receiving location. It also provides procedures for handling negative effective transmitting antenna heights and mixed-path propagation (i.e. with combinations of land and sea).

The wanted field-strength level values predicted [18] refer always to the median value at a receiving location with a receiving antenna in 10 m height above ground level. This antenna height is a generic value, used as stated only in rural or suburban areas, with constructions or vegetation below 10 m height. For the DAB system the wanted field-strength level values are provided at a receiving location with a receiving antenna at 1.5 m height above ground level. Otherwise the wanted field-strength values are predicted at the average construction or vegetation height at the receiving location. The true receiving antenna height influences the height loss correction factor (see § 3.4).

To take into account different receiving modes and circumstances into network planning correction factors have to be included to carry the minimum receiver input power level or the minimum field-strength level over to the median minimum field-strength level for predictions [18].

3.1 Reference frequencies

The planning parameters and correction factors in this Report are calculated for the reference frequencies given in Table 2.

TABLE 2

Reference frequencies for calculations

VHF band (frequency range)	I (47-68 MHz)	II (87.5-108 MHz)	III (174-230 MHz)
Reference frequency (MHz)	65	100	200

3.2 Antenna gain

The antenna gain G_D (dBd) references to a half-wave dipole.

3.2.1 Antenna gain for fixed reception

In Recommendation ITU-R BS.599 [25] and GE06 [1], the antenna pattern for fixed reception are given for both VHF Band II (4 dB) and VHF Band III (7 dB). In ETSI-DVB [3] the antenna pattern for fixed reception is given for VHF Band I (3 dB).

Taking into account the current use of roof-top antenna systems with omnidirectional dipole antennas or ground plane antennas for future planning it is recommended that an omnidirectional antenna pattern with a gain of 0 dBd is used (see Table 3).

TABLE 3

Antenna gain G_D for fixed reception

Frequency (MHz)	**65**	**100**	**200**
Antenna gain G_D (dBd)	0	0	0

3.2.2 Antenna gain for portable reception

GE06 [1] assumes an omnidirectional VHF antenna pattern with an antenna gain of −2.2 dBd for standard portable receiver planning. From this reference, the antenna gains G_D for portable reception are assumed to −2.2 dBd as given in Table 4.

TABLE 4

Antenna gain G_D for portable reception (1)

Frequency (MHz)	**65**	**100**	**200**
Antenna gain G_D (dBd)	−2.2	−2.2	−2.2

(1) The antenna gain values for DAB portable reception (PI, PO) is assumed –8 dBd – –10 dBd (further information can be found in EBU Report Tech 3391 [45]).

3.2.3 Antenna gain for portable and mobile handheld reception

Antenna gains G_D for portable and mobile handheld reception in VHF Band III (200 MHz) are given by EBU-3317 [2]:

– Receiver integrated antenna: $G_D = -17$ dBd
– External antenna (telescopic or wired headsets): $G_D = -13$ dBd
– Adapted antenna (for mobile reception): $G_D = -2.2$ dBd

The antenna gain for portable and mobile handheld reception in VHF Band I and VHF Band II can be calculated by the computation given in Annex 2 [4]. From it the antenna gains G_D (dB) for portable handheld reception modes with an external antenna are given in Table 5.

TABLE 5

Antenna gains G_D for portable and mobile handheld reception

Frequency (MHz)	**65**	**100**	**200**
Gain variation ΔG referenced to 200 MHz (dB)	−9.76	−6.02	0.00
Antenna gain G_D for receiver integrated antenna (dBd)	−26.76	−23.02	−17.00
Antenna gain G_D for portable handheld reception (external antenna, telescopic or wired headsets) (dBd)	−22.76	−19.02	−13.00

3.2.4 Antenna gain for mobile reception

For mobile reception an omnidirectional VHF antenna pattern with an antenna gain G_D of −2.2 dBd [1] is assumed, see Table 6.

TABLE 6

Antenna gains G_D for mobile reception (1)

Frequency (MHz)	**65**	**100**	**200**
Antenna gain G_D for adapted antenna (mobile reception) (dBd)	−2.2	−2.2	−2.2

(1) The antenna gain values for DAB mobile reception (MO) is assumed -5 dBd – -10 dBd (further information can be found in EBU Report Tech 3391 [45]).

3.3 Feeder loss

The feeder loss L_f expresses the signal attenuation from the receiving antenna to the receiver's RF input. The feeder loss L_f for fixed reception at 200 MHz is given in GE06 [1] with 2 dB for 10 m cable length. The frequency dependent cable attenuation per unit length L'_f is assumed to be equal to:

$$L'_f\,(\text{dB/m}) = \frac{2}{10}\sqrt{\frac{f\,(\text{MHz})}{200}} \qquad (1)$$

with f the frequency (MHz). The feeder loss values per unit length L'_f are given in Table 7.

TABLE 7

Feeder loss L'_f per unit length

Frequency (MHz)	**65**	**100**	**200**
Feeder loss L'_f (dB/m)	0.11	0.14	0.2

The feeder loss L_f is given by:

$$L_f \text{ (dB)} = L'_f \, l = \frac{2}{10}\sqrt{\frac{f\,(\text{MHz})}{200}}\, l \qquad \text{(m)} \tag{2}$$

with l the length of the feeder cable (m).

The cable length l for the different reception modes are given in Table 8, and the feeder losses L_f for different frequencies and reception modes are given in Table 9.

TABLE 8

Cable length *l* for reception modes

Reception mode	**Fixed reception (FX)**	**Portable and mobile handheld reception (PO, PI, PO-H, PI-H, MO-H)**	**Mobile reception (MO)**
Cable length l (m)	10	0	2

TABLE 9

Feeder loss L_f for different reception modes(1)

Frequency (MHz)		**65**	**100**	**200**
Feeder loss L_f	for fixed reception (FX) (dB)	1.1	1.4	2.0
	for portable and mobile handheld reception (PO, PI, PO-H, PI-H, MO-H) (dB)	0.0	0.0	0.0
	for mobile reception (MO) (dB)	0.22	0.28	0.4

(1) For the DAB system a feeder loss of 0 dB has been assumed for all reception modes.

3.4 Height loss correction factor

For portable reception a receiving antenna height of 1.5 m above ground level (outdoor and mobile) or above floor level (indoor) is assumed. The propagation prediction method usually provides field-strength values at 10 m. To correct the predicted value from 10 m to 1.5 m above ground level a height loss factor L_h (dB) has to be applied.

The height loss correction factor L_h for an antenna height of 1.5 m is given in GE06 [1] as follows:

L_h = 12 dB at 200 MHz

L_h = 16 dB at 500 MHz

L_h = 18 dB at 800 MHz

Therefore, the height loss correction factor L_h (dB) at 100 MHz is assumed to 10 dB, and at 65 MHz to 8 dB, for portable and mobile reception modes The height loss correction factor L_h for handheld reception with external antenna is given in EBU-3317 [2] for VHF Band III as 19 dB in urban areas and is assumed to 17 dB at 100 MHz and to 15 dB at 65 MHz.

The height loss correction factor L_h for different reception modes is given in Table 10.

TABLE 10

Height loss correction factor L_h for different reception modes(1)

Frequency (MHz)		**65**	**100**	**200**
Height loss correction factor L_h	for fixed reception (FX) (dB)	0	0	0
	for portable and mobile reception (PO, PI, MO) (dB)	8	10	12
	for portable handheld reception (PO-H, PI-H) (dB)	15	17	19

(1) For the DAB system the height loss is provided for different environment classes and typical clutter heights, see § 7.3.1.

3.5 Building entry loss

Traditionally the loss associated with the RF signal entering a building or vehicle was referred to as the 'penetration' loss [44]. In the latest ITU Recommendation on this subject [42], the term 'entry' has replaced 'penetration'.

The ratio between the mean field strength inside a building at a given height above ground level and the mean field strength outside the same building at the same height above ground level expressed in (dB) is the mean building entry loss (BEL).

Historically, the mean building entry loss L_b in VHF Band III was given in GE06 [1] and EBU-3317 [2] as 9 dB, which was proposed to be used for VHF Band II, too. The mean building entry loss for VHF Band I was given in ETSI-DVB [3] as 8 dB. The standard deviation of the building entry loss σ_b was always given by 3 dB.

Recently, the topic of building entry loss has been revisited and ITU has issued two documents: Report ITU-R P.2346 [43] and Recommendation ITU-R P.2109 [42].

A major finding of recent investigations is the observation that a principal distinction is to be made between buildings equipped with metalized windows and other measures to provide thermal efficiency and those which are not.

In accordance with Recommendation ITU-R P.2109 [42], the mean building entry loss L_b and the standard deviation σ_b are calculated as follow:

$$L_b = L_h + L_e$$

$$\sigma_b = u + v \log(f)$$

where:

L_h: median loss for horizontal paths, given by:

$$L_h = r + s \log(f) + t (\log(f))^2$$

L_e: correction for elevation angle of the path at the building facade:

$$L_e = 0.212 |\theta|$$

and:

f : frequency (GHz)

θ : elevation angle of the path at the building facade (degrees),

and the coefficients r, s, t, u and v, depending on the building type, listed in Table 11.

TABLE 11

Coefficients for the calculation of building entry loss

Building type	*r*	*s*	*t*	*u*	*v*
Traditional	12.64	3.72	0.96	9.6	2.0
Thermally-efficient	28.19	−3.00	8.48	13.5	3.8

In § 7.3.2.1 there is an example of the calculation of building entry loss where f = 0.2 GHz.

3.6 Allowance for man-made noise

The allowance for man-made noise (MMN) (dB), takes into account the effect of the MMN received by the antenna on the system performance. The system equivalent noise figure F_s (dB) to be used for coverage calculations is calculated from the receiver noise figure F_r (dB) and MMN (dB) (for details see Annex 2, § 2.2):

$$F_s\ (\text{dB}) = F_r + MMN \qquad (\text{dB}) \tag{3}$$

The allowance for man-made noise is calculated from an antenna noise factor f_a, which takes into account the man-made noise received by the antenna:

$$MMN\ (\text{dB}) = 10\ \log_{10}\left(1 + \frac{f_a - 1}{f_r}\right) \qquad (\text{dB}) \tag{4}$$

where:

f_r : the receiver noise factor:

$$f_r = 10^{\frac{F_r}{10}} \tag{5}$$

f_a : the antenna noise factor:

$$f_a = 10^{\frac{F_a}{10}} \tag{6}$$

where:

F_a : antenna noise figure.

3.6.1 Allowance for man-made noise for fixed, portable and mobile reception

Recommendation ITU-R P.372 [26] gives the legal values to calculate the allowance of man-man noise in different areas and frequencies with the definitions of the antenna noise figure, its mean values $F_{a,med}$ and the values of decile variations (10% and 90%) measured in different regions as a function of the frequency. The equation to calculate the antenna noise figure is given in [26] by:

$$F_{a,med}\ (\text{dB}) = c - d \cdot \log_{10}(f\ (\text{MHz}))\ \ (\text{dB}) \tag{7}$$

For all reception modes the residential area (Curve B in [26]) is assumed. In this case the values for the variables c and d are given by:

$$c = 72.5 \qquad d = 27.7$$

Herewith the values of the medium antenna noise figure $F_{a,med}$ (dB) can be computed. The results are shown in Table 12.

TABLE 12

Medium antenna noise figure $F_{a,med}$

Frequency (MHz)	**65**	**100**	**200**
Medium antenna noise figure $F_{a,med}$ for residential area (curve B) (dB)	22.28	17.10 (1)	8.76

(1) For HD Radio F_a value is equal to 21 dB.

Herewith the MMN (dB), taking into account a receiver noise figure F_r of 7 dB, can be computed. The results are shown in Table 13.

TABLE 13

Allowance for man-made noise (MMN) for fixed, portable and mobile reception

Frequency (MHz)	**65**	**100**	**200**
Allowance for man-made noise for fixed, portable and mobile reception (F_r = 7 dB) (dB)(1)	15.38	10.43 (2)	3.62

(1) For DAB a F_r of 6 dB needs to be used.

(2) For HD Radio F_a value is equal to 21 dB, which results in the MMN value of 14.1 dB.

However, the listed results are based on measurements taken in 1974, under completely different RF environments and different antenna system implementation approaches. More recent studies (2001-2003) by OFCOM, as indicated in [27] and [28], and by others in [29] show that the realistic noise may be substantially higher. For example, for the purpose of calculating MMN allowance, a reference F_a value of 21 dB (equivalent to a noise temperature of approximately 360 000 K) for 100 MHz is derived from OFCOM [28] and corresponds to a 'quiet' rural environment. The measurements for that environment resulted in the lowest standard deviation and may be considered the most repetitive. The use of that higher and much more realistic value has been extended to reception modes. A similar approach of adjusting the man-made noise allowance for cases with noticeable antenna losses (i.e. high integrated NF) is used in [2] and shows the result of 14.1 dB for the 100 MHz system with antenna gain higher than −2.2 dBd.

The IRT carried out indoor-measurements of man-made noise in 2005 [32]. SRG carried out indoor measurements of man-made noise in 2017 according to [33]. From these measurements, the extrapolated value of F_{am} for 200 MHz is shown in the last three lines of Table 14. The values of IRT and SRG are considerably higher than the values given in [26]. The ITU values were measured many years ago outside buildings when there were few PCs, no DSL-connections and no widespread mobile and WLAN telecommunication systems as found nowadays and which contribute significantly to man-made noise level. Today, especially in buildings, and in proximity to many noise sources, the antenna external noise figure F_{am} can have higher values than the values measured many years ago outside buildings.

TABLE 14

$F_{a,med}$ and P_{mmn} values in dB for 0 dBi antenna gain for 200 MHz band and different areas

Values for 200 MHz	$F_{a,med}$ (dB)	P_{mmn} (dB)
ITU Rural	3.5	1.6
ITU Residential/suburban	8.8	4.0
ITU City (Business)/urban	13.1	7.0
IRT Urban indoor [32] 2005	16.5	10.0
SRG Urban indoor 2017 @ 3 m [33]	21.1	14.3
SRG Urban indoor 2017 @ 1 m [33]	30.6	23.6

Antenna gain values for in-home and in-car receivers are generally much less than 0 dBi (−2.2 dBd) [44]. The negative antenna gains can be traced back to a lack of efficiency caused by mismatches between antenna and receiver, and between antenna and the received signal, often due to antenna size relative to the wanted signal wavelength. Therefore, the man-made noise received by the antenna is attenuated as is the wanted signal. Consequently, a negative antenna gain induces a modification of the man-made noise allowance value. Based upon the values in Table 14 the value of P_{mmn} for planning can be calculated for different antenna gains. Calculations are based upon [56][1].

The results are presented in Table 15. The calculations are based on the F_{am} values in Table 14 for different values of the antenna gain.

TABLE 15

P_{mmn} in dB as function of antenna gain (F_r = 6 dB, f = 200 MHz)

Antenna gain (dBd)	−2.2	−5	−8	−10	−13	−17
ITU Rural	1.6	0.9	**0.5**	0.3	0.2	0.1
ITU Residential/suburban	4.0	2.5	**1.5**	1.0	0.5	0.2
ITU City (Business)/urban	7.0	5.0	**3.2**	2.2	1.3	0.5
IRT Urban indoor [EBU_9] 2005 [32]	10.0	7.6	**5.3**	4.0	2.4	1.1
SRG urban indoor 2017 @3 m to interferer [33]	14.3	11.6	**8.9**	7.2	5.0	2.7
SRG Urban Indoor 2017 @1 m to interferer [33]	23.6	20.9	**17.9**	15.9	13.0	9.4

Field strength targets are usually focused on vehicles in rural areas and table top radios for in-building reception in suburban and urban grade areas. For a typical antenna gain value for planning of G_a = −8 dBd the resulting MMN adjustment value P_{mmn} to be used in coverage field strength planning is highlighted in Table 15.

Whilst witnessing an increase in man-made noise, further increases can be expected as new electronic devices, in particular LED lights, are introduced. As a consequence of these ongoing changes, levels of MMN need to be monitored; studies and measurements of MMN should continue.

1 The calculation presented in [56] is an updated version of the derivation in [57].

Recommendation ITU-R P.372 [26] gives the value of decile location variations (10% and 90%) in residential area by 5.8 dB. For 90% location probability the distribution factor $\mu = 1.28$. Therefore, the standard deviation of MMN for fixed, portable and mobile reception $\sigma_{MMN} = 4.53$ dB, see Table 16.

TABLE 16

Standard deviation of MMN σ_{MMN} for fixed, portable and mobile reception

Frequency (MHz)	**65**	**100**	**200**
Standard deviation of MMN σ_{MMN} (dB)	4.53	4.53	4.53

The standard deviation of MMN has to be considered in the calculation of the combined standard deviation for the wanted field-strength level (see § 3.8.2).

3.6.2 Allowance for man-made noise for portable handheld reception

The antenna gain is the product of directivity and efficiency. The lowest realistic directivity is the one of a short dipole (length l << λ) and it has the value 1.5 (1.8 dBi). Any gain lower than 1.8 dBi (−0.4 dBd) is due to an antenna efficiency η lower than 1. The interference power at the receiver input is reduced accordingly and the MMN equation is (see Annex 2, § 2.2):

$$MMN(\text{dB}) = 10 \log_{10}\left(1 + \eta \frac{f_a - 1}{f_r}\right) \qquad (\text{dB}) \tag{8}$$

The efficiency η can be calculated from the antenna gain G_D (dB) for gains lower than −0.4 dBd:

$$\eta = 10^{\frac{G_D + 0.4}{10}} \tag{9}$$

The MMN for portable handheld reception, taking the receiver noise figure as 7 dB, are given in Table 17.

TABLE 17

Allowance for man-made noise for portable handheld reception (external antenna)

Frequency (MHz)	**65**	**100**	**200**
Handheld antenna gain G_D (dBd)	−22.8	−19	−13
Efficiency η	0.0058	0.0138	0.055
Calculated MMN allowance (dB)	0.42	0.30	0.14
Allowance for man-made noise for portable handheld reception (dB)	**0.0**	**0.0**	**0.0 (1)**

(1) For DAB the allowance for man-made noise for portable handheld reception (dB) for an antenna gain of −13 dB is provided in Table 15.

In the further calculations the allowance for man-made noise is specified to 0 dB due to the very low calculated values.

3.7 Implementation loss factor

Implementation loss, as indicated in this document, reflects the correction factor to the minimum input power in order to compensate for the non-ideal receiver. Choosing such a factor may be subjective. For receivers that are internally spacious (i.e. reception circuitry not significantly limited by device size) and non-power-restricted (i.e. have constant or frequent access to durable power source), it is often considered to be 3 dB.

Advanced and highly integrated small receivers, such as handheld devices and particularly inclusion in smart phones, may experience additional higher implementation losses. Such losses may be due to the small physical dimensions, limited battery capacity, and co-existence with several additional hardware and radio wave-based functions. Therefore, the implementation loss, L_{im}, for such receivers are considered to be 5 dB. The implementation losses per reception mode are provided in Table 18.

TABLE 18

Implementation loss factor L_i for different reception modes (1)

	FX, MO, PO, PI	PO-H, PI-H
Implementation loss, L_i (dB)	3	5

(1) For the DAB system, no implementation loss factor is considered.

3.8 Correction factors for location variability

The random variation of the received signal field strength with location due to terrain irregularities and the effect of obstacles in the near vicinity of the receiver location is modelled by a statistical distribution (typically log normal) over a specified macro-scale area (typically a square with edge lengths of 100 m to 500 m). Considering the received signal field-strength level E (dB(µV/m)), the lognormal distribution is transformed in a Gaussian distribution with mean (and median) E_{med} (dB) and standard deviation σ (dB).

The field-strength level $E(p)$ (dB(µV/m)), used for coverage and interference predictions in the different reception modes, which will be exceeded for p (%) of locations for a land receiving/mobile antenna location, is given by:

$$E(p)\ (\mathrm{dB}(\mu\mathrm{V/m})) = E_{med}\ (\mathrm{dB}(\mu\mathrm{V/m})) + C_1(p)\ (\mathrm{dB}) \quad \text{for} \quad 50\% \le p \le 99\% \tag{10}$$

with:

$C_1(p)$ (dB) : location correction factor

E_{med} (dB(µV/m) : field-strength value for 50% of locations and 50% of time.

The location correction factor $C_l(p)$ (dB) depends on the so called combined standard deviation σ_c (dB) of the wanted field-strength level that sums the single standard deviations of all relevant signal parts that have to be taken into account and the so-called distribution factor $\mu(p)$, namely:

$$C_1(p)(\mathrm{dB}) = \mu(p) \cdot \sigma_C \qquad (\mathrm{dB}) \tag{11}$$

with:

$\mu(p) = \phi^{-1}\left(\frac{p}{100}\right)$: distribution factor and $\phi(x) = \int_{-\infty}^{x} \frac{1}{\sqrt{2\pi}} e^{-\frac{z^2}{2}}\,\mathrm{d}z$ (standard normal Gaussian CDF)

σ_C : combined standard deviation of the wanted field-strength level (dB).

3.8.1 Distribution factor

The distribution factors $\mu(p)$ of the different location probabilities taking into account the different receiving modes (see § 2) are given in Table 19.

TABLE 19

Distribution factor μ

Percentage of receiving locations p (%)	70	95	99
Reception mode	fixed	portable	mobile
Distribution factor μ	0.524	1.645	2.326

3.8.2 Combined standard deviation

The combined standard deviation σ_c (dB) takes into account the standard deviation of the wanted field-strength level σ_m (dB), the standard deviation of the MMN σ_{MMN} (dB), and, in the case of indoor reception, the standard deviation of the building entry loss, σ_b (dB), respectively.

Since the statistics of the received wanted field-strength level for macro-scale, the statistics of the MMN σ_{MMN} (dB), and the statistics of the building attenuation can be assumed to be statistically uncorrelated, the combined standard deviation σ_c (dB) is calculated by:

$$\sigma_c\,(\text{dB}) = \sqrt{\sigma_m^2 + \sigma_b^2 + \sigma_{MMN}^2} \tag{12}$$

The values of the standard deviations of the building entry loss σ_b (dB) and of the MMN σ_{MMN} (dB) are given in §§ 3.5 and 3.6, respectively.

The values of standard deviation σ_m (dB) of the wanted field-strength level E are dependent on frequency and environment, and empirical studies have shown a considerable spread. Representative values for areas of 500 m × 500 m are given by Recommendation ITU-R P.1546 as well as the expression to calculate the standard deviation σ_m (dB):

$$\sigma_m\left(\text{dB}\right) = K\ (\text{dB}) + 1.3\log_{10}(f\,(\text{MHz})) \tag{13}$$

where:

K = 1.2, for receivers with antennas below clutter height in urban or suburban environments for mobile systems with omnidirectional antennas at car-roof height

K = 1.0, for receivers with rooftop antennas near the clutter height

K = 0.5, for receivers in rural areas

f : required frequency (MHz).

The standard deviations σ_m (dB) for DRM, RAVIS and HD Radio in urban and suburban areas as well as in rural areas are given in Table 20.

TABLE 20

Standard deviation for DRM, HD Radio and RAVIS σ_m (1)

Frequency (MHz)		**65**	**100**	**200**
Standard deviation for DRM, RAVIS and HD Radio σ_m	in urban and suburban areas (dB)	3.56	3.80	4.19
	in rural areas (dB)	2.86	3.10	3.49

(1) For the DAB system σ_m is equal to 4.0 dB.

These values of the standard deviation take into account only the effects of slow fading, but not the effects of fast fading. Therefore it must be ensured that the determination of the minimum *C*/*N* value consider the effects of the fast fading. Otherwise a margin depending to the bandwidth of the signal of 1.6 dB at 8 MHz, 2.3 dB at 1.5 MHz and 4.6 dB at 120 kHz has to be added.

For DRM and RAVIS the effects of fast fading are included into the measurement method and therefore they do not have to be added.

For the different reception modes more or less parts of the given particular standard deviations have to be taken into account, see Table 21.

Due to these differences the combined standard deviation σ_c (dB) for the respective reception modes are given in Table 22.

TABLE 21

Allowance for the particular standard deviations for the different reception modes

Particular standard deviations		σ_m	σ_m	σ_m	σ_{MMN}	σ_b
Frequency (MHz)		65	100	200	all	all
Reception modes	fixed (FX) and portable outdoor (PO) (dB)	3.56	3.80	4.19	4.53	0.00
	portable handheld outdoor (PO-H) (dB)	3.56	3.80	4.19	0.00	0.00
	mobile (MO) (dB)	2.86	3.10	3.49	4.53	0.00
	portable indoor (PI) (dB)	3.56	3.80	4.19	4.53	3.00
	portable handheld indoor (PI-H) (dB)	3.56	3.80	4.19	0.00	3.00
	mobile handheld (MO-H)	n/a	n/a	4.19	0.00	2.00

TABLE 22

Combined standard deviation σ_c for the different reception modes (1)

Frequency (MHz)		65	100	200
Combined standard deviation σ_c for reception mode	fixed (FX) and portable outdoor (PO) (dB)	5.76	5.91	6.17
	portable handheld outdoor (PO-H) (dB)	3.56	3.80	4.19
	mobile (MO) (dB)	5.36	5.49	5.72
	portable indoor (PI) (dB)	6.49	6.63	6.86
	portable handheld indoor (PI-H) (dB)	4.65	4.84	5.15
	mobile handheld (MO-H)	n/a	n/a	4.64

(1) For the DAB system the combined standard deviation and location correction factor for different reception modes and service qualities see § 7.3.3.

3.8.3 Combined location correction factor for protection ratios

The needed protection of a wanted signal against an interfering signal is given as the basic protection ratio PR_{basic} (dB) for 50% of location probability.

In the case of higher location probability as given for all reception modes a so called combined location correction factor *CF* (dB) is used as a margin that has to be added to the basic protection ratio PR_{basic}, valid for the wanted field-strength level and the nuisance field-strength level, to the protection ratio $PR(p)$ corresponding to the needed percentage p (%) of locations for the wanted service [1].

$$PR(p)\,(\text{dB}) = RPR_{basic}(\text{dB}) + CF(p)\,(\text{dB}) \qquad \text{for} \quad 50\% \leq p \leq 99\% \tag{14}$$

with:

$$CF(p)\,(\text{dB}) = \mu(p)\sqrt{\sigma_w^2 + \sigma_n^2} \qquad (\text{dB}) \tag{15}$$

where σ_w and σ_n, both in (dB), denote the standard deviation of location variation for the wanted signal for the nuisance signal, respectively. The values for σ_w and σ_n are given in § 3.8.2 for the different broadcasting systems as σ_m.

3.9 Polarization discrimination

In principal it is possible to take advantage of polarization discrimination for fixed reception. GE84 [5] does not take into account polarization discrimination in the planning procedure for VHF Band II, except in specific cases with the agreement of administrations concerned. In such cases, a value of 10 dB was used for orthogonal polarization discrimination.

GE06 [1] gives that in VHF Band III polarization discrimination shall not be taken into account in the DAB planning procedures.

For the planning procedures of digital sound broadcasting systems in the VHF bands no polarization discrimination will be taken into account for all reception modes.

3.10 Calculation of minimum median field-strength level

The calculation of the minimum median field-strength level at 10 m above ground level for 50% of time and for 50% of locations is given in GE06 [1] by the following steps (for the DAB system as described in § 7, the minimum median field-strength levels are calculated at 1.5 m above ground level):

Step 1: Determine the receiver noise input power level P_n:

$$P_n \text{ (dBW)} = F \text{ (dB)} + 10\log_{10}(k \cdot T_0 \cdot B) \tag{16}$$

where:

F : receiver noise figure (dB)

k : Boltzmann's constant, $k = 1.38\ 10^{-23}$ (J/K)

T_0 : absolute temperature (K)

B : receiver noise bandwidth (Hz).

Step 2: Determine the minimum receiver input power level $P_{s,min}$:

$$P_{s,min} \text{ (dBW)} = (C/N)_{min} \text{ (dB)} + P_n \text{ (dBW)} \tag{17}$$

where:

$(C/N)_{min}$: minimum carrier-to-noise ratio at the digital broadcasting decoder input (dB).

Step 3: Determine the minimum power flux-density (i.e. the magnitude of the Poynting vector) at receiving place φ_{min}:

$$\varphi_{min} \text{(dBW/m}^2) = p_{s,min} \text{(dBW)} - A_a \text{ (dBm}^2) + L_f \text{ (dB)} \tag{18}$$

where:

L_f : feeder loss (dB)

A_a : effective antenna aperture (dBm^2).

$$A_a \text{ (dBm}^2) = 10 \cdot \log\left(\frac{1.64}{4\pi}\left(\frac{300}{f\text{(MHz)}}\right)^2\right) + G_D \text{ (dB)} \tag{19}$$

Step 4: Determine the minimum RMS field-strength level at the location of the receiving antenna E_{min}:

$$E_{min} \left(\text{dB}(\mu\text{V/m})\right) = \varphi_{min} \text{(dBW/m}^2) + 10 \log_{10}\left(Z_{F0}\right)\left(\text{dB}\Omega\right) + 20 \log_{10}\left(\frac{1\text{ V}}{1\,\mu\text{V}}\right) \tag{20}$$

with:

$$Z_{F0} = \sqrt{\frac{\mu_0}{\varepsilon_0}} \approx 120\,\pi\ (\Omega)\text{, the characteristic impedance in free space} \tag{21}$$

resulting in:

$$E_{min}\left(\text{dB}\left(\mu\text{V/m}\right)\right) = \varphi_{min}(\text{dBW/m}^2) + 145.8 \left(\text{dB}\Omega\right) \quad (22)$$

Step 5: Determine the minimum median RMS field-strength level E_{med}:

For the different receiving scenarios the minimum median RMS field strength is calculated as follows:

– for fixed reception:

$$E_{med} = E_{min} + P_{mmn} + C_l \quad (23)$$

– for portable outdoor and mobile reception:

$$E_{med} = E_{min} + P_{mmn} + C_l + L_h \quad (24)$$

– for portable indoor reception:

$$E_{med} = E_{min} + P_{mmn} + C_l + L_h + L_b \quad (25)$$

3.11 Calculation of minimum median field-strength level – integrated method for 100 MHz band

For the purpose of sensitivity calculations, antennas are often represented by gains, and then attached to receivers with separately calculated noise figure. Several legacy design and analysis approaches, as well as certain measurements, refer to the entire gain by a single factor. Then, only the low noise amplifier (LNA) noise figure (referred to as receiver noise figure) is applied to the overall gain and noise calculations. However, an antenna gain consists of fixed physical structure gain, which can be calculated, and additional gain (typically attenuation) component that depends on attached circuitry. While the physical positive gain higher than 0 dBi (−2.2 dBd) corresponds to radiation patterns, negative gains are related to impaired antenna efficiency, which is caused typically by mismatch between the antenna and the receiver, as described in [2].

Advanced receiver implementation techniques, may employ dynamically adjustable circuitry that may improve the matching of the receiver input network, including the LNA. Therefore, for such implementations it may be useful to calculate the combined receiver system noise figure, as resulting from the receiver input network, while separating it from the physical antenna gain. Then, a reference physical antenna gain (typically the lowest realistic gain) is used, and any further antenna attenuation is expressed by a combined noise figure. When a higher physical antenna gain is available, it may then be used to adjust the calculations, without affecting the combined noise figure calculations.

The effect of the matching circuitry on the overall noise, or otherwise on the integrated antenna gain is described further. Required adjustments for the physical antenna gain are further described in this section.

Antenna gain adjustment

The sensitivity (required field strength) based on the overall receiver system NF, already assumed antenna gain of 1.5 (‘net physical’ isotropic element of 1.8 dBi / −0.4 dBd, separate of matching loss), as indicated further. Therefore, antenna gain correction factor Δ_{AG} is applied where the physical element is different (noticeably larger). For fixed reception, an antenna gain of 4 dBd is used, as recommended in [26]. In all other reception modes, no physical antenna gains are available, and therefore are assumed to have no gain over the reference antenna.

The applicable antenna gain correction for all reception modes is provided in Table 23.

TABLE 23

Antenna physical gain correction

	FX	MO, PO, PI, PO-H, PI-H
Antenna gain correction. Δ_{AG} (dB)	4.4	0

Background for calculating the reference minimum field strength

Receiver sensitivity, being the minimum required signal field strength at the receiver antenna (E) is expressed as a function of the required pre-detection C/N_0, the noise, the effective length h_e of the antenna (h_e is a function of radiation resistance), and the antenna matching circuit $H_a(f)$. For a given signal field strength E (µV/m) impinging upon the antenna, C/N_0 is expressed as a function of the field strength, the antenna effective length $h_e(f)$, the transfer function of the antenna circuit (matched) filter $H_a(f)$, and the sum of noise sources comprising N_0.

NOTE – The expression is provided for the lowest realistic directivity antenna, which is the one of a short dipole (length, l << λ) and it has the gain value of 1.5 (1.76 dBi; −0.4 dBd). Any gain higher than −0.4 dBd has to be separately applied to the link budget calculations. Any gain lower than −0.4 dBd is assumed to result from reduced efficiency that is caused by a mismatched network, and is already included in the calculations, as provided in this section.

The signal power C (V^2) applied to the LNA input is given by:

$$C = \left[E\left(\mu V/m\right) \cdot 10^{-6} \cdot h_e(f) \cdot \left|H_a(f)\right| \right]^2 \qquad (26)$$

The noise power spectral density (PSD) at the LNA input (for a conjugately matched antenna) as a function of the ambient noise and the LNA noise figure (NFLNA) is given by:

$$No = \kappa \cdot T_0 \cdot R_{LNA} \cdot 10^{NF_{LNA}/10} + \kappa \cdot \left(T_{amb} - T_0\right) \cdot R_{LNA} \qquad (27)$$

For reference temperature (T_0) discussion, $T_{amb} = T_0$ is assumed. In addition, the LNA input is frequency dependent and may not be conjugately matched to the antenna. The combined noise PSD is given by:

$$No(f) = \kappa \cdot T_0 \cdot \left[R_{LNA} \cdot \left(10^{NF_{LNA}/10} - 2\right) + 4 \cdot \mathrm{Re}\{Z_{in}(f)\}\right] \qquad (28)$$

where Z_{in} is the input impedance seen at the LNA input, including the LNA input impedance, and NFLNA is the noise figure of the LNA. The receiver system NF is the ratio (in dB) of the overall noise to the noise produced by the antenna's radiation resistance:

$$NF = 10 \cdot \log\left(\frac{\kappa \cdot T_0 \cdot \left[R_{LNA} \cdot \left(10^{NFlna/10} - 2\right) + 4 \cdot \mathrm{Re}\{Z_{in}\}\right]}{4 \cdot \kappa \cdot T_0 \cdot R_a(f) \cdot \left|H_a(f)\right|^2}\right) \qquad (29)$$

or equivalently:

$$NF = 10 \cdot \log(No) + 204 - 10 \cdot \log\left(4 \cdot R_a(f) \cdot \left|H_a(f)\right|^2\right) \qquad (30)$$

C/N_0 at the output of the LNA is given by:

$$\frac{C}{No} = \frac{\left[E\left(\mu V/m\right) \cdot 10^{-6} \cdot h_e(f) \cdot \left|H_a(f)\right|\right]^2}{No} \qquad (31)$$

This is expressed in dB as:

$$C/No = 10\cdot\log\left(\frac{C}{No}\right) = E(dBu) - 120 + 10\cdot\log\left(h_e(f)^2\cdot\left|H_a(f)\right|^2\right) - 10\cdot\log(No) \tag{32}$$

or equivalently:

$$C/No = E(dBu) + 78 + 10\cdot\log\left(\frac{h_e(f)^2}{R_a(f)}\right) - NF \tag{33}$$

Then the required field strength *E* (dBu) as a function of the required CNR:

$$E(dBu) = C/No - 78 - 10\cdot\log\left(\frac{h_e(f)^2}{R_a(f)}\right) + NF \tag{34}$$

Using the antenna's effective length h_e as related to its radiation resistance R_a is given by:

$$h_e = 2\cdot\sqrt{\frac{R_a\cdot A_e}{Z_0}} \tag{35}$$

where $A_e = \frac{\lambda^2}{4\cdot\pi}\cdot G$, $Z_0 = 120\cdot\pi$, and G = 1.5 (1.8 dBi; −0.4 dBd) is the constant directivity for small antennas ($h_e << \lambda$):

$$10\cdot\log\left(\frac{h_e(f)^2}{R_a(f)}\right) = 10\cdot\log\left(\frac{\lambda^2}{120\cdot\pi^2}\cdot G\right) = 20\cdot\log(\lambda) - 29 \tag{36}$$

Then the required field strength, as a function of λ and receiver system *NF* is given by:

$$E(dBu) = C/No - 49 - 20\cdot\log(\lambda) + NF \tag{37}$$

Determining the minimum required field strength

For each system configuration and for each reception mode, the applicable *CNR* and the applicable *NF* where:

NF receiver system integrated noise figure (dB)

C/N_0 carrier-to-noise density ratio (dB-Hz).

The following relationship may be used for convenience:

$$C/No = 10\cdot\log\left(\frac{C}{No}\right) = S/N + 10\cdot\log(BWn) \tag{38}$$

where *BWn* is the receiver noise bandwidth (ideally the signal bandwidth).

When using λ = 3 m for 100 MHz, the minimum required field strength E_r is given by:

$$E_r(dBu) = C/No - 58.5 + NF \tag{39}$$

Physical antenna gain adjustment

Since the reference calculation in equation (39) is using the minimum realistic gain, of −0.4 dBd, then the difference should be calculated for any other higher indicated physical gain as follows:

$$\Delta_{AG}\ [\text{dB}] = Ag\ [\text{dB}] + 0.4 \tag{40}$$

where Δ_{AG} is antenna gain correction in dB.

Determining the minimum median required field strength

The minimum median field strength is calculated as follows:

$$E_{med} = E_r + MMN - \Delta_{AG} + L_{rl} + L_i \quad (41)$$

or otherwise:

$$E_{med} = C/N_0 - 58.5 + NF + MMN - \Delta_{AG} + L_{rl} + L_i \quad (42)$$

where:

$L_{rl} = \mu \cdot \sigma_m + L_h + L_f + L_b$: reception location loss (dB);

L_i : implementation loss (dB).

MMN is man-made noise allowance, calculated according to the recommended method in [12], but based on integrated *NF* rather than on antenna gain.

IBOC conversion of C/N_0 to S/N

The carrier-to-noise ratio, often written *CNR* or *C*/*N*, is the signal-to-noise ratio (*S*/*N*) of a modulated signal. The noise power *N* is typically defined in the signal's processing (reception) bandwidth.

The carrier-to-noise-density ratio (C/N_0) is similar to carrier-to-noise ratio, except that the noise N_0 is defined per unit Hz bandwidth.

For analysis, the digital modulation power of the signal *Cd* is often distinguished from the total signal power *C*. This is used in, for example, an FM Hybrid IBOC signal where the digital-only power *Cd* is distinguished from the FM analogue power *C*.

IBOC FM conversion of Cd/N_0 to digital C/N or S/N example

For a single 70-kHz digital signal bandwidth system configuration:

$$\begin{aligned} S/N_{dB} &\equiv (Cd/N)_{dB} = Cd_{dB} - N_{dB} \\ N_{dB} &= No_{dB} + 10 \cdot \log(70\ \text{kHz}) = No_{dB} + 48.45\ \text{dB} \end{aligned} \quad (43)$$

then:

$$S/N_{dB} \equiv (Cd/No)_{dB} - 48.45\ \text{dB} \quad (44)$$

4 Planning parameters for digital terrestrial broadcasting system DRM robustness mode E in VHF Bands I, II and III

Digital Radio Mondiale™ (DRM) was originally designed by the DRM Consortium as a digital broadcasting system for the radio bands below 30 MHz and it is standardized as ETSI ES 201 980 [6]. In 2009, DRM was extended by a mode E – called "DRM+" – to use DRM in radio bands up to 174 MHz.

The University of Applied Sciences in Kaiserslautern[2] (Germany) and the University of Hannover[3] (Germany) successfully conducted laboratory measurements and field trials with DRM in VHF Band II and in VHF Band III, respectively. Demonstrations were also given successfully in Paris in VHF Band I by the University of Applied Sciences in Kaiserslautern. Other field trials all over the

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[2] http://www.fh-kl.de; http://www.drm-radio-kl.eu.

[3] http://www.ikt.uni-hannover.de/.

world, especially in Brazil, Italy, Sri Lanka, the United Kingdom and in the Republic of Korea, have completed the tests.

The measurements and field trials have confirmed the technical parameters, and comparisons of coverage area have been performed between FM in VHF Band II and DRM also as with DAB in VHF Band III and DRM. In addition, protection ratio measurements have been performed and planning models have been used to predict coverage. The results from both German sites show that DRM works well in all VHF bands including VHF Band III.

From these results and based on relevant ITU Recommendations, this Report defines a framework for calculating all relevant DRM network planning parameters in all VHF bands. The focus lies on VHF Band II (87.5-108 MHz) and VHF Band III (174-230 MHz) in ITU Region 1, however where the values for the VHF Band I (47-68 MHz) are available, they are given.

Other frequency allocations in VHF bands assigned to broadcasting services are not exhaustively covered yet, e.g. areas in ITU Region 1 where allocations of the Wiesbaden T-DAB Agreement 1995 are still used (230-240 MHz) or in some Southern African countries, where the VHF Band III is allocated to the broadcasting services up to 254 MHz, or the broadcasting bands in ITU Regions 2 and 3, perhaps the OIRT FM band (65.8-74 MHz) or the Japanese FM band (76-90 MHz), respectively, that can later be adapted. Planning parameters for these unconsidered cases can be derived or taken from the given values, considering 254 MHz as the international top boundary of the VHF broadcasting spectrum[4].

4.1 DRM system parameters

The description of the DRM system parameters refers to Mode E of the DRM system [6].

4.1.1 Modes and code rates

4.1.1.1 Overview of SDC and MSC code rates

ETSI-DRM [6] defines the SDC code rates summarized in Table 24 and the MSC modes with code rates *R* given in Table 25.

TABLE 24

SDC code rates

MSC-mode 11 (4-QAM)		**MSC-mode 00 (16-QAM)**	
SDC-mode	**Code rate *R***	**SDC-mode**	**Code rate *R***
0	0.5	0	0.5
1	0.25	1	0.25

[4] Radio Regulations No. **5.252**: in Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia and Zimbabwe, the bands 230-238 MHz and 246-254 MHz are allocated to the broadcasting service on a primary basis, subject to agreement obtained under No. **9.21**.

TABLE 25

MSC code rates

Protection level	Code rate R for MSC mode 11: 4-QAM		Code rate R combinations for MSC mode 00: 16-QAM			
	R_{all}	R_0	R_{all}	R_0	R_1	RY_{lcm}
0	0.25	1/4	0.33	1/6	1/2	6
1	0.33	1/3	0.41	1/4	4/7	28
2	0.4	2/5	0.5	1/3	2/3	3
3	0.5	1/2	0.62	1/2	3/4	4

The net bit rate of the MSC varies from 37 kbit/s to 186 kbit/s depending of the used parameter set.

4.1.1.2 SDC and MSC code rates for calculations

Several of the derived parameters depend on the characteristic of the transmitted DRM signal. To limit the amount of tests two typical parameters sets were chosen as basic sets, see Table 26:

– DRM with 4-QAM as a high protected signal with a lower data rate which is suited for a robust audio signal with a low data rate data service.

– DRM with 16-QAM as a low protected signal with a high data rate which is suited for several audio signals or for an audio signal with a high data rate data service.

TABLE 26

MSC code rates for calculations

MSC mode	11-4-QAM	00-16-QAM
MSC protection level	1	2
MSC code rate *R*	1/3	1/2
SDC mode	1	1
SDC code rate *R*	0.25	0.25
Bit rate approx.	49.7 kbit/s	149.1 kbit/s

4.1.2 Propagation-related OFDM parameters

The propagation-related OFDM parameters of DRM are given in Table 27.

TABLE 27

OFDM parameters

Elementary time period T	83 1/3 μs
Duration of useful (orthogonal) part $T_u = 27 \cdot T$	2.25 ms
Duration of guard interval $T_g = 3 \cdot T$	0.25 ms
Duration of symbol $T_s = T_u + T_g$	2.5 ms
T_g/T_u	1/9
Duration of transmission frame T_f	100 ms
Number of symbols per frame N_s	40

TABLE 27 (*end*)

Channel bandwidth *B*	96 kHz
Carrier spacing $1/T_u$	444 4/9 Hz
Carrier number space	$K_{min} = -106$; $K_{max} = 106$
Unused carriers	none

4.1.3 Single frequency operation capability

DRM transmitter can be operating in single frequency networks (SFN). The maximum transmitter distance that has to go below to prevent self-interferences depends on the length of the OFDM guard interval.

The maximum transmitter distance is calculated with the maximum echo delay which is given by:

$$D_{echo(max)} \text{ (km)} = T_g \cdot c_0 \qquad (45)$$

where:

$c_0 =$ $300 \cdot 10^3$ (km/s)

$T_g =$ 0.25 (s).

Since the length T_g of the DRM guard interval is 0.25 ms, see Table 27, the maximum echo delay, and, therefore, the maximum transmitter distance, yields 75 km.

4.1.4 Channel models

Radio wave propagation in VHF bands is characterized by diffraction, scattering and reflection of the electromagnetic waves on their way between the transmitter and the receiver. Typically the waves arrive at different times and different angles at the receiver (multipath propagation) resulting in more or less strong frequency-selective fading (dependent on system bandwidth). In addition movements of the receiver or surrounding objects cause a time variation of the channel characteristic and can result in Doppler shift.

For calculation of the different reception modes, the channel models given in Table 28 [6] have been assumed and investigated. These channel models are considering the fading characteristics for different reception environments. For receivers with higher frequencies the fading in time direction is normally short, so the interleaving and error correction algorithms can work. With slow receiver velocities flat fading over a time, longer than the interleaver (600 ms) can result in signal drop outs.

TABLE 28

Channel models in the ETSI standard for DRM

Channel model (name)	Velocity	Remark
Channel 7 (AWGN)	0 km/h	no time variation
Channel 8 (urban)	2 km/h and 60 km/h	pedestrian and vehicle speed
Channel 9 (rural)	150 km/h	vehicle speed on highways
Channel 10 (terrain obstructed)	60 km/h	vehicle speed within built-in areas
Channel 11 (hilly terrain)	100 km/h	vehicle speed along country roads
Channel 12 (SFN)	150 km/h	vehicle speed on highways

4.2 DRM receiver parameters

4.2.1 General characteristics

A DRM receiver is intended to receive and decode programmes transmitted according to the DRM system specification Mode E (DRM+) [6].

The parameters relevant for determining the required minimum field-strength levels are:

– noise figure F_r (dB), measured from the antenna input to the I/Q base band DRM decoder input (including down conversion and A/D conversion);

– receiver noise input power P_n (dBW);

– minimum carrier-to-noise ratio $(C/N)_{min}$ (dB) at the DRM decoder input;

– minimum receiver input power level $P_{s,min}$ (dBW).

4.2.2 Receiver noise figure

In GE06 a receiver noise figure of 7 dB is been used for DVB-T. For having cost effective DRM receiver solutions, the receiver noise figure F is assumed to be F_r = 7 dB too for all VHF bands, see Table 29.

TABLE 29

Receiver noise figure F_r

Frequency (MHz)	65	100	200
Receiver noise figure F_r (dB)	7	7	7

4.2.3 Receiver noise input power

With B = 100 kHz and T = 290 K, the thermal receiver noise input power level P_n for DRM Mode E yields:

$$P_n\,(\text{dBW}) = F_r\ (\text{dB}) + 10\ \log_{10}(k \cdot T_0 \cdot B) = -146.98\ (\text{dBW}) \tag{46}$$

4.2.4 Minimum carrier to noise ratio

On basis of the channel models in the respective reception mode the required minimum values of the $(C/N)_{min}$ had been calculated. Therefore effects of the narrow-band system like fast fading are included in the calculated values of the $(C/N)_{min.}$

ETSI-DRM [6] gives a required $(C/N)_{min}$ for a transmission in VHF Band II to achieve an average coded bit error ratio BER = $1 \cdot 10^{-4}$ (bit) after the channel decoder for different channel models, see Table 30.

TABLE 30

$(C/N)_{min}$ with different channel models

Reception mode	Channel model	$(C/N)_{min}$ (dB) for 4-QAM, R = 1/3	$(C/N)_{min}$ (dB) for 16-QAM, R = 1/2
Fixed reception	Channel 7 (AWGN)	1.3	7.9
Portable reception	Channel 8 (urban@60 km/h)	7.3	15.4
	Channel 9 (rural)	5.6	13.1
	Channel 10 (terrain obstructed)	5.4	12.6
Mobile reception	Channel 11 (hilly terrain)	5.5	12.8
	Channel 12 (SFN)	5.4	12.3

4.2.5 Minimum receiver input power level

Based on the above equations and including the implementation loss factor, the minimum receiver input power level at the receiving location can be calculated for both 16-QAM and 4-QAM, see Table 31 and Table 32.

TABLE 31

Minimum receiver input power level $P_{s,min}$ for 4-QAM, R = 1/3

Reception mode		Fixed	Portable	Mobile
Receiver noise figure	F_r (dB)	7	7	7
Receiver noise input power level	P_n (dBW)	−146.98	−146.98	−146.98
Representative minimum C/N	$(C/N)_{min}$ (dB)	1.3	7.3	5.5
Implementation loss factor	L_i (dB)	3	3	3
Minimum receiver input power level	**$P_{s,min}$ (dBW)**	**−142.68**	**−136.68**	**−138.48**

TABLE 32

Minimum receiver input power level $P_{s,min}$ for 16-QAM, R = 1/2

Reception mode		Fixed	Portable	Mobile
Receiver noise figure	F_r (dB)	7	7	7
Receiver noise input power level	P_n (dBW)	−146.98	−146.98	−146.98
Representative minimum C/N	$(C/N)_{min}$ (dB)	7.9	15.4	12.8
Implementation loss factor	L_i (dB)	3	3	3
Minimum receiver input power level	**$P_{s,min}$ (dBW)**	**−136.08**	**−128.58**	**−131.18**

4.3 DRM planning parameters

4.3.1 Minimum median field-strength level

Based on the equations in § 3, the minimum median field-strength level for the respective reception modes had been calculated for both 16-QAM and 4-QAM, for VHF Bands I, II and III, see Table 33 to Table 38.

4.3.1.1 VHF Band I

TABLE 33

Minimum median field-strength level E_{med} for 4-QAM, R = 1/3 in VHF Band I

DRM modulation		4-QAM. R = 1/3					
Receiving situation		FX	PI	PI-H	PO	PO-H	MO
Minimum receiver input power level	$P_{s,min}$ (dBW)	−142.68	−136.68	−136.68	−136.68	−136.68	−138.48
Antenna gain	G_D (dBd)	0.00	−2.20	−22.76	−2.20	−22.76	−2.20
Effective antenna aperture	A_a (dBm^2)	4.44	2.24	−18.32	2.24	−18.32	2.24
Feeder-loss	L_c dB	1.10	0.00	0.00	0.00	0.00	0.22
Minimum power flux-density at receiving place	φ_{min} (dBW/m^2)	−146.02	−138.92	−118.36	−138.92	−118.36	−140.50
Minimum field-strength level at receiving antenna	E_{min} (dB(μV/m))	−0.25	6.85	27.41	6.85	27.41	5.27
Allowance for man-made noise	P_{mmn} (dB)	15.38	15.38	0.00	15.38	0.00	15.38
Antenna height loss	L_h (dB)	0.00	8.00	15.00	8.00	15.00	8.00
Building penetration loss	L_b (dB)	0.00	8.00	8.00	0.00	0.00	0.00
Location probability		70%	95%	95%	95%	95%	99%
Distribution factor	μ	0.52	1.64	1.64	1.64	1.64	2.33
Standard deviation of DRM field strength	σ_m (dB)	3.56	3.56	3.56	3.56	3.56	2.86
Standard deviation of MMN	σ_{MMN} (dB)	4.53	4.53	0.00	4.53	0.00	4.53
Standard deviation of building penetration loss	σ_b (dB)	0.00	3.00	3.00	0.00	0.00	0.00
Location correction factor	C_l (dB)	3.02	10.68	7.65	9.47	5.85	12.46
Minimum median field-strength level	E_{med} **(dB(μV/m))**	**18.15**	**48.91**	**58.06**	**39.71**	**48.26**	**41.11**

TABLE 34

Minimum median field-strength level E_{med} for 16 QAM, R = 1/2 in VHF Band I

DRM modulation		16-QAM. R = 1/2					
Receiving situation		FX	PI	PI-H	PO	PO-H	MO
Minimum receiver input power level	$P_{s,min}$ (dBW)	−136.08	−128.58	−128.58	−128.58	−128.58	−131.18
Antenna gain	G_D (dBd)	0.00	−2.20	−22.76	−2.20	−22.76	−2.20
Effective antenna aperture	A_a (dBm^2)	4.44	2.24	−18.32	2.24	−18.32	2.24
Feeder-loss	L_c (dB)	1.10	0.00	0.00	0.00	0.00	0.22
Minimum power flux-density at receiving place	φ_{min} (dBW/m^2)	−139.42	−130.82	−110.26	−130.82	−110.26	−133.20
Minimum field-strength level at receiving antenna	E_{min} (dB(μV/m))	6.35	14.95	35.51	14.95	35.51	12.57
Allowance for man-made noise	P_{mmn} (dB)	15.38	15.38	0.00	15.38	0.00	15.38
Antenna height loss	L_h (dB)	0.00	8.00	15.00	8.00	15.00	8.00
Building penetration loss	L_b (dB)	0.00	8.00	8.00	0.00	0.00	0.00
Location probability		70%	95%	95%	95%	95%	99%
Distribution factor	μ	0.52	1.64	1.64	1.64	1.64	2.33
Standard deviation of DRM field strength	σ_m (dB)	3.56	3.56	3.56	3.56	3.56	2.86
Standard deviation of MMN	σ_{MMN} (dB)	4.53	4.53	0.00	4.53	0.00	4.53
Standard deviation of building penetration loss	σ_b (dB)	0.00	3.00	3.00	0.00	0.00	0.00
Location correction factor	C_l (dB)	3.02	10.68	7.65	9.47	5.85	12.46
Minimum median field-strength level	**E_{med} (dB(μV/m))**	**24.75**	**57.01**	**66.16**	**47.81**	**56.36**	**48.41**

4.3.1.2 VHF Band II

TABLE 35

Minimum median field-strength level E_{med} for 4-QAM, R = 1/3 in VHF Band II

DRM modulation		4-QAM. R = 1/3					
Receiving situation		FX	PI	PI-H	PO	PO-H	MO
Minimum receiver input power level	$P_{s,min}$ (dBW)	−142.68	−136.68	−136.68	−136.68	−136.68	−138.48
Antenna gain	G_D (dBd)	0.00	−2.20	−19.02	−2.20	−19.02	−2.20
Effective antenna aperture	A_a (dBm^2)	0.70	−1.50	−18.32	−1.50	−18.32	−1.50
Feeder-loss	L_c (dB)	1.40	0.00	0.00	0.00	0.00	0.28
Minimum power flux-density at receiving place	φ_{min} (dBW/m^2)	−141.97	−135.17	−118.35	−135.17	−118.35	−136.69
Minimum field-strength level at receiving antenna	E_{min} (dB(μV/m))	3.79	10.59	27.41	10.59	27.41	9.07

TABLE 35 (*end*)

Allowance for man-made noise	P_{mmn} (dB)	10.43	10.43	0.00	10.43	0.00	10.43
Antenna height loss	L_h (dB)	0.00	10.00	17.00	10.00	17.00	10.00
Building penetration loss	L_b (dB)	0.00	9.00	9.00	0.00	0.00	0.00
Location probability		70%	95%	95%	95%	95%	99%
Distribution factor	μ	0.52	1.64	1.64	1.64	1.64	2.33
Standard deviation of DRM field strength	σ_m (dB)	3.80	3.80	3.80	3.80	3.80	3.10
Standard deviation of MMN	σ_{MMN} (dB)	4.53	4.53	0.00	4.53	0.00	4.53
Standard deviation of building penetration loss	σ_b (dB)	0.00	3.00	3.00	0.00	0.00	0.00
Location correction factor	C_l (dB)	3.10	10.91	7.96	9.73	6.25	12.77
Minimum median field-strength level	**E_{med} (dB(μV/m))**	**17.32**	**50.92**	**61.37**	**40.74**	**50.66**	**42.27**

TABLE 36

Minimum median field-strength level E_{med} for 16-QAM, R = 1/2 in VHF Band II

DRM modulation		16-QAM R = 1/2					
Receiving situation		FX	PI	PI-H	PO	PO-H	MO
Minimum receiver input power level	$P_{s,min}$ (dBW)	−136.08	−128.58	−128.58	−128.58	−128.58	−131.18
Antenna gain	G_D (dBd)	0.00	−2.20	−19.02	−2.20	−19.02	−2.20
Effective antenna aperture	A_a (dBm^2)	0.70	−1.50	−18.32	−1.50	−18.32	−1.50
Feeder-loss	L_c (dB)	1.40	0.00	0.00	0.00	0.00	0.28
Minimum power flux-density at receiving place	φ_{min} (dBW/m^2)	−135.37	−127.07	−110.25	−127.07	−110.25	−129.39
Minimum field-strength level at receiving antenna	E_{min} (dB(μV/m))	10.39	18.69	35.51	18.69	35.51	16.37
Allowance for man-made noise	P_{mmn} (dB)	10.43	10.43	0.00	10.43	0.00	10.43
Antenna height loss	L_h (dB)	0.00	10.00	17.00	10.00	17.00	10.00
Building penetration loss	L_b (dB)	0.00	9.00	9.00	0.00	0.00	0.00
Location probability		70%	95%	95%	95%	95%	99%
Distribution factor	μ	0.52	1.64	1.64	1.64	1.64	2.33

TABLE 36 (*end*)

Standard deviation of DRM field strength	σ_m (dB)	3.80	3.80	3.80	3.80	3.80	3.10
Standard deviation of MMN	σ_{MMN} (dB)	4.53	4.53	0.00	4.53	0.00	4.53
Standard deviation of building penetration loss	σ_b (dB)	0.00	3.00	3.00	0.00	0.00	0.00
Location correction factor	C_l (dB)	3.10	10.91	7.96	9.73	6.25	12.77
Minimum median field-strength level	**E_{med} (dB(μV/m))**	**23.92**	**59.02**	**69.47**	**48.84**	**58.76**	**49.57**

4.3.1.3 VHF Band III

TABLE 37

Minimum median field-strength level E_{med} for 4-QAM, R = 1/3 in VHF Band III

DRM modulation		4-QAM. R = 1/3					
Receiving situation		FX	PI	PI-H	PO	PO-H	MO
Minimum receiver input power level	$P_{s,min}$ (dBW)	−142.68	−136.68	−136.68	−136.68	−136.68	−138.48
Antenna gain	G_D (dBd)	0.00	−2.20	−13.00	−2.20	−13.00	−2.20
Effective antenna aperture	A_a (dBm^2)	−5.32	−7.52	−18.32	−7.52	−18.32	−7.52
Feeder-loss	L_c (dB)	2.00	0.00	0.00	0.00	0.00	0.40
Minimum power flux-density at receiving place	φ_{min} (dBW/m^2)	−135.35	−129.15	−118.35	−129.15	−118.35	−130.55
Minimum field-strength level at receiving antenna	E_{min} (dB(μV/m))	10.41	16.61	27.41	16.61	27.41	15.21
Allowance for man-made noise	P_{mmn} (dB)	3.62	3.62	0.00	3.62	0.00	3.62
Antenna height loss	L_h (dB)	0.00	12.00	19.00	12.00	19.00	12.00
Building penetration loss	L_b (dB)	0.00	9.00	9.00	0.00	0.00	0.00
Location probability		70%	95%	95%	95%	95%	99%
Distribution factor	μ	0.52	1.64	1.64	1.64	1.64	2.33
Standard deviation of DRM field strength	σ_m (dB)	4.19	4.19	4.19	4.19	4.19	3.49
Standard deviation of MMN	σ_{MMN} (dB)	4.53	4.53	0.00	4.53	0.00	4.53
Standard deviation of building penetration loss	σ_b (dB)	0.00	3.00	3.00	0.00	0.00	0.00
Location correction factor	C_l (dB)	3.24	11.29	8.48	10.15	6.89	13.31
Minimum median field-strength level	**E_{med} (dB(μV/m))**	**17.26**	**52.52**	**63.89**	**42.38**	**53.30**	**44.13**

TABLE 38

Minimum median field-strength level E_{med} for 16-QAM, R = 1/2 in VHF Band III

DRM modulation		16-QAM. R = ½					
Receiving situation		FX	PI	PI-H	PO	PO-H	MO
Minimum receiver input power level	$P_{s,min}$ (dBW)	−136.08	−128.58	−128.58	−128.58	−128.58	−131.18
Antenna gain	G_D (dBd)	0.00	−2.20	−13.00	−2.20	−13.00	−2.20
Effective antenna aperture	A_a (dBm^2)	−5.32	−7.52	−18.32	−7.52	−18.32	−7.52
Feeder-loss	L_c (dB)	2.00	0.00	0.00	0.00	0.00	0.40
Minimum power flux-density at receiving place	φ_{min} (dBW/m^2)	−128.75	−121.05	−110.25	−121.05	−110.25	−123.25
Minimum field-strength level at receiving antenna	E_{min} (dB(μV/m))	17.01	24.71	35.51	24.71	35.51	22.51
Allowance for man-made noise	P_{mmn} (dB)	3.62	3.62	0.00	3.62	0.00	3.62
Antenna height loss	L_h (dB)	0.00	12.00	19.00	12.00	19.00	12.00
Building penetration loss	L_b (dB)	0.00	9.00	9.00	0.00	0.00	0.00
Location probability		70%	95%	95%	95%	95%	99%
Distribution factor	μ	0.52	1.64	1.64	1.64	1.64	2.33
Standard deviation of DRM field strength	σ_m (dB)	4.19	4.19	4.19	4.19	4.19	3.49
Standard deviation of MMN	σ_{MMN}(dB)	4.53	4.53	0.00	4.53	0.00	4.53
Standard deviation of building penetration loss	σ_b (dB)	0.00	3.00	3.00	0.00	0.00	0.00
Location correction factor	C_l (dB)	3.24	11.29	8.48	10.15	6.89	13.31
Minimum median field-strength level	**E_{med} (dB(μV/m))**	**23.86**	**60.62**	**71.99**	**50.48**	**61.40**	**51.43**

4.3.2 Position of DRM frequencies

The DRM system is designed to be used at any frequency with variable channelization constraints and propagation conditions throughout these bands [6].

Referring to the legal frequency plans in ITU Region 1 this Report covers DRM:

– in VHF Band I as well as in VHF Band II regarding to GE84 [5];

– in VHF Band III regarding to GE06 [1].

Other areas in the VHF bands assigned for sound broadcasting services, e.g. areas in ITU Region 1 where allocations of the Wiesbaden T-DAB Agreement 1995 are still used (230-240 MHz) or in southern Africa, where the VHF Band III is allocated to the broadcasting services up to 254 MHz, or the broadcasting bands in ITU Region 2 and 3, perhaps the OIRT FM band (65.8-74 MHz) or the

Japanese FM band (76-90 MHz), respectively, are not yet covered in this section and can be adapted later.

4.3.2.1 VHF Band I and VHF Band II

The DRM centre frequencies are positioned in 100 kHz distance according to the FM frequency grid in VHF Band II. The nominal carrier frequencies are, in principle, integral multiples of 100 kHz [5]. The DRM system is designed to be used with this raster [6].

The table of centre frequencies of DRM in VHF Band II is given in Annex 2.

On the other hand it has to be considered to allow a spacing of 50 kHz in VHF Band II to achieve the full potential of the DRM hybrid mode and to alleviate the deployment of new DRM transmitters in the overcrowded FM band.

4.3.2.2 VHF Band III

The DRM centre frequencies are positioned in 100 kHz distance beginning by 174.05 MHz and integral multiples of 100 kHz up to the end of VHF Band III.

The table of the centre frequencies of DRM in VHF Band III in the range from 174 to 230 MHz is given in Annex 2.

4.3.3 Out-of-band spectrum mask

The power density spectrum at the transmitter output is important to determine the adjacent channel interference.

The spectrum characteristics of an OFDM system are given in Recommendation ITU-R SM.328, Annex 6, § 5.

4.3.3.1 VHF Band I and VHF Band II

An out-of-band spectrum mask for DRM in VHF Band I and VHF Band II, respectively, as minimum transmitter requirement is proposed in Fig. 1 and Table 39. The vertices of the symmetric out-of-band spectrum mask for FM transmitters are given in ETSI-FM [7].

Note that the out-of-band spectrum masks are defined for a resolution bandwidth (RBW) of 1 kHz.

FIGURE 1

Out-of-band spectrum masks for FM in VHF Band II and DRM in VHF Bands I and II

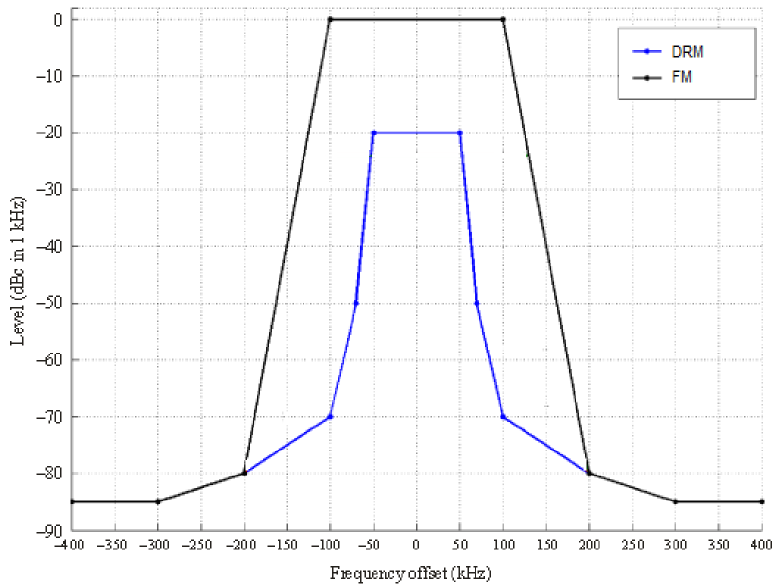

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TABLE 39

Out-of-band spectrum masks for FM in VHF Band II and DRM in VHF Bands I and II

Spectrum mask (100 kHz channel)/ relative level for FM		**Spectrum mask (100 kHz channel)/ relative level for DRM**	
Frequency offset (kHz)	**Level (dBc)/(1 kHz)**	**Frequency offset (kHz)**	**Level (dBc)/(1 kHz)**
0	0	**0**	−20
±50	0	**±50**	−20
±70	0	**±70**	−50
±100	0	**±100**	−70
±200	−80	**±200**	−80
±300	−85	**±300**	−85
±400	−85	**±400**	−85

4.3.3.2 VHF Band III

The vertices of the symmetric out-of-band spectrum masks for DAB transmitters are given in Recommendation ITU-R BS.1660 [44]. An out-of-band spectrum mask for DRM is proposed that fits into the DAB masks, see Fig. 2 and Table 40.

Note that the out-of-band spectrum masks are defined for a resolution bandwidth (RBW) of 4 kHz. Thus the value of −14 dBr results for DRM.

FIGURE 2

Out-of-band spectrum masks for DAB and DRM in VHF Band III

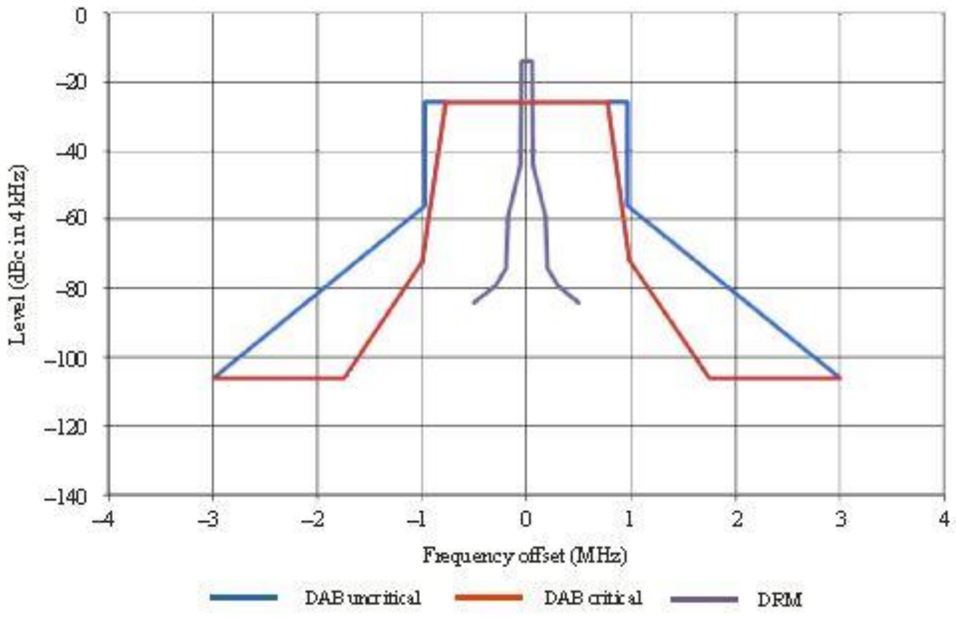


TABLE 40

Out-of-band spectrum masks for DRM in VHF Band III

Spectrum mask (100 kHz channel) relative level for DRM	
Frequency offset (kHz)	**Level (dBc)**
0	−14
±50	−14
±60	−44
±181.25	−59
±200	−74
±300	−79
±500	−84

4.3.4 Protection ratios

The minimum acceptable ratio between a wanted signal and interfering signals to protect the reception of the wanted signal is defined as the protection ratio *PR* (dB). The values of protection ratios are given as:

– Basic protection ratio PR_{basic} for a wanted signal interfered with by an unwanted signal at 50% location probability. These values are determined in accordance with Recommendation ITU-R BS.641.

– Combined location correction factor *CF* (dB) as a margin that has to be added to the basic protection ratio for a wanted signal interfered with by an unwanted signal for the calculation of protection ratios at location probability greater as 50%. The equation for the calculation is given in § 3.8.3.

– Corresponding protection ratio $PR(p)$ for a wanted digital signal interfered with by an unwanted signal at location probability greater than 50% taking into account the respective location probability of the corresponding reception modes that have higher protection requirements due to the higher location probability to be protected.

4.3.4.1 Protection ratios for DRM

The DRM signal parameters are given in § 4.1.

4.3.4.1.1 DRM interfered with by DRM

The basic protection ratio PR_{basic} for DRM is valid for all VHF bands, see Table 41. For the standard deviation of DRM differs in the respective VHF bands the combined location correction factors CF, see Table 42, are different in the respective VHF bands as well as the corresponding protection ratios $PR(p)$, see Table 43 for 4-QAM and Table 44 for 16-QAM.

TABLE 41

Basic protection ratios PR_{basic} for DRM interfered with by DRM

Frequency offset (kHz)		**0**	**±100**	**±200**
DRM (4-QAM, R = 1/3)	PR_{basic} (dB)	4	−16	−40
DRM (16-QAM, R = 1/2)	PR_{basic} (dB)	10	−10	−34

TABLE 42

Combined location correction factor *CF* for DRM interfered with by DRM

Reference frequency band (MHz)		**65 MHz VHF Band I**			**100 MHz VHF Band II**			**200 MHz VHF Band III**		
Location probability p (%)		70	95	99	70	95	99	70	95	99
Combined location correction factor in urban and suburban area for fixed and portable reception	*CF* (dB)	2.64	8.27	11.70	2.82	8.84	12.50	3.11	9.75	13.79
Combined location correction factor in rural area for mobile reception	*CF* (dB)	2.12	6.65	9.40	2.30	7.21	10.20	2.59	8.12	11.49

TABLE 43

Corresponding protection ratios *PR*(*p*) to reception modes for DRM (4-QAM. *R* = 1/3) interfered with by DRM

Reference frequency band (MHz)		**65 MHz VHF Band I**		
Frequency offset (kHz)		0	±100	±200
Fixed reception (FX)	*PR*(*p*) (dB)	6.64	−13.36	−37.36
Portable reception (PO, PI, PO-H, PI-H)	*PR*(*p*) (dB)	12.27	−7.73	−31.73
Mobile reception (MO)	*PR*(*p*) (dB)	13.40	−6.60	−30.60

Reference frequency band (MHz)		**100 MHz VHF Band II**		
Frequency offset (kHz)		0	±100	±200
Fixed reception (FX)	*PR*(*p*) (dB)	6.82	−13.18	−37.18
Portable reception (PO, PI, PO-H, PI-H)	*PR*(*p*) (dB)	12.84	−7.16	−31.16
Mobile reception (MO)	*PR*(*p*) (dB)	14.20	−5.80	−29.80

Reference frequency band (MHz)		**200 MHz VHF Band III**		
Frequency offset (kHz)		0	±100	±200
Fixed reception (FX)	*PR*(*p*) (dB)	7.11	−12.89	−36.89
Portable reception (PO. PI. PO-H. PI-H)	*PR*(*p*) (dB)	13.75	−6.25	−30.25
Mobile reception (MO)	*PR*(*p*) (dB)	15.49	−4.51	−28.51

TABLE 44

Corresponding protection ratios *PR*(*p*) to reception modes for DRM (16-QAM. *R* = 1/2) interfered with by DRM

Reference frequency band (MHz)		**65 MHz VHF Band I**		
Frequency offset (kHz)		0	±100	±200
Fixed reception (FX)	*PR*(*p*) (dB)	12.64	−7.36	−31.36
Portable reception (PO. PI. PO-H. PI-H)	*PR*(*p*) (dB)	18.27	−1.73	−25.73
Mobile reception (MO)	*PR*(*p*) (dB)	19.40	−0.60	−24.60

Reference frequency band (MHz)		**100 MHz VHF Band II**		
Frequency offset (kHz)		0	±100	±200
Fixed reception (FX)	*PR*(*p*) (dB)	12.82	−7.18	−31.18
Portable reception (PO, PI, PO-H, PI-H)	*PR*(*p*) (dB)	18.84	−1.16	−25.16
Mobile reception (MO)	*PR*(*p*) (dB)	20.20	0.20	−23.80

TABLE 44 (*end*)

Reference frequency band (MHz)		200 MHz VHF Band III		
Frequency offset (kHz)		0	±100	±200
Fixed reception (FX)	*PR*(*p*) (dB)	13.11	−6.89	−30.89
Portable reception (PO, PI, PO-H, PI-H)	*PR*(*p*) (dB)	19.75	−0.25	−24.25
Mobile reception (MO)	*PR*(*p*) (dB)	21.49	1.49	−22.51

4.3.4.1.2 DRM interfered with by FM in VHF Band II

The basic protection ratio PR_{basic} for DRM interfered with by FM in VHF Band II is given in Table 45. The values for the combined location correction factors *CF* are given in Table 46, and for the corresponding protection ratios *PR*(*p*), are given in Table 47 for 4-QAM and in Table 48 for 16-QAM, respectively.

TABLE 45

Basic protection ratios PR_{basic} for DRM interfered with by FM

Frequency offset (kHz)		0	±100	±200
DRM (4-QAM. *R* = 1/3) interfered with by FM (stereo)	PR_{basic} (dB)	11	−13	−54
DRM (16-QAM. *R* = 1/2) interfered with by FM (stereo)	PR_{basic} (dB)	18	−9	−49

TABLE 46

Combined location correction *CF* factor for DRM interfered with by FM

Location probability *p* (%)		70	95	99
Combined location correction factor in urban and suburban area for fixed and portable reception	*CF* (dB)	4.79	15.02	21.24
Combined location correction factor in rural area for mobile reception	*CF* (dB)	4.65	14.57	20.61

TABLE 47

Corresponding protection ratios *PR*(*p*) to reception modes for DRM (4-QAM. *R* = 1/3) interfered with by FM stereo

Frequency offset (kHz)		0	±100	±200
Fixed reception (FX)	*PR*(*p*) (dB)	15.79	−8.21	−49.21
Portable reception (PO, PI, PO-H, PI-H)	*PR*(*p*) (dB)	26.02	2.02	−38.98
Mobile reception (MO)	*PR*(*p*) (dB)	31.61	7.61	−33.39

TABLE 48

Corresponding protection ratios *PR*(*p*) to reception modes for DRM (16-QAM. *R* = 1/2) interfered with by FM stereo

Frequency offset (kHz)		0	±100	±200
Fixed reception (FX)	*PR*(*p*) (dB)	22.79	−4.21	−44.21
Portable reception (PO, PI, PO-H, PI-H)	*PR*(*p*) (dB)	33.02	6.02	−33.98
Mobile reception (MO)	*PR*(*p*) (dB)	38.61	11.61	−28.39

4.3.4.1.3 DRM interfered with by DAB in VHF Band III

The basic protection ratio PR_{basic} for DRM interfered with by DAB in VHF Band III is given in Table 49. The values for the combined location correction factors CF are given in Table 50, and for the corresponding protection ratios *PR*(*p*), are given in Table 51 for 4-QAM and in Table 52 for 16-QAM, respectively. For the protection ratios of DRM interfered with DAB+, see § 7.4.4.

TABLE 49

Basic protection ratios PR_{basic} of DRM interfered with by DAB

Frequency offset (kHz)		0	±100	±200
Basic protection ratio for DRM (4-QAM. *R* = 1/3)	PR_{basic} (dB)	−7	−36	−40
Basic protection ratio for DRM (16-QAM. *R* = 1/2)	PR_{basic} (dB)	−2	−18	−40

TABLE 50

Combined location correction factor *CF* of DRM interfered with by DAB

Location probability *p* (%)		70	95	99
Combined location correction factor **in urban and suburban area for fixed and portable reception**	*CF* (dB)	3.63	11.37	16.09
Combined location correction factor i**n rural area for mobile reception**	*CF* (dB)	3.42	10.72	15.16

TABLE 51

Corresponding protection ratios *PR*(*p*) to reception modes for DRM (4-QAM. *R* = 1/3) interfered with by DAB

Frequency offset (kHz)		0	±100	±200
Fixed reception (FX)	*PR*(*p*) (dB)	−3.37	−32.37	−50.37
Portable reception (PO, PI, PO-H, PI-H)	*PR*(*p*) (dB)	4.37	−24.63	−42.63
Mobile reception (MO)	*PR*(*p*) (dB)	8.16	−20.84	−38.84

TABLE 52

Corresponding protection ratios *PR*(*p*) to reception modes for DRM (16-QAM. *R* = 1/2) interfered with by DAB

Frequency offset (kHz)		0	±100	±200
Fixed reception (FX)	*PR*(*p*) (dB)	1.63	−14.37	−45.37
Portable reception (PO, PI, PO-H, PI-H)	*PR*(*p*) (dB)	9.37	−6.63	−37.63
Mobile reception (MO)	*PR*(*p*) (dB)	13.16	−2.84	−33.84

4.3.4.1.4 DRM interfered with by DVB-T in VHF Band III

Since the impact mechanisms of DAB into DRM is the same as that of DVB-T it is proposed that the same protection ratios for DRM interfered with by DVB-T in VHF Band III can be assumed as for DRM interfered with by DAB in VHF Band III.

4.3.4.2 Protection ratios for broadcasting systems interfered with by DRM

4.3.4.2.1 Protection ratios for FM in VHF Band II

The FM signal parameters are given in Recommendation ITU-R BS.412.

Recommendation ITU-R BS.412, Annex 5 states that interferences can be caused by intermodulation of strong FM signals in a frequency offset greater than 400 kHz. This cross modulation effect from a high interfering signal level in a range up to 1 MHz offset has also to be taken into account when planning OFDM systems into the VHF Band II. Therefore not only the protection ratios PR_{basic} are given in the range 0 kHz to ±400 kHz, and for ±500 kHz and ±1 000 MHz, see Table 53. The values for ±600 kHz to ±900 kHz can be found by linear interpolation.

TABLE 53

Basic protection ratios PR_{basic} for FM interfered with by DRM

Frequency offset (kHz)		0	±100	±200	±300	±400	±500	±1 000
Basic protection ratio for FM (stereo)	PR_{basic} (dB)	49	30	3	−8	−11	−13	−21

4.3.4.2.2 Protection ratios for DAB in VHF Band III

The DAB signal parameters are given in Recommendation ITU-R BS.1660. In GE06 [1] it is given that the DAB planning should be able to deal with mobile reception with a location probability of 99%, and with portable indoor reception with a location probability of 95%, respectively. In addition the values for fixed reception with a location probability of 70% are given.

The basic protection ratios for DAB interfered with by DRM are given in Table 54, the related combined location correction factors are given in Table 55, and the corresponding protection ratios *PR(p)* are given in Table 56, respectively. For the protection ratios of DAB+ interfered with DRM, see § 7.4.4.

TABLE 54

Basic protection ratios PR_{basic} for DAB interfered with by DRM

Frequency offset (kHz)		0	±100	±200
Basic protection ratio for T-DAB	PR_{basic} (dB)	10	−40	−40

TABLE 55

Combined location correction factor *CF* for DAB interfered with by DRM

Location probability *p* (%)		70	95	99
Combined location correction factor in urban and suburban area for fixed and portable reception	*CF* (dB)	3.63	11.37	16.09
Combined location correction factor in rural area for mobile reception	*CF* (dB)	3.42	10.72	15.16

TABLE 56

Corresponding protection ratios *PR*(*p*) to reception modes for DAB interfered with by DRM

Frequency offset (kHz)		0	±100	±200
DAB fixed reception	*PR*(*p*) (dB)	13.63	−36.37	−36.37
DAB portable reception	*PR*(*p*) (dB)	21.37	−28.63	−28.63
DAB mobile reception	*PR*(*p*) (dB)	25.16	−24.84	−24.84

4.3.4.2.3 Protection ratios for DVB-T in VHF Band III

The DVB-T signal parameters are given in Recommendation ITU-R BT.1368.

In VHF Band III not only DAB but also may be DVB-T operated additionally as an interferer into DRM or to be interfered with by DRM.

DRM as an interferer against a DAB wanted signal has the same impact as a DAB interferer under the assumption that more than one DRM interferer with different frequencies in a DAB block has to be included, see Table 54.

The same proposal can be assumed if DVB-T is the wanted signal. If there is more than one DRM interferer with different frequencies in a DVB-T channel the impact may be the same as it is caused by a DAB signal. Therefore, it is proposed that the protection ratios of DVB-T interfered with by DRM are the same as DVB-T is interfered with by DAB.

In Recommendation ITU-R BT.1368 the basic protection ratios for DVB-T interfered with DAB are given, see Table 57. These protection rations are proposed for the interferences by a DRM signal also. In the adjacent channels no impact is proposed.

TABLE 57

Co-channel basic protection ratios PR_{basic} for DVB-T interfered with by DAB (Recommendation ITU-R BT.1368) and by DRM

Wanted signal DVB-T constellation-code rate	*PR* (dB)
QPSK-1/2	10
QPSK-2/3	12
QPSK-3/4	14
16-QAM-1/2	15
16-QAM-2/3	18
16-QAM-3/4	20
64-QAM-1/2	20
64-QAM-2/3	24
64-QAM-3/4	26
64-QAM-7/8	31

4.3.4.3 Protection ratios for other services interfered with by DRM

4.3.4.3.1 Other services below the radio broadcasting VHF Band II

Below the VHF Band II broadcasting band, land mobile services with security tasks are located. The interference potential of DRM into these services is not higher as the one of FM signals. Provided sufficient additional band-pass filtering of the output of the transmitter is applied, the interference potential of DRM into narrow-band FM (BOS) reception is not substantially higher than that of a standard FM broadcast signal [8].

4.3.4.3.2 Other services above the radio broadcasting VHF Band II

Above the VHF Band II broadcasting band, aeronautical radio navigation services are located. The interference potential of DRM into these services is not higher as the one of FM signals. For frequency offsets of less than 200 kHz, the interference potential of DRM into VOR and ILS localizer reception is much less than of a standard FM broadcast signal (up to 30 dB less). For larger frequency offsets, both signals produce roughly the same interference, provided sufficient additional band-pass filtering of the output of the transmitter is deployed [8].

4.3.4.3.3 Other services in the radio broadcasting VHF Band III

The values and the procedures to take into account other services in VHF Band III is given in GE06. For DRM the same values as for DAB shall be applied.

4.3.5 Calculation of the resulting sum field strength of interferers

To calculate the resulting interfering sum field-strength level from several signal sources E_{sum}

– **in VHF Band I and VHF Band II** the simplified multiplication method (see Report ITU-R BS.945) shall be applied according to GE84 [5];

– **in VHF Band III** the log-normal methods (see Report ITU-R BS.945) according to the planning procedures of T-DAB and DVB-T [1] shall be applied.

5 Planning parameters for digital terrestrial broadcasting system RAVIS in VHF Bands I and II

The RAVIS system is designed for digital sound and multimedia broadcasting in VHF Bands I and II. The system is nationally standardized in the Russian Federation [9-13]. Main characteristics and features of RAVIS can be found in Report ITU-R BT.2049 – Broadcasting of multimedia and data applications for mobile reception.

5.1 System parameters of RAVIS

5.1.1 RAVIS signal parameters

RAVIS supports three types of radio channel bandwidth: 100, 200 and 250 kHz.

RAVIS supports three different coding rates for logical channel of main service: 1/2, 2/3 and 3/4.

RAVIS supports three different modulation types for logical channel of main service: QPSK, 16-QAM and 64-QAM.

Rounded bit rates for different combinations of system parameters are given in Table 58.

TABLE 58

Bit rates for RAVIS

Modulation type	Code rate	Bit rate (kbit/s)		
		100 kHz channel	200 kHz channel	250 kHz channel
QPSK	1/2	80	160	200
	2/3	100	210	270
	3/4	120	240	300
16-QAM	1/2	150	320	400
	2/3	210	420	530
	3/4	230	470	600
64-QAM	1/2	230	470	600
	2/3	310	630	800
	3/4	350	710	900

Main OFDM parameters of RAVIS signal are given in Table 59.

TABLE 59

OFDM parameters of RAVIS

Channel bandwidth B	100 kHz	200 kHz	250 kHz
Number of curriers	215	439	553
Number of information curriers	196	400	504
Distance between first and last curriers	95.1 kHz	194.7 kHz	245.3 kHz
Carrier spacing $1/T_u$	4 000/9 Hz = 444 4/9 Hz		
Duration of useful part of symbol T_u	2.25 ms		
Duration of guard interval T_g	281.25 ms		

TABLE 59 (*end*)

Duration of symbol $T_s = T_u + T_g$	2.53125 ms
T_g/T_u	1/8
Duration of transmission frame T_f	103.8 ms
Number of symbols per frame N_s	41

5.1.2 SFN operation capabilities

RAVIS can operate in single frequency networks (SFN). The maximum transmitter distance that has to go below to prevent self-interferences depends on the length of the OFDM guard interval. The maximum transmitter distance defined by (45) is calculated through the multiplication of velocity of light ($3 \cdot 10^5$ km/s) by guard interval duration (~0.28 ms for RAVIS). So maximum transmitter distance is about 84 km.

5.1.3 Channel models

Channel models used for simulation of RAVIS operation corresponds to the models defined in DRM standard [6] and used for DRM operation simulation (see Table 28).

5.2 RAVIS radio receiver related parameters

RAVIS receiver is intended to receive and decode programmes transmitted according to the RAVIS system standard [9].

The parameters relevant for determining the required minimum field-strength levels are:

– noise figure F_r (dB), measured from the antenna input to the I/Q base band RAVIS decoder input (including down conversion and A/D conversion);

– receiver noise input power P_n (dBW);

– minimum carrier-to-noise ratio $(C/N)_{min}$ (dB) at the RAVIS decoder input;

– minimum receiver input power level $P_{s,min}$ (dBW).

For having cost effective RAVIS receiver solutions the receiver noise figure F is assumed to be F_r = 7 dB as for DRM receiver for all VHF bands, see Table 29.

Receiver noise input power P_n is calculated according to (16) and depends on input signal bandwidth (T = 290 K):

P_n (dBW) = –146.98 (dBW) for 100 kHz signal bandwidth;

P_n (dBW) = –143.97 (dBW) for 200 kHz signal bandwidth;

P_n (dBW) = –143.00 (dBW) for 250 kHz signal bandwidth.

Required $(C/N)_{min}$ for a transmission in VHF Band II to achieve an average coded bit error ratio BER = $1 \cdot 10^{-4}$ (bit) after the channel decoder for system parameters and different channel models are given in Tables 60 to 62. Channel models correspond to the models from [6], Annex B.2. Channel 7 (AWGN) models fixed reception mode, channel 8 (Urban) models portable reception mode, channel 11 (Hilly terrain) models mobile reception mode.

TABLE 60

$(C/N)_{min}$ for RAVIS with 100 kHz channel bandwidth

Channel model/ reception mode	**$(C/N)_{min}$ (dB)**								
	QPSK			**16-QAM**			**64-QAM**		
	***R* = 1/2**	***R* = 2/3**	***R* = 3/4**	***R* = 1/2**	***R* = 2/3**	***R* = 3/4**	***R* = 1/2**	***R* = 2/3**	***R* = 3/4**
Channel 7 (AWGN)/fixed reception	5 1.2	6 3.4	6 4.3	8 6.6	1 9.2	1 10.3	1 10.9	1 14.2	1 15.6
Channel 8 (urban)/ portable reception	1 6.5	1 9.5	1 11.7	1 12.6	1 15.1	1 17.2	2 16.3	2 19.6	2 22.2
Channel 11 (hilly terrain)/mobile reception	9 5.6	1 8.7	1 10.0	1 10.5	1 13.3	1 15.8	1 14.8	2 18.1	2 20.7

TABLE 61

$(C/N)_{min}$ for RAVIS with 200 kHz channel bandwidth

Channel model/ reception mode	**$(C/N)_{min}$ (dB)**								
	QPSK			**16-QAM**			**64-QAM**		
	***R* = 1/2**	***R* = 2/3**	***R* = 3/4**	***R* = 1/2**	***R* = 2/3**	***R* = 3/4**	***R* = 1/2**	***R* = 2/3**	***R* = 3/4**
Channel 7 (AWGN)/fixed reception	4 1.1	5 3.3	6 4.2	8 6.4	1 9.1	1 10.2	1 10.8	1 14.0	1 15.4
Channel 8 (urban)/ portable reception	1 6.4	1 9.4	1 11.5	1 12.5	1 14.9	1 17.0	2 16.2	2 19.4	2 22.0
Channel 11 (hilly terrain)/mobile reception	1 5.5	1 8.6	1 9.8	1 10.4	1 13.2	1 15.6	1 14.7	2 17.9	2 20.5

TABLE 62

$(C/N)_{min}$ for RAVIS with 250 kHz channel bandwidth

Channel model /reception mode	**$(C/N)_{min}$ (dB)**								
	QPSK			**16-QAM**			**64-QAM**		
	***R* = 1/2**	***R* = 2/3**	***R* = 3/4**	***R* = 1/2**	***R* = 2/3**	***R* = 3/4**	***R* = 1/2**	***R* = 2/3**	***R* = 3/4**
Channel 7 (AWGN) /fixed reception	5 1.1	5 3.2	6 4.2	8 6.3	1 9.1	1 10.2	1 10.6	1 14.0	1 15.4
Channel 8 (urban) /portable reception	1 6.4	1 9.4	1 11.5	1 12.4	2 14.9	2 17.0	2 16.1	2 19.4	2 22.0
Channel 11 (hilly terrain)/mobile reception	1 5.5	1 8.5	1 9.8	1 10.3	1 13.2	1 15.6	2 14.6	2 17.9	2 20.5

5.3 RAVIS planning parameters

5.3.1 Minimum median field-strength

Based on the parameters and equations set above, the minimum median field-strength level for different reception modes and frequency Bands I and II can be calculated for all sets of RAVIS system parameters, as shown in Tables 63 to 80.

TABLE 63

Minimum median field-strength level E_{med} for 100 kHz channel bandwidth and QPSK modulation in Band I

Reception mode			FX	PI	PI-H	PO	PO-H	MO
Receiver noise figure	F (dB)		7.00	7.00	7.00	7.00	7.00	7.00
Receiver noise input power	P_n (dBW)		−146.98	−146.98	−146.98	−146.98	−146.98	−146.98
Minimum C/N	$(C/N)_{min}$ (dB)	R = 1/2	51.2	16.5	16.5	16.5	16.5	95.6
		R = 2/3	63.4	19.5	19.5	19.5	19.5	18.7
		R = 3/4	64.3	111.7	111.7	111.7	111.7	110.0
Implementation loss	L_i (dB)		3.00	3.00	3.00	3.00	3.00	3.00
Minimum receiver input power level	$P_{s,min}$ (dBW)	R = 1/2	−142.78	−137.48	−137.48	−137.48	−137.48	−138.38
		R = 2/3	−140.58	−134.48	−134.48	−134.48	−134.48	−135.28
		R = 3/4	−139.68	−132.28	−132.28	−132.28	−132.28	−133.98
Antenna gain	G_d (dBd)		0.00	−2.20	−22.76	−2.20	−22.76	−2.20
Effective antenna aperture	A_a (dBm^2)		4.44	2.24	−18.32	2.24	−18.32	2.24
Feeder-loss	L_f (dB)		1.10	0.00	0.00	0.00	0.00	0.22
Minimum power flux-density at receiving place	φ_{min} (dBW/m^2)	R = 1/2	−146.12	−139.72	−119.16	−139.72	−119.16	−140.40
		R = 2/3	−143.92	−136.72	−116.16	−136.72	−116.16	−137.30
		R = 3/4	−143.02	−134.52	−113.96	−134.52	−113.96	−136.00
Minimum field-strength level at receiving antenna	E_{min} (dB(μV/m))	R = 1/2	−0.32	6.08	26.64	6.08	26.64	5.40
		R = 2/3	1.88	9.08	29.64	9.08	29.64	8.50
		R = 3/4	2.78	11.28	31.84	11.28	31.84	9.80
Allowance for man-made noise	P_{MMN} (dB)		15.38	15.38	0.00	15.38	0.00	15.38
Location probability	p (%)		70.00	95.00	95.00	95.00	95.00	99.00
Distribution factor	μ		0.52	1.65	1.65	1.65	1.65	2.33
Standard deviation of field strength	σ_m (dB)		3.56	3.56	3.56	83.56	83.56	82.86
Standard deviation of man-made noise	σ_{MMN} (dB)		4.53	4.53	0.00	4.53	0.00	4.53
Standard deviation of building penetration loss	σ_b (dB)		0.00	3.00	3.00	0.00	0.00	0.00
Combined standard deviation of field strength	σ_c (dB)		5.76	6.50	4.66	5.76	3.56	5.36
Location correction factor	C_l (dB)		3.00	10.72	7.68	9.51	5.87	12.48
Antenna height loss	L_h (dB)		0.00	8.00	815.00	8.00	815.00	8.00
Building penetration loss	L_b (dB)		0.00	98.00	98.00	0.00	0.00	0.00
Minimum median field-strength level	E_{med} (dB(μV/m))	R = 1/2	18.06	48.18	57.32	38.97	47.51	41.26
		R = 2/3	20.26	51.18	60.32	41.97	50.51	44.36
		R = 3/4	21.16	53.38	62.52	44.17	52.71	45.66

TABLE 64

Minimum median field-strength level E_{med} for 100 kHz channel bandwidth and QPSK modulation in Band II

Reception mode			FX	PI	PI−H	PO	PO−H	MO
Receiver noise figure	F (dB)		7.00	7.00	7.00	7.00	7.00	7.00
Receiver noise input power	P_n (dBW)		−146.98	−146.98	−146.98	−146.98	−146.98	−146.98
Minimum C/N	$(C/N)_{min}$ (dB)	R = 1/2	1.20	6.50	6.50	6.50	6.50	5.60
		R = 2/3	3.40	9.50	9.50	9.50	9.50	8.70
		R = 3/4	4.30	11.70	11.70	11.70	11.70	10.00
Implementation loss	L_i (dB)		3.00	3.00	3.00	3.00	3.00	3.00
Minimum receiver input power level	$P_{s,min}$ (dBW)	R = 1/2	−142.78	−137.48	−137.48	−137.48	−137.48	−138.38
		R = 2/3	−140.58	−134.48	−134.48	−134.48	−134.48	−135.28
		R = 3/4	−139.68	−132.28	−132.28	−132.28	−132.28	−133.98
Antenna gain	G_d (dBd)		0.00	−2.20	−19.02	−2.20	−19.02	−2.20
Effective antenna aperture	A_a (dBm^2)		0.70	−1.50	−18.32	−1.50	−18.32	−1.50
Feeder-loss	L_f (dB)		1.40	0.00	0.00	0.00	0.00	0.28
Minimum power flux-density at receiving place	φ_{min} (dBW/m^2)	R = 1/2	−142.08	−135.98	−119.16	−135.98	−119.16	−136.60
		R = 2/3	−139.88	−132.98	−116.16	−132.98	−116.16	−133.50
		R = 3/4	−138.98	−130.78	−113.96	−130.78	−113.96	−132.20
Minimum field-strength level at receiving antenna	E_{min} (dB(μV/m))	R = 1/2	3.72	9.82	26.64	9.82	26.64	9.20
		R = 2/3	5.92	12.82	29.64	12.82	29.64	12.30
		R = 3/4	6.82	15.02	31.84	15.02	31.84	13.60
Allowance for man-made noise	P_{MMN} (dB)		10.43	10.43	0.00	10.43	0.00	10.43
Location probability	p (%)		70.00	95.00	95.00	95.00	95.00	99.00
Distribution factor	μ		0.52	1.65	1.65	1.65	1.65	2.33
Standard deviation of field strength	σ_m (dB)		3.80	3.80	3.80	3.80	3.80	3.10
Standard deviation of man-made noise	σ_{MMN} (dB)		4.53	4.53	0.00	4.53	0.00	4.53
Standard deviation of building penetration loss	σ_b (dB)		0.00	3.00	3.00	0.00	0.00	0.00
Combined standard deviation of field strength	σ_c (dB)		5.91	6.63	4.84	5.91	3.80	5.49
Location correction factor	C_l (dB)		3.07	10.94	7.99	9.76	6.27	12.79
Antenna height loss	L_h (dB)		0.00	10.00	17.00	10.00	17.00	10.00
Building penetration loss	L_b (dB)		0.00	9.00	9.00	0.00	0.00	0.00
Minimum median field-strength level	E_{med} (dB(μV/m))	R = 1/2	17.23	50.19	60.63	40.01	49.91	42.42
		R = 2/3	19.43	53.19	63.63	43.01	52.91	45.52
		R = 3/4	20.33	55.39	65.83	45.21	55.11	46.82

TABLE 65

Minimum median field-strength level E_{med} for 100 kHz channel bandwidth and 16-QAM modulation in Band I

Reception mode			FX	PI	PI−H	PO	PO−H	MO
Receiver noise figure	F (dB)		7.00	7.00	7.00	7.00	7.00	7.00
Receiver noise input power	P_n (dBW)		−146.98	−146.98	−146.98	−146.98	−146.98	−146.98
Minimum C/N	$(C/N)_{min}$ (dB)	R = 1/2	6.60	12.60	12.60	12.60	12.60	10.50
		R = 2/3	9.20	15.10	15.10	15.10	15.10	13.30
		R = 3/4	10.30	17.20	17.20	17.20	17.20	15.80
Implementation loss	L_i (dB)		3.00	3.00	3.00	3.00	3.00	3.00
Minimum receiver input power level	$P_{s,min}$ (dBW)	R = 1/2	−137.38	−131.38	−131.38	−131.38	−131.38	−133.48
		R = 2/3	−134.78	−128.88	−128.88	−128.88	−128.88	−130.68
		R = 3/4	−133.68	−126.78	−126.78	−126.78	−126.78	−128.18
Antenna gain	G_d (dBd)		0.00	−2.20	−22.76	−2.20	−22.76	−2.20
Effective antenna aperture	A_a (dBm^2)		4.44	2.24	−18.32	2.24	−18.32	2.24
Feeder-loss	L_f (dB)		1.10	0.00	0.00	0.00	0.00	0.22
Minimum power flux-density at receiving place	φ_{min} (dBW/m^2)	R = 1/2	−140.72	−133.62	−113.06	−133.62	−113.06	−135.50
		R = 2/3	−138.12	−131.12	−110.56	−131.12	−110.56	−132.70
		R = 3/4	−137.02	−129.02	−108.46	−129.02	−108.46	−130.20
Minimum field-strength level at receiving antenna	E_{min} (dB(μV/m))	R = 1/2	5.08	12.18	32.74	12.18	32.74	10.30
		R = 2/3	7.68	14.68	35.24	14.68	35.24	13.10
		R = 3/4	8.78	16.78	37.34	16.78	37.34	15.60
Allowance for man-made noise	P_{MMN} (dB)		15.38	15.38	0.00	15.38	0.00	15.38
Location probability	p (%)		70.00	95.00	95.00	95.00	95.00	99.00
Distribution factor	μ		0.52	1.65	1.65	1.65	1.65	2.33
Standard deviation of field strength	σ_m (dB)		3.56	3.56	3.56	3.56	3.56	2.86
Standard deviation of man-made noise	σ_{MMN} (dB)		4.53	4.53	0.00	4.53	0.00	4.53
Standard deviation of building penetration loss	σ_b (dB)		0.00	3.00	3.00	0.00	0.00	0.00
Combined standard deviation of field strength	σ_c (dB)		5.76	6.50	4.66	5.76	3.56	5.36
Location correction factor	C_l (dB)		3.00	10.72	7.68	9.51	5.87	12.48
Antenna height loss	L_h (dB)		0.00	8.00	815.00	8.00	815.00	8.00
Building penetration loss	L_b		0.00	98.00	98.00	0.00	0.00	0.00
Minimum median field-strength level	E_{med} (dB(μV/m))	R = 1/2	23.46	54.28	63.42	45.07	53.61	46.16
		R = 2/3	26.06	56.78	65.92	47.57	56.11	48.96
		R = 3/4	27.16	58.88	68.02	49.67	58.21	51.46

TABLE 66

Minimum median field-strength level E_{med} for 100 kHz channel bandwidth and 16-QAM modulation in Band II

Reception mode			FX	PI	PI-H	PO	PO-H	MO
Receiver noise figure	F (dB)		7.00	7.00	7.00	7.00	7.00	7.00
Receiver noise input power	P_n (dBW)		−146.98	−146.98	−146.98	−146.98	−146.98	−146.98
Minimum C/N	$(C/N)_{min}$ (dB)	R = 1/2	6.60	12.60	12.60	12.60	12.60	10.50
		R = 2/3	9.20	15.10	15.10	15.10	15.10	13.30
		R = 3/4	10.30	17.20	17.20	17.20	17.20	15.80
Implementation loss	L_i (dB)		3.00	3.00	3.00	3.00	3.00	3.00
Minimum receiver input power level	$P_{s,min}$ (dBW)	R = 1/2	−137.38	−131.38	−131.38	−131.38	−131.38	−133.48
		R = 2/3	−134.78	−128.88	−128.88	−128.88	−128.88	−130.68
		R = 3/4	−133.68	−126.78	−126.78	−126.78	−126.78	−128.18
Antenna gain	G_d (dBd)		0.00	−2.20	−19.02	−2.20	−19.02	−2.20
Effective antenna aperture	A_a (dBm^2)		0.70	−1.50	−18.32	−1.50	−18.32	−1.50
Feeder-loss	L_f (dB)		1.40	0.00	0.00	0.00	0.00	0.28
Minimum power flux-density at receiving place	φ_{min} (dBW/m^2)	R = 1/2	−136.68	−129.88	−113.06	−129.88	−113.06	−131.70
		R = 2/3	−134.08	−127.38	−110.56	−127.38	−110.56	−128.90
		R = 3/4	−132.98	−125.28	−108.46	−125.28	−108.46	−126.40
Minimum field-strength level at receiving antenna	E_{min} (dB(μV/m))	R = 1/2	9.12	15.92	32.74	15.92	32.74	14.10
		R = 2/3	11.72	18.42	35.24	18.42	35.24	16.90
		R = 3/4	12.82	20.52	37.34	20.52	37.34	19.40
Allowance for man-made noise	P_{MMN} (dB)		10.43	10.43	0.00	10.43	0.00	10.43
Location probability	p (%)		70.00	95.00	95.00	95.00	95.00	99.00
Distribution factor	μ		0.52	1.65	1.65	1.65	1.65	2.33
Standard deviation of field strength	σ_m (dB)		3.80	3.80	3.80	3.80	3.80	3.10
Standard deviation of man-made noise	σ_{MMN} (dB)		4.53	4.53	0.00	4.53	0.00	4.53
Standard deviation of building penetration loss	σ_b (dB)		0.00	3.00	3.00	0.00	0.00	0.00
Combined standard deviation of field strength	σ_c (dB)		5.91	6.63	4.84	5.91	3.80	5.49
Location correction factor	C_l (dB)		3.07	10.94	7.99	9.76	6.27	12.79
Antenna height loss	L_h (dB)		0.00	10.00	17.00	10.00	17.00	10.00
Building penetration loss	L_b (dB)		0.00	9.00	9.00	0.00	0.00	0.00
Minimum median field-strength level	E_{med} (dB(μV/m))	R = 1/2	22.63	56.29	66.73	46.11	56.01	47.32
		R = 2/3	25.23	58.79	69.23	48.61	58.51	50.12
		R = 3/4	26.33	60.89	71.33	50.71	60.61	52.62

TABLE 67

Minimum median field-strength level E_{med} for 100 kHz channel bandwidth and 64-QAM modulation in Band I

Reception mode			FX	PI	PI-H	PO	PO-H	MO
Receiver noise figure	F (dB)		7.00	7.00	7.00	7.00	7.00	7.00
Receiver noise input power	P_n (dBW)		−146.98	−146.98	−146.98	−146.98	−146.98	−146.98
Minimum C/N	$(C/N)_{min}$ (dB)	R = 1/2	10.90	16.30	16.30	16.30	16.30	14.80
		R = 2/3	14.20	19.60	19.60	19.60	19.60	18.10
		R = 3/4	15.60	22.20	22.20	22.20	22.20	20.70
Implementation loss	L_i (dB)		3.00	3.00	3.00	3.00	3.00	3.00
Minimum receiver input power level	$P_{s,min}$ (dBW)	R = 1/2	−133.08	−127.68	−127.68	−127.68	−127.68	−129.18
		R = 2/3	−129.78	−124.38	−124.38	−124.38	−124.38	−125.88
		R = 3/4	−128.38	−121.78	−121.78	−121.78	−121.78	−123.28
Antenna gain	G_d (dBd)		0.00	−2.20	−22.76	−2.20	−22.76	−2.20
Effective antenna aperture	A_a (dBm^2)		4.44	2.24	−18.32	2.24	−18.32	2.24
Feeder-loss	L_f (dB)		1.10	0.00	0.00	0.00	0.00	0.22
Minimum power flux-density at receiving place	φ_{min} (dBW/m^2)	R = 1/2	−136.42	−129.92	−109.36	−129.92	−109.36	−131.20
		R = 2/3	−133.12	−126.62	−106.06	−126.62	−106.06	−127.90
		R = 3/4	−131.72	−124.02	−103.46	−124.02	−103.46	−125.30
Minimum field-strength level at receiving antenna	E_{min} (dB(μV/m))	R = 1/2	9.38	15.88	36.44	15.88	36.44	14.60
		R = 2/3	12.68	19.18	39.74	19.18	39.74	17.90
		R = 3/4	14.08	21.78	42.34	21.78	42.34	20.50
Allowance for man-made noise	P_{MMN} (dB)		15.38	15.38	0.00	15.38	0.00	15.38
Location probability	p (%)		70.00	95.00	95.00	95.00	95.00	99.00
Distribution factor	μ		0.52	1.65	1.65	1.65	1.65	2.33
Standard deviation of field strength	σ_m (dB)		3.56	3.56	3.56	3.56	3.56	2.86
Standard deviation of man-made noise	σ_{MMN} (dB)		4.53	4.53	0.00	4.53	0.00	4.53
Standard deviation of building penetration loss	σ_b (dB)		0.00	3.00	3.00	0.00	0.00	0.00
Combined standard deviation of field strength	σ_c (dB)		5.76	6.50	4.66	5.76	3.56	5.36
Location correction factor	C_l (dB)		3.00	10.72	7.68	9.51	5.87	12.48
Antenna height loss	L_h (dB)		0.00	8.00	815.00	8.00	815.00	8.00
Building penetration loss	L_b (dB)		0.00	98.00	98.00	0.00	0.00	0.00
Minimum median field-strength level	E_{med} (dB(μV/m))	R = 1/2	27.76	57.98	67.12	48.77	57.31	50.46
		R = 2/3	31.06	61.28	70.42	52.07	60.61	53.76
		R = 3/4	32.46	63.88	73.02	54.67	63.21	56.36

TABLE 68

Minimum median field-strength level E_{med} for 100 kHz channel bandwidth and 64-QAM modulation in Band II

Reception mode			FX	PI	PI-H	PO	PO-H	MO
Receiver noise figure	F (dB)		7.00	7.00	7.00	7.00	7.00	7.00
Receiver noise input power	P_n (dBW)		−146.98	−146.98	−146.98	−146.98	−146.98	−146.98
Minimum C/N	$(C/N)_{min}$ (dB)	R = 1/2	10.90	16.30	16.30	16.30	16.30	14.80
		R = 2/3	14.20	19.60	19.60	19.60	19.60	18.10
		R = 3/4	15.60	22.20	22.20	22.20	22.20	20.70
Implementation loss	L_i (dB)		3.00	3.00	3.00	3.00	3.00	3.00
Minimum receiver input power level	$P_{s,min}$ (dBW)	R = 1/2	−133.08	−127.68	−127.68	−127.68	−127.68	−129.18
		R = 2/3	−129.78	−124.38	−124.38	−124.38	−124.38	−125.88
		R = 3/4	−128.38	−121.78	−121.78	−121.78	−121.78	−123.28
Antenna gain	G_d (dBd)		0.00	−2.20	−19.02	−2.20	−19.02	−2.20
Effective antenna aperture	A_a (dBm^2)		0.70	−1.50	−18.32	−1.50	−18.32	−1.50
Feeder-loss	L_f (dB)		1.40	0.00	0.00	0.00	0.00	0.28
Minimum power flux-density at receiving place	φ_{min} (dBW/m^2)	R = 1/2	−132.38	−126.18	−109.36	−126.18	−109.36	−127.40
		R = 2/3	−129.08	−122.88	−106.06	−122.88	−106.06	−124.10
		R = 3/4	−127.68	−120.28	−103.46	−120.28	−103.46	−121.50
Minimum field-strength level at receiving antenna	E_{min} (dB(μV/m))	R = 1/2	13.42	19.62	36.44	19.62	36.44	18.40
		R = 2/3	16.72	22.92	39.74	22.92	39.74	21.70
		R = 3/4	18.12	25.52	42.34	25.52	42.34	24.30
Allowance for man-made noise	P_{MMN} (dB)		10.43	10.43	0.00	10.43	0.00	10.43
Location probability	p (%)		70.00	95.00	95.00	95.00	95.00	99.00
Distribution factor	μ		0.52	1.65	1.65	1.65	1.65	2.33
Standard deviation of field strength	σ_m (dB)		3.80	3.80	3.80	3.80	3.80	3.10
Standard deviation of man-made noise	σ_{MMN} (dB)		4.53	4.53	0.00	4.53	0.00	4.53
Standard deviation of building penetration loss	σ_b (dB)		0.00	3.00	3.00	0.00	0.00	0.00
Combined standard deviation of field strength	σ_c (dB)		5.91	6.63	4.84	5.91	3.80	5.49
Location correction factor	C_l (dB)		3.07	10.94	7.99	9.76	6.27	12.79
Antenna height loss	L_h (dB)		0.00	10.00	17.00	10.00	17.00	10.00
Building penetration loss	L_b (dB)		0.00	9.00	9.00	0.00	0.00	0.00
Minimum median field-strength level	E_{med} (dB(μV/m))	R = 1/2	26.93	59.99	70.43	49.81	59.71	51.62
		R = 2/3	30.23	63.29	73.73	53.11	63.01	54.92
		R = 3/4	31.63	65.89	76.33	55.71	65.61	57.52

TABLE 69

Minimum median field-strength level E_{med} for 200 kHz channel bandwidth and QPSK modulation in Band I

Reception mode			FX	PI	PI-H	PO	PO-H	MO
Receiver noise figure	F (dB)		7.00	7.00	7.00	7.00	7.00	7.00
Receiver noise input power	P_n (dBW)		−143.97	−143.97	−143.97	−143.97	−143.97	−143.97
Minimum C/N	$(C/N)_{min}$ (dB)	R = 1/2	1.10	6.40	6.40	6.40	6.40	5.50
		R = 2/3	3.30	9.40	9.40	9.40	9.40	8.60
		R = 3/4	4.20	11.50	11.50	11.50	11.50	9.80
Implementation loss	L_i (dB)		3.00	3.00	3.00	3.00	3.00	3.00
Minimum receiver input power level	$P_{s,min}$ (dBW)	R = 1/2	−139.87	−134.57	−134.57	−134.57	−134.57	−135.47
		R = 2/3	−137.67	−131.57	−131.57	−131.57	−131.57	−132.37
		R = 3/4	−136.77	−129.47	−129.47	−129.47	−129.47	−131.17
Antenna gain	G_d (dBd)		0.00	−2.20	−22.76	−2.20	−22.76	−2.20
Effective antenna aperture	A_a (dBm^2)		4.44	2.24	−18.32	2.24	−18.32	2.24
Feeder-loss	L_f (dB)		1.10	0.00	0.00	0.00	0.00	0.22
Minimum power flux-density at receiving place	φ_{min} (dBW/m^2)	R = 1/2	−143.21	−136.81	−116.25	−136.81	−116.25	−137.49
		R = 2/3	−141.01	−133.81	−113.25	−133.81	−113.25	−134.39
		R = 3/4	−140.11	−131.71	−111.15	−131.71	−111.15	−133.19
Minimum field-strength level at receiving antenna	E_{min} (dB(μV/m))	R = 1/2	2.59	8.99	29.55	8.99	29.55	8.31
		R = 2/3	4.79	11.99	32.55	11.99	32.55	11.41
		R = 3/4	5.69	14.09	34.65	14.09	34.65	12.61
Allowance for man-made noise	P_{MMN} (dB)		15.38	15.38	0.00	15.38	0.00	15.38
Location probability	p (%)		70.00	95.00	95.00	95.00	95.00	99.00
Distribution factor	μ		0.52	1.65	1.65	1.65	1.65	2.33
Standard deviation of field strength	σ_m (dB)		3.56	3.56	3.56	3.56	3.56	2.86
Standard deviation of man-made noise	σ_{MMN} (dB)		4.53	4.53	0.00	4.53	0.00	4.53
Standard deviation of building penetration loss	σ_b (dB)		0.00	3.00	3.00	0.00	0.00	0.00
Combined standard deviation of field strength	σ_c (dB)		5.76	6.50	4.66	5.76	3.56	5.36
Location correction factor	C_l (dB)		3.00	10.72	7.68	9.51	5.87	12.48
Antenna height loss	L_h (dB)		0.00	8.00	815.00	8.00	815.00	8.00
Building penetration loss	L_b (dB)		0.00	98.00	98.00	0.00	0.00	0.00
Minimum median field-strength level	E_{med} (dB(μV/m))	R = 1/2	20.97	51.09	60.23	41.88	50.42	44.17
		R = 2/3	23.17	54.09	63.23	44.88	53.42	47.27
		R = 3/4	24.07	56.19	65.33	46.98	55.52	48.47

TABLE 70

Minimum median field-strength level E_{med} for 200 kHz channel bandwidth and QPSK modulation in Band II

Reception mode			**FX**	**PI**	**PI-H**	**PO**	**PO-H**	**MO**
Receiver noise figure	F (dB)		7.00	7.00	7.00	7.00	7.00	7.00
Receiver noise input power	P_n (dBW)		−143.97	−143.97	−143.97	−143.97	−143.97	−143.97
Minimum C/N	$(C/N)_{min}$ (dB)	R = 1/2	1.10	6.40	6.40	6.40	6.40	5.50
		R = 2/3	3.30	9.40	9.40	9.40	9.40	8.60
		R = 3/4	4.20	11.50	11.50	11.50	11.50	9.80
Implementation loss	L_i (dB)		3.00	3.00	3.00	3.00	3.00	3.00
Minimum receiver input power level	$P_{s,min}$ (dBW)	R = 1/2	−139.87	−134.57	−134.57	−134.57	−134.57	−135.47
		R = 2/3	−137.67	−131.57	−131.57	−131.57	−131.57	−132.37
		R = 3/4	−136.77	−129.47	−129.47	−129.47	−129.47	−131.17
Antenna gain	G_d (dBd)		0.00	−2.20	−19.02	−2.20	−19.02	−2.20
Effective antenna aperture	A_a (dBm^2)		0.70	−1.50	−18.32	−1.50	−18.32	−1.50
Feeder-loss	L_f (dB)		1.40	0.00	0.00	0.00	0.00	0.28
Minimum power flux-density at receiving place	φ_{min} (dBW/m^2)	R = 1/2	−139.17	−133.07	−116.25	−133.07	−116.25	−133.69
		R = 2/3	−136.97	−130.07	−113.25	−130.07	−113.25	−130.59
		R = 3/4	−136.07	−127.97	−111.15	−127.97	−111.15	−129.39
Minimum field-strength level at receiving antenna	E_{min} (dB(μV/m))	R = 1/2	6.63	12.73	29.55	12.73	29.55	12.11
		R = 2/3	8.83	15.73	32.55	15.73	32.55	15.21
		R = 3/4	9.73	17.83	34.65	17.83	34.65	16.41
Allowance for man-made noise	P_{MMN} (dB)		10.43	10.43	0.00	10.43	0.00	10.43
Location probability	p (%)		70.00	95.00	95.00	95.00	95.00	99.00
Distribution factor	μ		0.52	1.65	1.65	1.65	1.65	2.33
Standard deviation of field strength	σ_m (dB)		3.80	3.80	3.80	3.80	3.80	3.10
Standard deviation of man-made noise	σ_{MMN} (dB)		4.53	4.53	0.00	4.53	0.00	4.53
Standard deviation of building penetration loss	σ_b (dB)		0.00	3.00	3.00	0.00	0.00	0.00
Combined standard deviation of field strength	σ_c (dB)		5.91	6.63	4.84	5.91	3.80	5.49
Location correction factor	C_l (dB)		3.07	10.94	7.99	9.76	6.27	12.79
Antenna height loss	L_h (dB)		0.00	10.00	17.00	10.00	17.00	10.00
Building penetration loss	L_b (dB)		0.00	9.00	9.00	0.00	0.00	0.00
Minimum median field-strength level	E_{med} (dB(μV/m))	R = 1/2	20.14	53.10	63.54	42.92	52.82	45.33
		R = 2/3	22.34	56.10	66.54	45.92	55.82	48.43
		R = 3/4	23.24	58.20	68.64	48.02	57.92	49.63

TABLE 71

Minimum median field-strength level E_{med} for 200 kHz channel bandwidth and 16-QAM modulation in Band I

Reception mode			**FX**	**PI**	**PI-H**	**PO**	**PO-H**	**MO**
Receiver noise figure	F (dB)		7.00	7.00	7.00	7.00	7.00	7.00
Receiver noise input power	P_n (dBW)		−143.97	−143.97	−143.97	−143.97	−143.97	−143.97
Minimum C/N	$(C/N)_{min}$ (dB)	R = 1/2	6.40	12.50	12.50	12.50	12.50	10.40
		R = 2/3	9.10	14.90	14.90	14.90	14.90	13.20
		R = 3/4	10.20	17.00	17.00	17.00	17.00	15.60
Implementation loss	L_i (dB)		3.00	3.00	3.00	3.00	3.00	3.00
Minimum receiver input power level	$P_{s,min}$ (dBW)	R = 1/2	−134.57	−128.47	−128.47	−128.47	−128.47	−130.57
		R = 2/3	−131.87	−126.07	−126.07	−126.07	−126.07	−127.77
		R = 3/4	−130.77	−123.97	−123.97	−123.97	−123.97	−125.37
Antenna gain	G_d (dBd)		0.00	−2.20	−22.76	−2.20	−22.76	−2.20
Effective antenna aperture	A_a (dBm^2)		4.44	2.24	−18.32	2.24	−18.32	2.24
Feeder-loss	L_f (dB)		1.10	0.00	0.00	0.00	0.00	0.22
Minimum power flux-density at receiving place	φ_{min} (dBW/m^2)	R = 1/2	−137.91	−130.71	−110.15	−130.71	−110.15	−132.59
		R = 2/3	−135.21	−128.31	−107.75	−128.31	−107.75	−129.79
		R = 3/4	−134.11	−126.21	−105.65	−126.21	−105.65	−127.39
Minimum field-strength level at receiving antenna	E_{min} (dB(μV/m))	R = 1/2	7.89	15.09	35.65	15.09	35.65	13.21
		R = 2/3	10.59	17.49	38.05	17.49	38.05	16.01
		R = 3/4	11.69	19.59	40.15	19.59	40.15	18.41
Allowance for man-made noise	P_{MMN} (dB)		15.38	15.38	0.00	15.38	0.00	15.38
Location probability	p (%)		70.00	95.00	95.00	95.00	95.00	99.00
Distribution factor	μ		0.52	1.65	1.65	1.65	1.65	2.33
Standard deviation of field strength	σ_m (dB)		3.56	3.56	3.56	3.56	3.56	2.86
Standard deviation of man-made noise	σ_{MMN} (dB)		4.53	4.53	0.00	4.53	0.00	4.53
Standard deviation of building penetration loss	σ_b (dB)		0.00	3.00	3.00	0.00	0.00	0.00
Combined standard deviation of field strength	σ_c (dB)		5.76	6.50	4.66	5.76	3.56	5.36
Location correction factor	C_l (dB)		3.00	10.72	7.68	9.51	5.87	12.48
Antenna height loss	L_h (dB)		0.00	8.00	815.00	8.00	815.00	8.00
Building penetration loss	L_b (dB)		0.00	98.00	98.00	0.00	0.00	0.00
Minimum median field-strength level	E_{med} (dB(μV/m))	R = 1/2	26.27	57.19	66.33	47.98	56.52	49.07
		R = 2/3	28.97	59.59	68.73	50.38	58.92	51.87
		R = 3/4	30.07	61.69	70.83	52.48	61.02	54.27

TABLE 72

Minimum median field-strength level E_{med} for 200 kHz channel bandwidth and 16-QAM modulation in Band II

Reception mode			**FX**	**PI**	**PI-H**	**PO**	**PO-H**	**MO**
Receiver noise figure	F (dB)		7.00	7.00	7.00	7.00	7.00	7.00
Receiver noise input power	P_n (dBW)		−143.97	−143.97	−143.97	−143.97	−143.97	−143.97
Minimum C/N	$(C/N)_{min}$ (dB)	R = 1/2	6.40	12.50	12.50	12.50	12.50	10.40
		R = 2/3	9.10	14.90	14.90	14.90	14.90	13.20
		R = 3/4	10.20	17.00	17.00	17.00	17.00	15.60
Implementation loss	L_i (dB)		3.00	3.00	3.00	3.00	3.00	3.00
Minimum receiver input power level	$P_{s\ min}$ (dBW)	R = 1/2	−134.57	−128.47	−128.47	−128.47	−128.47	−130.57
		R = 2/3	−131.87	−126.07	−126.07	−126.07	−126.07	−127.77
		R = 3/4	−130.77	−123.97	−123.97	−123.97	−123.97	−125.37
Antenna gain	G_d (dBd)		0.00	−2.20	−19.02	−2.20	−19.02	−2.20
Effective antenna aperture	A_a (dBm^2)		0.70	−1.50	−18.32	−1.50	−18.32	−1.50
Feeder-loss	L_f (dB)		1.40	0.00	0.00	0.00	0.00	0.28
Minimum power flux-density at receiving place	φ_{min} (dBW/m^2)	R = 1/2	−133.87	−126.97	−110.15	−126.97	−110.15	−128.79
		R = 2/3	−131.17	−124.57	−107.75	−124.57	−107.75	−125.99
		R = 3/4	−130.07	−122.47	−105.65	−122.47	−105.65	−123.59
Minimum field-strength level at receiving antenna	E_{min} (dB(μV/m))	R = 1/2	11.93	18.83	35.65	18.83	35.65	17.01
		R = 2/3	14.63	21.23	38.05	21.23	38.05	19.81
		R = 3/4	15.73	23.33	40.15	23.33	40.15	22.21
Allowance for man-made noise	P_{MMN} (dB)		10.43	10.43	0.00	10.43	0.00	10.43
Location probability	p (%)		70.00	95.00	95.00	95.00	95.00	99.00
Distribution factor	μ		0.52	1.65	1.65	1.65	1.65	2.33
Standard deviation of field strength	σ_m (dB)		3.80	3.80	3.80	3.80	3.80	3.10
Standard deviation of man-made noise	σ_{MMN} (dB)		4.53	4.53	0.00	4.53	0.00	4.53
Standard deviation of building penetration loss	σ_b (dB)		0.00	3.00	3.00	0.00	0.00	0.00
Combined standard deviation of field strength	σ_c (dB)		5.91	6.63	4.84	5.91	3.80	5.49
Location correction factor	C_l (dB)		3.07	10.94	7.99	9.76	6.27	12.79
Antenna height loss	L_h (dB)		0.00	10.00	17.00	10.00	17.00	10.00
Building penetration loss	L_b (dB)		0.00	9.00	9.00	0.00	0.00	0.00
Minimum median field-strength level	E_{med} (dB(μV/m))	R = 1/2	25.44	59.20	69.64	49.02	58.92	50.23
		R = 2/3	28.14	61.60	72.04	51.42	61.32	53.03
		R = 3/4	29.24	63.70	74.14	53.52	63.42	55.43

TABLE 73

Minimum median field-strength level E_{med} for 200 kHz channel bandwidth and 64-QAM modulation in Band I

Reception mode			**FX**	**PI**	**PI-H**	**PO**	**PO-H**	**MO**
Receiver noise figure	F (dB)		7.00	7.00	7.00	7.00	7.00	7.00
Receiver noise input power	P_n (dBW)		−143.97	−143.97	−143.97	−143.97	−143.97	−143.97
Minimum C/N	$(C/N)_{min}$ (dB)	R = 1/2	10.80	16.20	16.20	16.20	16.20	14.70
		R = 2/3	14.00	19.40	19.40	19.40	19.40	17.90
		R = 3/4	15.40	22.00	22.00	22.00	22.00	20.50
Implementation loss	L_i (dB)		3.00	3.00	3.00	3.00	3.00	3.00
Minimum receiver input power level	$P_{s,min}$ (dBW)	R = 1/2	−130.17	−124.77	−124.77	−124.77	−124.77	−126.27
		R = 2/3	−126.97	−121.57	−121.57	−121.57	−121.57	−123.07
		R = 3/4	−125.57	−118.97	−118.97	−118.97	−118.97	−120.47
Antenna gain	G_d (dBd)		0.00	−2.20	−22.76	−2.20	−22.76	−2.20
Effective antenna aperture	A_a (dBm^2)		4.44	2.24	−18.32	2.24	−18.32	2.24
Feeder-loss	L_f (dB)		1.10	0.00	0.00	0.00	0.00	0.22
Minimum power flux-density at receiving place	φ_{min} (dBW/m^2)	R = 1/2	−133.51	−127.01	−106.45	−127.01	−106.45	−128.29
		R = 2/3	−130.31	−123.81	−103.25	−123.81	−103.25	−125.09
		R = 3/4	−128.91	−121.21	−100.65	−121.21	−100.65	−122.49
Minimum field-strength level at receiving antenna	E_{min} (dB(μV/m))	R = 1/2	12.29	18.79	39.35	18.79	39.35	17.51
		R = 2/3	15.49	21.99	42.55	21.99	42.55	20.71
		R = 3/4	16.89	24.59	45.15	24.59	45.15	23.31
Allowance for man-made noise	P_{MMN} (dB)		15.38	15.38	0.00	15.38	0.00	15.38
Location probability	p (%)		70.00	95.00	95.00	95.00	95.00	99.00
Distribution factor	μ		0.52	1.65	1.65	1.65	1.65	2.33
Standard deviation of field strength	σ_m (dB)		3.56	3.56	3.56	3.56	3.56	2.86
Standard deviation of man-made noise	σ_{MMN} (dB)		4.53	4.53	0.00	4.53	0.00	4.53
Standard deviation of building penetration loss	σ_b (dB)		0.00	3.00	3.00	0.00	0.00	0.00
Combined standard deviation of field strength	σ_c (dB)		5.76	6.50	4.66	5.76	3.56	5.36
Location correction factor	C_l (dB)		3.00	10.72	7.68	9.51	5.87	12.48
Antenna height loss	L_h (dB)		0.00	8.00	815.00	815.00	8.00	8.00
Building penetration loss	L_b (dB)		0.00	98.00	98.00	0.00	0.00	0.00
Minimum median field-strength level	E_{med} (dB(μV/m))	R = 1/2	30.67	60.89	70.03	51.68	60.22	53.37
		R = 2/3	33.87	64.09	73.23	54.88	63.42	56.57
		R = 3/4	35.27	66.69	75.83	57.48	66.02	59.17

TABLE 74

Minimum median field-strength level E_{med} for 200 kHz channel bandwidth and 64-QAM modulation in Band II

Reception mode			FX	PI	PI-H	PO	PO-H	MO
Receiver noise figure	F (dB)		7.00	7.00	7.00	7.00	7.00	7.00
Receiver noise input power	P_n (dBW)		−143.97	−143.97	−143.97	−143.97	−143.97	−143.97
Minimum C/N	$(C/N)_{min}$ (dB)	R = 1/2	10.80	16.20	16.20	16.20	16.20	14.70
		R = 2/3	14.00	19.40	19.40	19.40	19.40	17.90
		R = 3/4	15.40	22.00	22.00	22.00	22.00	20.50
Implementation loss	L_i (dB)		3.00	3.00	3.00	3.00	3.00	3.00
Minimum receiver input power level	$P_{s,min}$ (dBW)	R = 1/2	−130.17	−124.77	−124.77	−124.77	−124.77	−126.27
		R = 2/3	−126.97	−121.57	−121.57	−121.57	−121.57	−123.07
		R = 3/4	−125.57	−118.97	−118.97	−118.97	−118.97	−120.47
Antenna gain	G_d (dBd)		0.00	−2.20	−19.02	−2.20	−19.02	−2.20
Effective antenna aperture	A_a (dBm^2)		0.70	−1.50	−18.32	−1.50	−18.32	−1.50
Feeder-loss	L_f (dB)		1.40	0.00	0.00	0.00	0.00	0.28
Minimum power flux-density at receiving place	φ_{min} (dBW/m^2)	R = 1/2	−129.47	−123.27	−106.45	−123.27	−106.45	−124.49
		R = 2/3	−126.27	−120.07	−103.25	−120.07	−103.25	−121.29
		R = 3/4	−124.87	−117.47	−100.65	−117.47	−100.65	−118.69
Minimum field-strength level at receiving antenna	E_{min} (dB(μV/m))	R = 1/2	16.33	22.53	39.35	22.53	39.35	21.31
		R = 2/3	19.53	25.73	42.55	25.73	42.55	24.51
		R = 3/4	20.93	28.33	45.15	28.33	45.15	27.11
Allowance for man-made noise	P_{MMN} (dB)		10.43	10.43	0.00	10.43	0.00	10.43
Location probability	p (%)		70.00	95.00	95.00	95.00	95.00	99.00
Distribution factor	μ		0.52	1.65	1.65	1.65	1.65	2.33
Standard deviation of field strength	σ_m (dB)		3.80	3.80	3.80	3.80	3.80	3.10
Standard deviation of man-made noise	σ_{MMN} (dB)		4.53	4.53	0.00	4.53	0.00	4.53
Standard deviation of building penetration loss	σ_b (dB)		0.00	3.00	3.00	0.00	0.00	0.00
Combined standard deviation of field strength	σ_c (dB)		5.91	6.63	4.84	5.91	3.80	5.49
Location correction factor	C_l (dB)		3.07	10.94	7.99	9.76	6.27	12.79
Antenna height loss	L_h (dB)		0.00	10.00	17.00	10.00	17.00	10.00
Building penetration loss	L_b (dB)		0.00	9.00	9.00	0.00	0.00	0.00
Minimum median field-strength level	E_{med} (dBμV/m)	R = 1/2	29.84	62.90	73.34	52.72	62.62	54.53
		R = 2/3	33.04	66.10	76.54	55.92	65.82	57.73
		R = 3/4	34.44	68.70	79.14	58.52	68.42	60.33

TABLE 75

Minimum median field-strength level E_{med} for 250 kHz channel bandwidth and QPSK modulation in Band I

Reception mode			FX	PI	PI-H	PO	PO-H	MO
Receiver noise figure	F (dB)		7.00	7.00	7.00	7.00	7.00	7.00
Receiver noise input power	P_n (dBW)		−143.00	−143.00	−143.00	−143.00	−143.00	−143.00
Minimum C/N	$(C/N)_{min}$ (dB)	R = 1/2	1.10	6.40	6.40	6.40	6.40	5.50
		R = 2/3	3.20	9.40	9.40	9.40	9.40	8.50
		R = 3/4	4.20	11.50	11.50	11.50	11.50	9.80
Implementation loss	L_i (dB)		3.00	3.00	3.00	3.00	3.00	3.00
Minimum receiver input power level	$P_{s,min}$ (dBW)	R = 1/2	−138.90	−133.60	−133.60	−133.60	−133.60	−134.50
		R = 2/3	−136.80	−130.60	−130.60	−130.60	−130.60	−131.50
		R = 3/4	−135.80	−128.50	−128.50	−128.50	−128.50	−130.20
Antenna gain	G_d (dBd)		0.00	−2.20	−22.76	−2.20	−22.76	−2.20
Effective antenna aperture	A_a (dBm^2)		4.44	2.24	−18.32	2.24	−18.32	2.24
Feeder-loss	L_f (dB)		1.10	0.00	0.00	0.00	0.00	0.22
Minimum power flux-density at receiving place	φ_{min} (dBW/m^2)	R = 1/2	−142.24	−135.84	−115.28	−135.84	−115.28	−136.52
		R = 2/3	−140.14	−132.84	−112.28	−132.84	−112.28	−133.52
		R = 3/4	−139.14	−130.74	−110.18	−130.74	−110.18	−132.22
Minimum field-strength level at receiving antenna	E_{min} (dB(μV/m))	R = 1/2	3.56	9.96	30.52	9.96	30.52	9.28
		R = 2/3	5.66	12.96	33.52	12.96	33.52	12.28
		R = 3/4	6.66	15.06	35.62	15.06	35.62	13.58
Allowance for man-made noise	P_{MMN} (dB)		15.38	15.38	0.00	15.38	0.00	15.38
Location probability	p (%)		70.00	95.00	95.00	95.00	95.00	99.00
Distribution factor	μ		0.52	1.65	1.65	1.65	1.65	2.33
Standard deviation of field strength	σ_m (dB)		3.56	3.56	3.56	3.56	3.56	2.86
Standard deviation of man-made noise	σ_{MMN} (dB)		4.53	4.53	0.00	4.53	0.00	4.53
Standard deviation of building penetration loss	σ_b (dB)		0.00	3.00	3.00	0.00	0.00	0.00
Combined standard deviation of field strength	σ_c (dB)		5.76	6.50	4.66	5.76	3.56	5.36
Location correction factor	C_l (dB)		3.00	10.72	7.68	9.51	5.87	12.48
Antenna height loss	L_h (dB)		0.00	8.00	815.00	8.00	815.00	8.00
Building penetration loss	L_b (dB)		0.00	98.00	98.00	0.00	0.00	0.00
Minimum median field-strength level	E_{med} (dB(μV/m))	R = 1/2	21.93	52.06	61.20	42.85	51.39	45.14
		R = 2/3	24.03	55.06	64.20	45.85	54.39	48.14
		R = 3/4	25.03	57.16	66.30	47.95	56.49	49.44

TABLE 76

Minimum median field-strength level E_{med} for 250 kHz channel bandwidth and QPSK modulation in Band II

Reception mode			FX	PI	PI-H	PO	PO-H	MO
Receiver noise figure	F (dB)		7.00	7.00	7.00	7.00	7.00	7.00
Receiver noise input power	P_n (dBW)		−143.00	−143.00	−143.00	−143.00	−143.00	−143.00
Minimum C/N	$(C/N)_{min}$ (dB)	R = 1/2	1.10	6.40	6.40	6.40	6.40	5.50
		R = 2/3	3.20	9.40	9.40	9.40	9.40	8.50
		R = 3/4	4.20	11.50	11.50	11.50	11.50	9.80
Implementation loss	L_i (dB)		3.00	3.00	3.00	3.00	3.00	3.00
Minimum receiver input power level	$P_{s,min}$ (dBW)	R = 1/2	−138.90	−133.60	−133.60	−133.60	−133.60	−134.50
		R = 2/3	−136.80	−130.60	−130.60	−130.60	−130.60	−131.50
		R = 3/4	−135.80	−128.50	−128.50	−128.50	−128.50	−130.20
Antenna gain	G_d (dBd)		0.00	−2.20	−19.02	−2.20	−19.02	−2.20
Effective antenna aperture	A_a (dBm^2)		0.70	−1.50	−18.32	−1.50	−18.32	−1.50
Feeder-loss	L_f (dB)		1.40	0.00	0.00	0.00	0.00	0.28
Minimum power flux-density at receiving place	φ_{min} (dBW/m^2)	R = 1/2	−138.20	−132.10	−115.28	−132.10	−115.28	−132.72
		R = 2/3	−136.10	−129.10	−112.28	−129.10	−112.28	−129.72
		R = 3/4	−135.10	−127.00	−110.18	−127.00	−110.18	−128.42
Minimum field-strength level at receiving antenna	E_{min} (dB(μV/m))	R = 1/2	7.60	13.70	30.52	13.70	30.52	13.08
		R = 2/3	9.70	16.70	33.52	16.70	33.52	16.08
		R = 3/4	10.70	18.80	35.62	18.80	35.62	17.38
Allowance for man-made noise	P_{MMN} (dB)		10.43	10.43	0.00	10.43	0.00	10.43
Location probability	p (%)		70.00	95.00	95.00	95.00	95.00	99.00
Distribution factor	μ		0.52	1.65	1.65	1.65	1.65	2.33
Standard deviation of field strength	σ_m (dB)		3.80	3.80	3.80	3.80	3.80	3.10
Standard deviation of man-made noise	σ_{MMN} (dB)		4.53	4.53	0.00	4.53	0.00	4.53
Standard deviation of building penetration loss	σ_b (dB)		0.00	3.00	3.00	0.00	0.00	0.00
Combined standard deviation of field strength	σ_c (dB)		5.91	6.63	4.84	5.91	3.80	5.49
Location correction factor	C_l (dB)		3.07	10.94	7.99	9.76	6.27	12.79
Antenna height loss	L_h (dB)		0.00	10.00	17.00	10.00	170.00	10.00
Building penetration loss	L_b (dB)		0.00	9.00	9.00	0.00	0.00	0.00
Minimum median field-strength level	E_{med} (dB(μV/m))	R = 1/2	21.11	54.07	64.51	43.89	53.79	46.30
		R = 2/3	23.21	57.07	67.51	46.89	56.79	49.30
		R = 3/4	24.21	59.17	69.61	48.99	58.89	50.60

TABLE 77

Minimum median field-strength level E_{med} for 250 kHz channel bandwidth and 16-QAM modulation in Band I

Reception mode			**FX**	**PI**	**PI-H**	**PO**	**PO-H**	**MO**
Receiver noise figure	F (dB)		7.00	7.00	7.00	7.00	7.00	7.00
Receiver noise input power	P_n (dBW)		−143.00	−143.00	−143.00	−143.00	−143.00	−143.00
Minimum C/N	$(C/N)_{min}$ (dB)	R = 1/2	6.30	12.40	12.40	12.40	12.40	10.30
		R = 2/3	9.10	14.90	14.90	14.90	14.90	13.20
		R = 3/4	10.20	17.00	17.00	17.00	17.00	15.60
Implementation loss	L_i (dB)		3.00	3.00	3.00	3.00	3.00	3.00
Minimum receiver input power level	$P_{s,min}$ (dBW)	R = 1/2	−133.70	−127.60	−127.60	−127.60	−127.60	−129.70
		R = 2/3	−130.90	−125.10	−125.10	−125.10	−125.10	−126.80
		R = 3/4	−129.80	−123.00	−123.00	−123.00	−123.00	−124.40
Antenna gain	G_d (dBd)		0.00	−2.20	−22.76	−2.20	−22.76	−2.20
Effective antenna aperture	A_a (dBm^2)		4.44	2.24	−18.32	2.24	−18.32	2.24
Feeder-loss	L_f (dB)		1.10	0.00	0.00	0.00	0.00	0.22
Minimum power flux-density at receiving place	φ_{min} (dBW/m^2)	R = 1/2	−137.04	−129.84	−109.28	−129.84	−109.28	−131.72
		R = 2/3	−134.24	−127.34	−106.78	−127.34	−106.78	−128.82
		R = 3/4	−133.14	−125.24	−104.68	−125.24	−104.68	−126.42
Minimum field-strength level at receiving antenna	E_{min} (dB(μV/m))	R = 1/2	8.76	15.96	36.52	15.96	36.52	14.08
		R = 2/3	11.56	18.46	39.02	18.46	39.02	16.98
		R = 3/4	12.66	20.56	41.12	20.56	41.12	19.38
Allowance for man-made noise	P_{MMN} (dB)		15.38	15.38	0.00	15.38	0.00	15.38
Location probability	p (%)		70.00	95.00	95.00	95.00	95.00	99.00
Distribution factor	μ		0.52	1.65	1.65	1.65	1.65	2.33
Standard deviation of field strength	σ_m (dB)		3.56	3.56	3.56	3.56	3.56	2.86
Standard deviation of man-made noise	σ_{MMN} (dB)		4.53	4.53	0.00	4.53	0.00	4.53
Standard deviation of building penetration loss	σ_b (dB)		0.00	3.00	3.00	0.00	0.00	0.00
Combined standard deviation of field strength	σ_c (dB)		5.76	6.50	4.66	5.76	3.56	5.36
Location correction factor	C_l (dB)		3.00	10.72	7.68	9.51	5.87	12.48
Antenna height loss	L_h (dB)		0.00	8.00	815.00	8.00	815.00	8.00
Building penetration loss	L_b (dB)		0.00	98.00	98.00	0.00	0.00	0.00
Minimum median field-strength level	E_{med} (dB(μV/m))	R = 1/2	27.13	58.06	67.20	48.85	57.39	49.94
		R = 2/3	29.93	60.56	69.70	51.35	59.89	52.84
		R = 3/4	31.03	62.66	71.80	53.45	61.99	55.24

TABLE 78

Minimum median field-strength level E_{med} for 250 kHz channel bandwidth and 16-QAM modulation in Band II

Reception mode			**FX**	**PI**	**PI-H**	**PO**	**PO-H**	**MO**
Receiver noise figure	F (dB)		7.00	7.00	7.00	7.00	7.00	7.00
Receiver noise input power	P_n (dBW)		−143.00	−143.00	−143.00	−143.00	−143.00	−143.00
Minimum C/N	$(C/N)_{min}$ (dB)	R = 1/2	6.30	12.40	12.40	12.40	12.40	10.30
		R = 2/3	9.10	14.90	14.90	14.90	14.90	13.20
		R = 3/4	10.20	17.00	17.00	17.00	17.00	15.60
Implementation loss	L_i (dB)		3.00	3.00	3.00	3.00	3.00	3.00
Minimum receiver input power level	$P_{s,min}$ (dBW)	R = 1/2	−133.70	−127.60	−127.60	−127.60	−127.60	−129.70
		R = 2/3	−130.90	−125.10	−125.10	−125.10	−125.10	−126.80
		R = 3/4	−129.80	−123.00	−123.00	−123.00	−123.00	−124.40
Antenna gain	G_d (dBd)		0.00	−2.20	−19.02	−2.20	−19.02	−2.20
Effective antenna aperture	A_a (dBm^2)		0.70	−1.50	−18.32	−1.50	−18.32	−1.50
Feeder-loss	L_f (dB)		1.40	0.00	0.00	0.00	0.00	0.28
Minimum power flux-density at receiving place	φ_{min} (dBW/m^2)	R = 1/2	−133.00	−126.10	−109.28	−126.10	−109.28	−127.92
		R = 2/3	−130.20	−123.60	−106.78	−123.60	−106.78	−125.02
		R = 3/4	−129.10	−121.50	−104.68	−121.50	−104.68	−122.62
Minimum field-strength level at receiving antenna	E_{min} (dB(μV/m))	R = 1/2	12.80	19.70	36.52	19.70	36.52	17.88
		R = 2/3	15.60	22.20	39.02	22.20	39.02	20.78
		R = 3/4	16.70	24.30	41.12	24.30	41.12	23.18
Allowance for man-made noise	P_{MMN} (dB)		10.43	10.43	0.00	10.43	0.00	10.43
Location probability	p (%)		70.00	95.00	95.00	95.00	95.00	99.00
Distribution factor	μ		0.52	1.65	1.65	1.65	1.65	2.33
Standard deviation of field strength	σ_m (dB)		3.80	3.80	3.80	3.80	3.80	3.10
Standard deviation of man-made noise	σ_{MMN} (dB)		4.53	4.53	0.00	4.53	0.00	4.53
Standard deviation of building penetration loss	σ_b (dB)		0.00	3.00	3.00	0.00	0.00	0.00
Combined standard deviation of field strength	σ_c (dB)		5.91	6.63	4.84	5.91	3.80	5.49
Location correction factor	C_l (dB)		3.07	10.94	7.99	9.76	6.27	12.79
Antenna height loss	L_h (dB)		0.00	10.00	17.00	10.00	17.00	10.00
Building penetration loss	L_b (dB)		0.00	9.00	9.00	0.00	0.00	0.00
Minimum median field-strength level	E_{med} (dB(μV/m))	R = 1/2	26.31	60.07	70.51	49.89	59.79	51.10
		R = 2/3	29.11	62.57	73.01	52.39	62.29	54.00
		R = 3/4	30.21	64.67	75.11	54.49	64.39	56.40

TABLE 79

Minimum median field-strength level E_{med} for 250 kHz channel bandwidth and 64-QAM modulation in Band I

Reception mode			**FX**	**PI**	**PI-H**	**PO**	**PO-H**	**MO**
Receiver noise figure	F (dB)		7.00	7.00	7.00	7.00	7.00	7.00
Receiver noise input power	P_n (dBW)		−143.00	−143.00	−143.00	−143.00	−143.00	−143.00
Minimum C/N	$(C/N)_{min}$ (dB)	R = 1/2	10.60	16.10	16.10	16.10	16.10	14.60
		R = 2/3	14.00	19.40	19.40	19.40	19.40	17.90
		R = 3/4	15.40	22.00	22.00	22.00	22.00	20.50
Implementation loss	L_i (dB)		3.00	3.00	3.00	3.00	3.00	3.00
Minimum receiver input power level	$P_{s,min}$ (dBW)	R = 1/2	−129.40	−123.90	−123.90	−123.90	−123.90	−125.40
		R = 2/3	−126.00	−120.60	−120.60	−120.60	−120.60	−122.10
		R = 3/4	−124.60	−118.00	−118.00	−118.00	−118.00	−119.50
Antenna gain	G_d (dBd)		0.00	−2.20	−22.76	−2.20	−22.76	−2.20
Effective antenna aperture	A_a (dBm^2)		4.44	2.24	−18.32	2.24	−18.32	2.24
Feeder-loss	L_f (dB)		1.10	0.00	0.00	0.00	0.00	0.22
Minimum power flux-density at receiving place	φ_{min} (dBW/m^2)	R = 1/2	−132.74	−126.14	−105.58	−126.14	−105.58	−127.42
		R = 2/3	−129.34	−122.84	−102.28	−122.84	−102.28	−124.12
		R = 3/4	−127.94	−120.24	−99.68	−120.24	−99.68	−121.52
Minimum field-strength level at receiving antenna	E_{min} (dB(μV/m))	R = 1/2	13.06	19.66	40.22	19.66	40.22	18.38
		R = 2/3	16.46	22.96	43.52	22.96	43.52	21.68
		R = 3/4	17.86	25.56	46.12	25.56	46.12	24.28
Allowance for man-made noise	P_{MMN} (dB)		15.38	15.38	0.00	15.38	0.00	15.38
Location probability	p (%)		70.00	95.00	95.00	95.00	95.00	99.00
Distribution factor	μ		0.52	1.65	1.65	1.65	1.65	2.33
Standard deviation of field strength	σ_m (dB)		3.56	3.56	3.56	3.56	3.56	2.86
Standard deviation of man-made noise	σ_{MMN} (dB)		4.53	4.53	0.00	4.53	0.00	4.53
Standard deviation of building penetration loss	σ_b (dB)		0.00	3.00	3.00	0.00	0.00	0.00
Combined standard deviation of field strength	σ_c (dB)		5.76	6.50	4.66	5.76	3.56	5.36
Location correction factor	C_l (dB)		3.00	10.72	7.68	9.51	5.87	12.48
Antenna height loss	L_h (dB)		0.00	8.00	815.00	8.00	815.00	8.00
Building penetration loss	L_b (dB)		0.00	98.00	98.00	0.00	0.00	0.00
Minimum median field-strength level	E_{med} (dB(μV/m))	R = 1/2	31.43	61.76	70.90	52.55	61.09	54.24
		R = 2/3	34.83	65.06	74.20	55.85	64.39	57.54
		R = 3/4	36.23	67.66	76.80	58.45	66.99	60.14

TABLE 80

Minimum median field-strength level E_{med} for 250 kHz channel bandwidth and 64-QAM modulation in Band II

Reception mode			FX	PI	PI-H	PO	PO-H	MO
Receiver noise figure	F (dB)		7.00	7.00	7.00	7.00	7.00	7.00
Receiver noise input power	P_n (dBW)		−143.00	−143.00	−143.00	−143.00	−143.00	−143.00
Minimum C/N	$(C/N)_{min}$ (dB)	R = 1/2	10.60	16.10	16.10	16.10	16.10	14.60
		R = 2/3	14.00	19.40	19.40	19.40	19.40	17.90
		R = 3/4	15.40	22.00	22.00	22.00	22.00	20.50
Implementation loss	L_i (dB)		3.00	3.00	3.00	3.00	3.00	3.00
Minimum receiver input power level	$P_{s,min}$ (dBW)	R = 1/2	−129.40	−123.90	−123.90	−123.90	−123.90	−125.40
		R = 2/3	−126.00	−120.60	−120.60	−120.60	−120.60	−122.10
		R = 3/4	−124.60	−118.00	−118.00	−118.00	−118.00	−119.50
Antenna gain	G_d (dBd)		0.00	−2.20	−19.02	−2.20	−19.02	−2.20
Effective antenna aperture	A_a (dBm^2)		0.70	−1.50	−18.32	−1.50	−18.32	−1.50
Feeder-loss	L_f (dB)		1.40	0.00	0.00	0.00	0.00	0.28
Minimum power flux-density at receiving place	φ_{min} (dBW/m^2)	R = 1/2	−128.70	−122.40	−105.58	−122.40	−105.58	−123.62
		R = 2/3	−125.30	−119.10	−102.28	−119.10	−102.28	−120.32
		R = 3/4	−123.90	−116.50	−99.68	−116.50	−99.68	−117.72
Minimum field-strength level at receiving antenna	E_{min} (dB(μV/m))	R = 1/2	17.10	23.40	40.22	23.40	40.22	22.18
		R = 2/3	20.50	26.70	43.52	26.70	43.52	25.48
		R = 3/4	21.90	29.30	46.12	29.30	46.12	28.08
Allowance for man-made noise	P_{MMN} (dB)		10.43	10.43	0.00	10.43	0.00	10.43
Location probability	p (%)		70.00	95.00	95.00	95.00	95.00	99.00
Distribution factor	μ		0.52	1.65	1.65	1.65	1.65	2.33
Standard deviation of field strength	σ_m (dB)		3.80	3.80	3.80	3.80	3.80	3.10
Standard deviation of man-made noise	σ_{MMN} (dB)		4.53	4.53	0.00	4.53	0.00	4.53
Standard deviation of building penetration loss	σ_b(dB)		0.00	3.00	3.00	0.00	0.00	0.00
Combined standard deviation of field strength	σ_c (dB)		5.91	6.63	4.84	5.91	3.80	5.49
Location correction factor	C_l (dB)		3.07	10.94	7.99	9.76	6.27	12.79
Antenna height loss	L_h		0.00	10.00	17.00	10.00	17.00	10.00
Building penetration loss	L_b		0.00	9.00	9.00	0.00	0.00	0.00
Minimum median field-strength level	E_{med} (dB(μV/m))	R = 1/2	30.61	63.77	74.21	53.59	63.49	55.40
		R = 2/3	34.01	67.07	77.51	56.89	66.79	58.70
		R = 3/4	35.41	69.67	80.11	59.49	69.39	61.30

5.3.2 Out-of-band emissions

The spectrum masks for RAVIS transmission (for three types of channel bandwidth) [10] compared to spectrum mask for analogue FM (according to ETSI EN 302 018-2 [7]) are given in Tables 81 to 84 and Fig. 3. RAVIS spectrum masks are fitting into analogue FM spectrum mask.

TABLE 81

Spectrum mask for FM transmission

Frequency offset (kHz)	Level (dBc)/(1 kHz)
0	0
±100	0
±200	−80
±300	−85
±400	−85

TABLE 82

Spectrum mask for RAVIS transmission, 100 kHz channel bandwidth

Frequency offset (kHz)	Level (dBc)/(1 kHz)
0	−20
±50	−20
±70	−50
±100	−70
±200	−80
±300	−85
±400	−85

TABLE 83

Spectrum mask for RAVIS transmission, 200 kHz channel bandwidth

Frequency offset (kHz)	Level (dBc)/(1 kHz)
0	−23
±100	−23
±120	−50
±150	−70
±200	−80
±300	−85
±400	−85

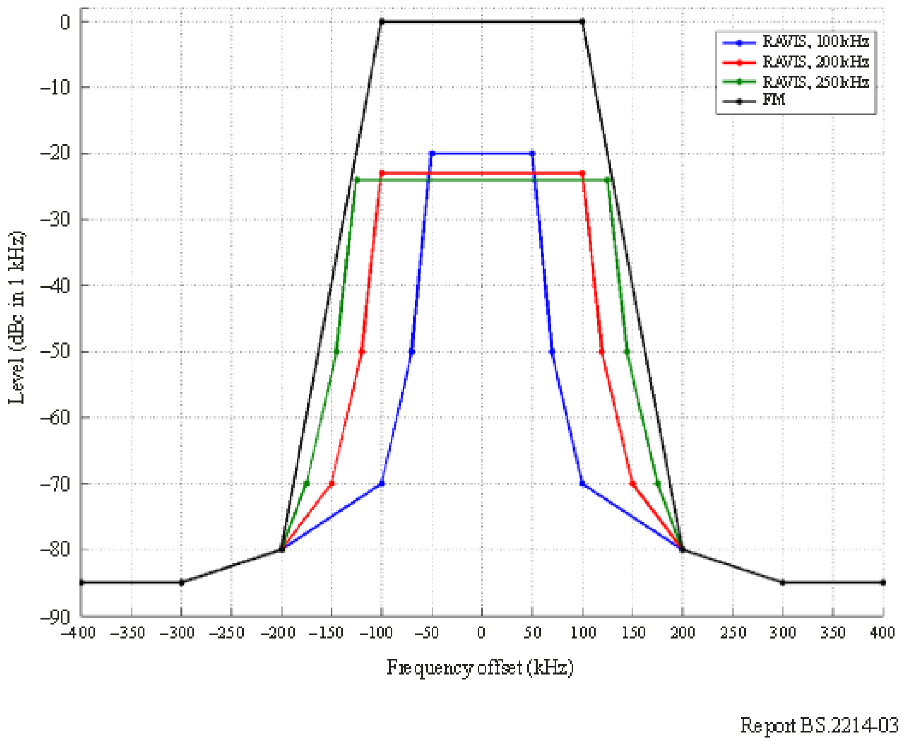
TABLE 84

Spectrum mask for RAVIS transmission, 250 kHz channel bandwidth

Frequency offset (kHz)	Level (dBc)/(1 kHz)
0	−24
±125	−24
±145	−50
±175	−70
±200	−80
±300	−85
±400	−85

FIGURE 3

Spectrum mask for RAVIS and FM transmission



5.3.3 Protection ratios

5.3.3.1 Protection ratios for FM

Basic protection ratios for FM interfered with by RAVIS are given in Table 85.

TABLE 85

Basic protection ratios PR_{basic} for FM interfered with by RAVIS

Frequency offset (kHz)		0	±100	±200	±300	±400
Basic protection ratio, channel bandwidth B = 100 kHz	PR_{basic} (dB)	50	35	5	−5	−10
Basic protection ratio, channel bandwidth B = 200 kHz	PR_{basic} (dB)	50				
Basic protection ratio, channel bandwidth B = 250 kHz	PR_{basic} (dB)	50				

5.3.3.2 Protection ratios for RAVIS

Basic protection ratios for RAVIS interfered with by RAVIS are given in Table 86.

TABLE 86

Basic protection ratios PR_{basic} for RAVIS interfered with by RAVIS

Frequency offset (kHz)		0	±100	±200	±300	±400
B = 100 kHz, QPSK, R = 1/2	PR_{basic} (dB)	8	0	−48	−55	−56
B = 100 kHz, QPSK, R = 2/3	PR_{basic} (dB)	9	2	−47	−54	−55
B = 100 kHz, QPSK, R = 3/4	PR_{basic} (dB)	10	3	−46	−53	−54
B = 100 kHz, 16-QAM, R = 1/2	PR_{basic} (dB)	12	6	−43	−51	−52
B = 100 kHz, 16-QAM, R = 2/3	PR_{basic} (dB)	14	8	−41	−49	−50
B = 100 kHz, 16-QAM, R = 3/4	PR_{basic} (dB)	15	9	−40	−48	−49
B = 100 kHz, 64-QAM, R = 1/2	PR_{basic} (dB)	16	10	−39	−47	−48
B = 100 kHz, 64-QAM, R = 2/3	PR_{basic} (dB)	19	13	−36	−44	−45
B = 100 kHz, 64-QAM, R = 3/4	PR_{basic} (dB)	20	14	−35	−43	−44
B = 200 kHz, QPSK, R = 1/2	PR_{basic} (dB)	8	6	−22	−51	−54
B = 200 kHz, QPSK, R = 2/3	PR_{basic} (dB)	9	7	−6	−50	−53
B = 200 kHz, QPSK, R = 3/4	PR_{basic} (dB)	10	8	−1	−49	−52
B = 200 kHz, 16-QAM, R = 1/2	PR_{basic} (dB)	12	10	2	−47	−49
B = 200 kHz, 16-QAM, R = 2/3	PR_{basic} (dB)	14	12	5	−45	−48
B = 200 kHz, 16-QAM, R = 3/4	PR_{basic} (dB)	15	13	6	−44	−47
B = 200 kHz, 64-QAM, R = 1/2	PR_{basic} (dB)	16	14	7	−42	−46
B = 200 kHz, 64-QAM, R = 2/3	PR_{basic} (dB)	19	17	10	−39	−43
B = 200 kHz, 64-QAM, R = 3/4	PR_{basic} (dB)	20	18	11	−38	−41
B = 250 kHz, QPSK, R = 1/2	PR_{basic} (dB)	8	6	2	−47	−52
B = 250 kHz, QPSK, R = 2/3	PR_{basic} (dB)	9	7	3	−46	−51
B = 250 kHz, QPSK, R = 3/4	PR_{basic} (dB)	10	8	5	−44	−50
B = 250 kHz, 16-QAM, R = 1/2	PR_{basic} (dB)	12	10	7	−41	−48
B = 250 kHz, 16-QAM, R = 2/3	PR_{basic} (dB)	14	12	9	−35	−46

TABLE 86 (*end*)

Frequency offset (kHz)		0	±100	±200	±300	±400
B = 250 kHz, 16-QAM, R = 3/4	PR_{basic} (dB)	15	13	10	−32	−45
B = 250 kHz, 64-QAM, R = 1/2	PR_{basic} (dB)	16	14	11	−30	−44
B = 250 kHz, 64-QAM, R = 2/3	PR_{basic} (dB)	19	17	14	−24	−41
B = 250 kHz, 64-QAM, R = 3/4	PR_{basic} (dB)	20	18	15	−23	−40

Basic protection ratios for RAVIS interfered with by FM are given in Table 87.

TABLE 87

Basic protection ratios PR_{basic} for RAVIS interfered with by RAVIS

Frequency offset (kHz)		0	±100	±200	±300	±400
B = 100 kHz, QPSK, R = 1/2	PR_{basic} (dB)	8	28	20	−55	−56
B = 100 kHz, QPSK, R = 2/3	PR_{basic} (dB)	9	29	22	−54	−55
B = 100 kHz, QPSK, R = 3/4	PR_{basic} (dB)	10	30	23	−53	−54
B = 100 kHz, 16-QAM, R = 1/2	PR_{basic} (dB)	12	29	25	−51	−52
B = 100 kHz, 16-QAM, R = 2/3	PR_{basic} (dB)	14	26	27	−49	−50
B = 100 kHz, 16-QAM, R = 3/4	PR_{basic} (dB)	15	25	28	−48	−49
B = 100 kHz, 64-QAM, R = 1/2	PR_{basic} (dB)	16	24	29	−47	−48
B = 100 kHz, 64-QAM, R = 2/3	PR_{basic} (dB)	19	21	32	−44	−45
B = 100 kHz, 64-QAM, R = 3/4	PR_{basic} (dB)	20	20	33	−43	−44
B = 200 kHz, QPSK, R = 1/2	PR_{basic} (dB)	8	30	26	−51	−54
B = 200 kHz, QPSK, R = 2/3	PR_{basic} (dB)	9	31	27	−49	−53
B = 200 kHz, QPSK, R = 3/4	PR_{basic} (dB)	10	32	28	−48	−51
B = 200 kHz, 16-QAM, R = 1/2	PR_{basic} (dB)	12	34	30	−46	−49
B = 200 kHz, 16-QAM, R = 2/3	PR_{basic} (dB)	14	36	32	−45	−47
B = 200 kHz, 16-QAM, R = 3/4	PR_{basic} (dB)	15	37	33	−44	−46
B = 200 kHz, 64-QAM, R = 1/2	PR_{basic} (dB)	16	38	34	−43	−45
B = 200 kHz, 64-QAM, R = 2/3	PR_{basic} (dB)	19	41	37	−40	−42
B = 200 kHz, 64-QAM, R = 3/4	PR_{basic} (dB)	20	42	38	−39	−39
B = 250 kHz, QPSK, R = 1/2	PR_{basic} (dB)	8	30	27	−45	−52
B = 250 kHz, QPSK, R = 2/3	PR_{basic} (dB)	9	31	28	7	−51
B = 250 kHz, QPSK, R = 3/4	PR_{basic} (dB)	10	32	29	16	−50
B = 250 kHz, 16-QAM, R = 1/2	PR_{basic} (dB)	12	34	31	20	−48
B = 250 kHz, 16-QAM, R = 2/3	PR_{basic} (dB)	14	36	33	23	−46
B = 250 kHz, 16-QAM, R = 3/4	PR_{basic} (dB)	15	37	34	24	−45
B = 250 kHz, 64-QAM, R = 1/2	PR_{basic} (dB)	16	38	35	25	−44
B = 250 kHz, 64-QAM, R = 2/3	PR_{basic} (dB)	19	41	38	28	−41
B = 250 kHz, 64-QAM, R = 3/4	PR_{basic} (dB)	20	42	39	30	−40

5.3.4 Sharing criteria with other services

The potential interference from RAVIS to the services in adjacent frequency ranges (for example, to aeronautical radionavigation service in the band above 108.0 MHz) is not higher as the one of analogue FM service.

6 Planning parameters for Digital System C (HD Radio) in VHF Band II

The HD Radio hybrid configuration makes use of the existing VHF Band II allocations and embeds new audio and data services along with the existing analogue FM. The In-Band On-Channel (IBOC) implementation preserves the analogue broadcast located on the main frequency assignment and adds low-level digital signals immediately adjacent to the analogue signal. These digital signals, immediately adjacent to the analogue, may be on either side of the analogue signal or on both sides. This approach is defined as System C in Recommendation ITU-R BS.1114.

IBOC, as implemented by the HD Radio system, retains the power of the analogue signal, while adding digital carriers within a controlled bandwidth and at lower power levels. This design allows for adjustment of the bandwidth and power of the digital signal, making possible controllable trade-offs between coverage of the digital signal and adjacent channel availability.

For the purpose of deploying the HD Radio FM system in the VHF Band II, certain reception performance may be considered.

This Report provides a summary of requirements in order to allow for adequate reception performance. The analysis follows the guidance in the applicable requirements documents. As a complementary measure and where applicable, the analysis follows other applicable guiding documents and practices from ITU Regions 1, 2, 3, and from the USA.

6.1 HD Radio system parameters

The HD Radio system is designed to allow for numerous configurations. The configurations allow for different bandwidth settings, frequency positioning, band combining, and different throughput. These configurations are captured in standard documents, such as NRSC-5-D or other design documents. While the system has provision for several configurations, only a subset is initially implemented and proposed for deployment in ITU Regions 1, 2 and 3. However, at a future time, additional configurations may be implemented as suitable for one location or another. A subset of these configurations is briefly described in the present document in conjunction with the provided planning parameters and deployment aspects.

6.1.1 System configurations

This analysis includes the configurations that are considered suitable for initial deployment in ITU Regions 1, 2 and 3. At a future time, additional configurations may be considered for deployment in ITU Regions 1, 2 and 3. The analysis can then be expanded to include such additional configurations.

The system can be configured to use a single frequency block that employs 70-kHz digital signal bandwidth or a single frequency block that employs 100-kHz digital signal bandwidth. The configuration is defined by system modes, and provides various combinations of logical channels, bit rates, and protection levels.

When configured to use a single frequency block that employs 70-kHz bandwidth, the system may be configured by mode MP9. It then employs logical channel P1 and provides a throughput (net bit rate) of 98.3 kbit/s. The employed modulation is QPSK.

When configured to use a single frequency block that employs 100-kHz bandwidth, the system may be configured to mode MP12 or mode MP19, which allows for a trade-off between throughput (net bit rate) and robustness. When configured to mode MP12, the system employs logical channel P1 and provides a throughput (net bit rate) of 98.3 kbit/s. When configured to mode MP19, the system employs logical channels P1 and P3, and provides a throughput (net bit rate) of 122.9 kbit/s. The employed modulation is QPSK.

The HD Radio system also supports joint configurations of two digital bands. These two digital bands are treated as two independent signals, in the context of planning, sharing, and compatibility for Band II. The joint configurations provide higher robustness or otherwise support higher throughput (net bit rate). When configured to use 2 × 70-kHz bandwidth, the system may be configured by mode MP1. It then employs logical channel P1 and provides a throughput (net bit rate) of 98.3 kbit/s. When configured to use 2 × 100-kHz bandwidth, the system may be configured by mode MP11. It then employs logical channels P1, P3 and P4, and provides a throughput (net bit rate) of 147.5 kbit/s.

The essential characteristics of the HD Radio system configurations (operating modes) are summarized in Table 88.

TABLE 88

Characteristics of various HD radio system operating modes

System mode	**Used BW (kHz)**	**Total (1) bit rate**	**Channel P1**		**Channel P3**		**Channel P4**		**Comments**
			Code rate	**Bit (1) rate**	**Code rate**	**Bit (1) rate**	**Code rate**	**Bit (1) rate**	**Interleaver span**
MP9	70	98.3	4/5	98.3	–	–	–	–	P1: ~1.5s
MP12	100	98.3	4/7	98.3	–	–	–	–	P1: ~1.5s; additional diversity delay
MP19	100	122.9	4/5	98.3	1/2	24.6	–	–	P1: ~1.5s; P3: ~3s
MP1(2)	2× 70	98.3	2/5	98.3	–	–	–	–	P1: ~1.5s
MP11(2)	2× 100	147.5	2/5	98.3	1/2	24.6	1/2	24.6	P1: ~1.5s; P3/P4: ~3s

(1) The bit rates reflect the throughput ('net' bit rate) by the application layer, and do not include the overhead used by the physical layer.

(2) Joint configuration of two digital signal blocks for enhanced performance or features. The digital blocks may be adjusted independently for power level.

Additional HD Radio system signal parameters (physical layer) for VHF Band II are provided in Table 89.

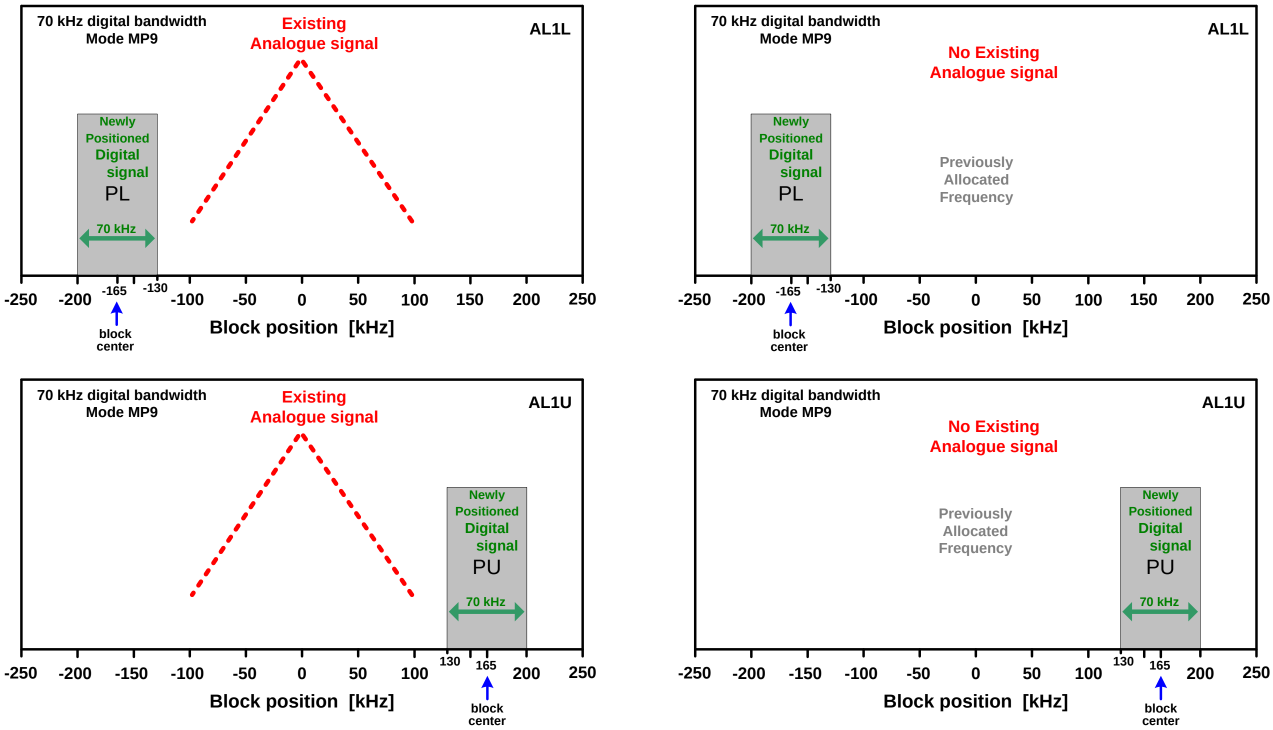
TABLE 89

HD radio system physical layer parameters

Parameter name	Computed value (rounded)
Cyclic prefix width α	0.1586 ms
Symbol duration (with prefix) T_s	2.902 ms
Number of symbols in a block	32
Block duration T_b	9.288 ms
Number of blocks in a frame	16
Frame duration T_f	1.486 s
OFDM subcarrier spacing Δ*f*	363.4 Hz
Number of carriers	70 kHz band: 191 100 kHz band: 267
Used bandwidth	70 kHz band: 69.4 kHz 100 kHz band: 97.0 kHz

FIGURE 4

HD radio system 70-kHz digital block positioning examples



Note: PL and PU are used for indicating lower positioning and upper positioning (respectively) of the digital block. The indication is for convenience only, and does not suggest an actual difference in the signal.

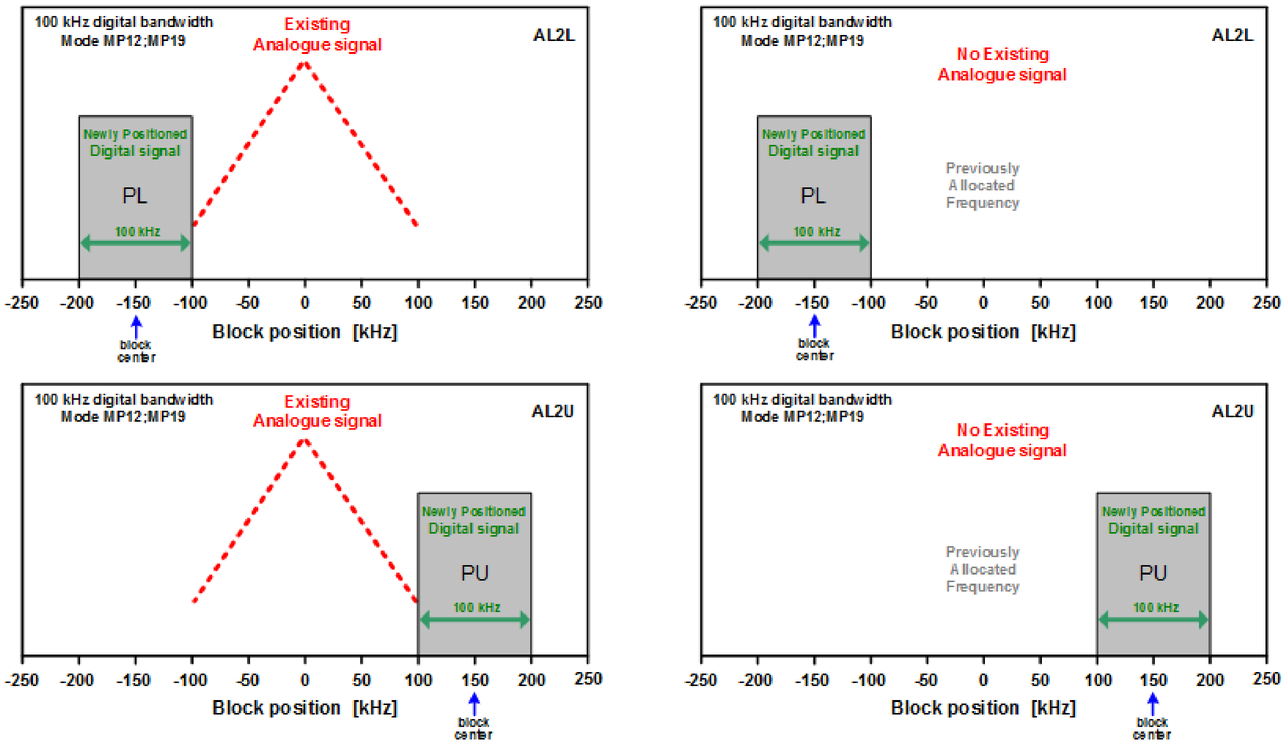
In the USA, the fundamental channel raster in VHF Band II is based on 200-kHz spacing. The HD Radio system presumes that the digital signal blocks are at pre-defined positions. As can be seen from the diagrams in Figs 4 and 5, these positions are not centred on the 200-kHz raster but in between. It has to be noted that the block position of 0 kHz in the Figures below corresponds to the reference analogue frequency for the HD Radio signal.

The reference analogue frequency may represent an actual analogue host signal when operating in hybrid configuration and employing a composition of either two signals (one analogue and one digital band) or three signals (one analogue and two digital bands). The analogue reference frequency may represent the centre frequency of a vacant band of a previously existing analogue host signal, while the system operates in all digital configurations. Such reference also demonstrates that a transition from hybrid configuration to all digital configurations does not have to change the digital signal allocation or configuration. Practically, it is expected to be followed by increasing the digital signal power.

Additional configurations allow for expanded signal composition, where two digital blocks of 70 kHz each as shown in Fig. 6, or two digital signal blocks of 100 kHz each as shown in Fig. 7, are employed jointly for providing more options for trade-off between throughput (net bit rate) and robustness.

FIGURE 5

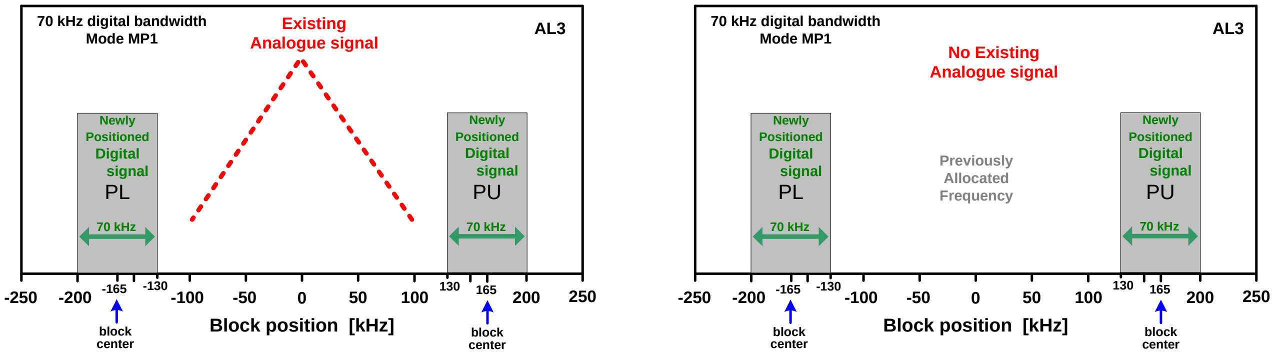
HD radio system 100-kHz digital block positioning examples



Note: PL and PU are used for indicating lower positioning and upper positioning (respectively) of the digital block. The indication is for convenience only, and does not suggest an actual difference in the signal.

FIGURE 6

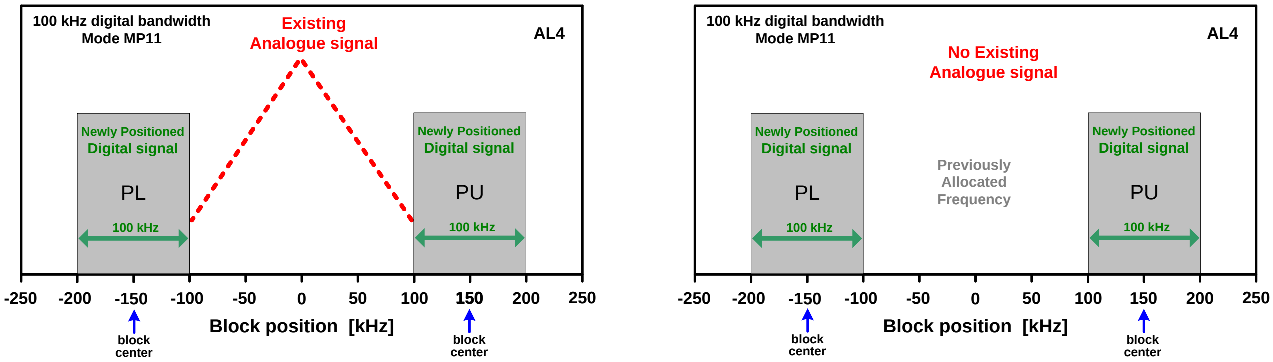
HD radio system 2 × 70-kHz digital block positioning examples



Note: PL and PU are used for indicating lower positioning and upper positioning (respectively) of the digital block. The indication is for convenience only, and does not suggest an actual difference in the signal.

FIGURE 7

HD radio system 2 × 100-kHz digital block positioning examples



Note: PL and PU are used for indicating lower positioning and upper positioning (respectively) of the digital block. The indication is for convenience only, and does not suggest an actual difference in the signal.

6.1.2 Channel models and fading margins

The specific EIA-approved channel (fading) models used in this analysis are provided further. Attempting to address all the reception modes along with the possible channel models may result in a significant number of combinations, thus prolonging the analysis work. For the specific purpose of providing planning parameters and in order to cover all of the combinations by using as few analysis cases as possible, the analysis brings forward the more demanding cases (in terms of required CNR and the resulting field strength), while assuming that the less demanding cases are then accounted for. For example, it may be assumed that reception under urban slow fading is more demanding than reception under suburban slow fading; therefore only the case of using the urban slow fading model has to be analysed. In another example, while considering the urban multipath profile in comparison to the suburban multipath profile, it may be assumed that reception under urban fast (60 km/h) fading is more demanding than reception under suburban fast (150 km/h) fading; therefore only the case of using the urban fast fading model is analysed for planning purposes.

In accordance with the analysis of a reduced number of cases, the reception modes and channel models combinations for planning purposes are provided in Table 90.

TABLE 90

Definition of reception modes and channel models

Reception mode	FX	MO	PO	PI	PO-H	PI-H
Antenna type	External	External	External	External	Integrated	Integrated
Antenna location	Outdoor	Outdoor	Outdoor	Indoor	Outdoor	Indoor
Environment	Suburban / Urban	Suburban / Urban	Suburban / Urban	Suburban / Urban	Urban	Urban
Reception percentage	70%	99%	95%	99%	95%	99%
Analysis speed (km/h)	0 (static)	60 (driving)	2 (walking)	0 (quasi-static)	2 (walking)	0 (quasi-static)
Analysis channel model	FXWGN	UFRM	USRM	FXWGN	USRM	FXWGN

Channel models

The channel models included in this section may apply to the reception modes.

TABLE 91

Fixed Reception under White Gaussian Noise (FXWGN) channel model

Ray	**Delay (μs)**	**Attenuation (dB)**	**Doppler Frequency (Hz)**
1	0.0	0.0	0

TABLE 92

Urban Slow Rayleigh Multipath (USRM) channel model

Ray	**Delay (μs)**	**Attenuation (dB)**	**Doppler Frequency (Hz)**
1	0.0	2.0	0.174 (reflects ~2 km/h
2	0.2	0.0	
3	0.5	3.0	
4	0.9	4.0	
5	1.2	2.0	
6	1.4	0.0	
7	2.0	3.0	
8	2.4	5.0	
9	3.0	10.0	

TABLE 93

Urban Fast Rayleigh Multipath (UFRM) channel model

Ray	Delay (μs)	Attenuation (dB)	Doppler Frequency (Hz)
1	0.0	2.0	5.231 (reflects ~60 km/h
2	0.2	0.0	
3	0.5	3.0	
4	0.9	4.0	
5	1.2	2.0	
6	1.4	0.0	
7	2.0	3.0	
8	2.4	5.0	
9	3.0	10.0	

TABLE 94

Rural Fast Rayleigh Multipath (RFRM) channel model

Ray	Delay (μs)	Attenuation (dB)	Doppler Frequency (Hz)
1	0.0	4.0	13.08 (reflects ~150 km/h
2	0.3	8.0	
3	0.5	0.0	
4	0.9	5.0	
5	1.2	16.0	
6	1.9	18.0	
7	2.1	14.0	
8	2.5	20.0	
9	3.0	25.0	

TABLE 95

Terrain Obstructed Fast Rayleigh Multipath (TORM) channel model

Ray	Delay (µs)	Attenuation (dB)	Doppler Frequency (Hz)
1	0.0	10.0	5.231 (reflects ~60 km/h
2	1.0	4.0	
3	2.5	2.0	
4	3.5	3.0	
5	5.0	4.0	
6	8.0	5.0	
7	12.0	2.0	
8	14.0	8.0	
9	16.0	5.0	

6.2 HD Radio receiver parameters

6.2.1 Minimum *C*/*N*

C/*N* calculations for various reception scenarios employed various channel models. Followed by long term experience with commercial HD Radio receivers, the models correlation with actual reception conditions has been observed. As a result, the more performance impacting (i.e. requiring higher *C*/*N*) models are provided for planning purposes.

C/*N* values (f = 100 MHz) are provided for an average decoded BER of 0.5×10^{-4} as a reference operating point for providing services.

In considering the approach for planning parameters as indicated in [2] and based on potential (and actual) usage scenarios of various HD Radio receiver types, the following is assumed for planning:

1) Handheld portable receivers may be used while walking or while driving. Slow (up to 2 km/h) fading conditions are likely to affect reception at a walking speed, while fast (60 km/h) fading conditions likely to affect reception while driving. The slow urban fading conditions are expected to have much more severe impact on the reception than fast fading conditions and therefore will be used for planning purpose.

2) Portable receivers may be used in quasi-static (0 km/h) conditions or while driven. Due to their larger form factor in comparison to handheld receivers, it is assumed that they are likely to be used for quasi-static reception. Therefore, quasi-static reception is used in conjunction with portable receivers for planning purposes.

3) For mobile receivers, typical usage is more likely to be experienced in urban areas. In addition, calculations and actual tests have not shown significant difference of impact on reception, between urban conditions (60 km/h) and rural conditions (150 km/h). Therefore, urban reception conditions analysis, which employ more aggressive multipath profiles, are used for planning purposes.

The cases (and models) and their related required C_d/N_0 (digital power to noise density ratio) as analysed for planning purposes are provided in Table 96.

TABLE 96

HD radio receiver required *C*/*N* for various reception modes

Reception mode	FX	MO	PO	PI	PO-H	PI-H
Channel model symbol	FXWGN	UFRM	USRM	FXWGN	USRM	FXWGN
Environment	Fixed	Urban	Urban	Indoor	Urban	Indoor
Speed (km/h)	0	60	2 (walking)	0 (quasi-static)	2 (walking)	0 (quasi-static)
MP9 Required Cd/N_0 (dB-Hz)	55.3	59.7	64.3	55.3	64.3	55.3
MP12 Required Cd/N_0 (dB-Hz)	54.4	58.5	62.5	54.4	62.5	54.4
MP19 Required Cd/N_0 (dB-Hz)	56.8	61.2	65.8	56.8	65.8	56.8
MP1 Required Cd/N_0 (dB-Hz)	53.8	57.2	61.3	53.8	61.3	53.8
MP11 Required Cd/N_0 (dB-Hz]	56.3	58.7	62.8	56.3	62.8	56.3

6.2.2 Receiver integrated noise figure

Based on calculations and certain deployments, the HD Radio receiver system noise figure (NF) for link budget calculations is shown in Table 97. Considering the reality of constant device miniaturization and integration, it is believed that for handheld reception, both external (ear bud) antenna and internal integrated antenna should be considered for planning purposes.

The integrated noise figure calculations employ conservative practical values, in accordance with the methodology for antenna for maximum voltage transfer (to the LNA), as indicated in § 3.11 and in [30].

In portable devices, power constraints are assumed to result in LNA NF that may be slightly higher (approximately 1 dB) than LNA NF for fixed or automotive reception which may not have power constraints.

In handheld devices, the best achievable antenna matching may be impacted by limited radiating element dimensions, varying elements and varying spatial orientation, which may collectively result in relatively high integrated noise figures. In all other cases (where the physical antenna, receiver structure, and their spatial orientation may be considered stable and reasonably defined), the antenna matching network is assumed to achieve the best required matching for maximum voltage transfer; thus resulting in values that may be common to those of the receiver only, as indicated in [2].

TABLE 97

HD radio overall receiver system NF

Reception mode	FX	MO	PO	PI	PO-H	PI-H
Antenna type	External fixed	Adapted	External telescopic / ear bud	External telescopic / ear bud	Internal	Internal
Receiver System NF (dB)	7	7	8	8	25	25

The sensitivity (required field strength) based on the overall receiver system NF already assumed antenna gain of 1.5 (‘net physical’ isotropic element, separate of matching loss), while all losses are included in NF. Therefore, the antenna gain correction factor Δ_{AG} is applied only where the physical element is different (noticeably larger).

6.2.2.1 Receiver noise input power

This section does not include any operational values and is provided only as a place holder for reiterating that such a legacy approach is irrelevant for HD Radio field strength calculations, since an integrated NF approach is used.

6.3 HD Radio planning parameters

6.3.1 Minimum wanted field strength used for planning

The minimum median required field strength calculations are according to the integrated approach, as described in §§ 3.10 and 3.11.

In certain configurations (i.e. system modes) where both channels P1 and P3/P4 are active, and where field strength requirements for channel P1 are different from the field strength requirements for channels P3/P4, the more demanding requirements (higher *C*/*N*) are used for planning and are provided in the Tables in this section.

The minimum median field strength E_{med} for the HD Radio system is indicated in Tables 98 to 102.

It is noted that while the calculations follow the ITU guidelines as indicated in the respective sections in this Report, the chosen values are intended to ensure adequate reception in realistic conditions. Specifically, the following is noted:

– The HD Radio system’s approach to signal reception considers 99% for ‘good’ indoor reception, while certain other systems’ approaches may consider only 95% for indoor reception, potentially leading to inadequate reception. This higher requirement (of 99%) results in considering higher field strength requirements of 3.4 dB more than the field strength for only 95% indoor reception. This is relevant for reception modes PI and PI-H (and reflected in higher total reception location losses for these modes).

– Broad industry experience with advanced and highly integrated small receivers, such as those in handheld devices and particularly their inclusion in smart phones, may require considering higher implementation losses than the implementation losses for discrete classes of receivers (i.e. automotive, portable). These higher losses result in considering higher field strength requirements of 2 dB more than the field strength for only discrete classes of receivers. This is relevant for reception modes PO-H and PI-H.

– The technological advances over the last tens of years have resulted in increased man-made noise, as has been indicated in certain published referenced documents. The HD Radio system’s analysis approach employs such man-made noise data from the year 2000 or later while certain other systems’ approaches may consider other data from referenced documents which have been established in 1974 or earlier. The HD Radio system’s approach considers such old data to be outdated and potentially leading to an inadequate reception. The consideration of the higher man-made noise data results in considering higher field strength requirements of 6.2 dB more than the field strength considered for the lower and potentially non-realistic man-made noise. This is relevant for all outdoor reception modes: FX, MO, PO and PI.

– The HD Radio system’s analysis approach considers the often outdoor use of handheld and portable receivers in both walking speed and driving speed. Adverse reception conditions for walking speed are considered much more demanding (requiring higher *C*/*N*) due to the slow fading impacts. While certain other systems' approaches may consider analysis in driving speed to be sufficient, the HD Radio system considers the field strength requirements for walking speed to be adequate for planning. The consideration of walking speed reception results in considering higher field strength requirements of up to 4.6 dB more than the field strength considered for driving. This is relevant for all outdoor reception modes PO and PO-H.

The HD Radio system's analysis for deriving field strength requirements considers the most probable usage scenarios along with conservative assumptions regarding adverse channel conditions, environmental noise (man-made), and deployment margins. Considering less conservative parameters or outdated data may lead to potential reduction of more than 10 dB in field strength requirements, which may potentially lead to inadequate planning and then inadequate reception.

TABLE 98

HD radio mode MP9 minimum median field strength versus reception modes

Reception mode	**FX**	**MO**	**PO**	**PI**	**PO-H**	**PI-H**
MP9 Required Cd/N_0 (dB-Hz)	55.3	59.7	64.3	55.3	64.3	55.3
Antenna gain correction, Δ_{AG} (dB)	4.4	0	0	0	0	0
Reception location losses, L_{rl} (dB)	3.4	19.1	16.2	30.3	23.2	37.3
Implementation loss, L_{im} (dB)	3	3	3	3	5	5
Receiver System, *NF* (dB)	7	7	8	8	25	25
Man-made noise allowance, P_{mmn} (dB)	14.1	14.1	14.1	14.1	0	0
Minimum median field strength (dBμV/m)	19.9	44.4	47.1	52.2	59.0	64.1

TABLE 99

HD radio mode MP12 minimum median field strength versus reception modes

Reception mode	**FX**	**MO**	**PO**	**PI**	**PO-H**	**PI-H**
MP12 Required Cd/N_0 (dB-Hz)	54.4	58.5	62.5	54.4	62.5	54.4
Antenna gain correction, Δ_{AG} (dB)	4.4	0	0	0	0	0
Reception location losses, L_{rl} (dB)	3.4	19.1	16.2	30.3	23.2	37.3
Implementation loss, L_{im} (dB)	3	3	3	3	5	5
Receiver System, *NF* (dB)	7	7	8	8	25	25
Man-made noise allowance, P_{mmn} (dB)	14.1	14.1	14.1	14.1	0	0
Minimum median field strength (dBμV/m)	19.0	43.2	45.3	51.3	57.3	63.2

TABLE 100

HD radio mode MP19 minimum median field strength versus reception modes

Reception mode	**FX**	**MO**	**PO**	**PI**	**PO-H**	**PI-H**
MP19 Required Cd/N_0 (dB-Hz)	56.8	61.2	65.8	56.8	65.8	56.8
Antenna gain correction, Δ_{AG} (dB)	4.4	0	0	0	0	0
Reception location losses, L_{rl} (dB)	3.4	19.1	16.2	30.3	23.2	37.3
Implementation loss, L_{im} (dB)	3	3	3	3	5	5
Receiver System, *NF* (dB)	7	7	8	8	25	25
Man-made noise allowance, P_{mmn} (dB)	14.1	14.1	14.1	14.1	0	0
Minimum median field strength (dBμV/m)	21.4	45.9	48.6	53.7	60.5	65.6

TABLE 101

HD radio mode MP1 minimum median field strength versus reception modes

Reception mode	**FX**	**MO**	**PO**	**PI**	**PO-H**	**PI-H**
MP1 Required Cd/N_0 (dB-Hz)	53.8	57.2	61.3	53.8	61.3	53.8
Antenna gain correction, Δ_{AG} (dB)	4.4	0	0	0	0	0
Reception location losses, L_{rl} (dB)	3.4	19.1	16.2	30.3	23.2	37.3
Implementation loss, L_{im} (dB)	3	3	3	3	5	5
Receiver System, *NF* (dB)	7	7	8	8	25	25
Man-made noise allowance, P_{mmn} (dB)	14.1	14.1	14.1	14.1	0	0
Minimum median field strength (dBμV/m)	18.4	41.9	44.1	50.7	56.0	62.6

TABLE 102

HD radio mode MP11 minimum median field strength versus reception modes

Reception mode	**FX**	**MO**	**PO**	**PI**	**PO-H**	**PI-H**
MP11 Required Cd/N_0 (dB-Hz)	56.3	58.7	62.8	56.3	62.8	56.3
Antenna gain correction, Δ_{AG} (dB)	4.4	0	0	0	0	0
Reception location losses, L_{rl} (dB)	3.4	19.1	16.2	30.3	23.2	37.3
Implementation loss, L_{im} (dB)	3	3	3	3	5	5
Receiver System, *NF* (dB)	7	7	8	8	25	25
Man-made noise allowance, P_{mmn} (dB)	14.1	14.1	14.1	14.1	0	0
Minimum median field strength (dBμV/m)	20.9	43.4	45.6	53.2	57.5	65.1

7 Planning parameters for Digital System A (DAB) in VHF Band III

In May 2018, the European Broadcasting Union (EBU) published the Report Tech 3391 ‘Guidelines for DAB network planning’ [45]. This Report was jointly developed with Broadcast Networks Europe (BNE) and is the basis for the information provided in the present Report.

The use of the term 'DAB' in this Report applies to both DAB and DAB+ systems (see § 7.1). Where there is a difference in the impact on network planning between the two systems, this is explained.

7.1 System parameters of DAB

Short review of DAB standards

The DAB digital broadcasting system originated from a European funded project known as Eureka 147. The members of the project team decided to standardize the system at ETSI and the system standard was first published in 1995 as ETS 300 401 [34]. The DAB standard has been supported and developed for many years by the WorldDAB Forum, a not for profit membership organization, and is actively supported by the EBU. The latest version of the DAB standard was published by ETSI in January 2017 as EN 300 401 V2.1.1 [35].

The core DAB standard describes the coding, modulation and transmission system parameters. Two basic data mechanisms are provided: stream mode and packet mode. Also defined is the signalling channel that allows a receiver to make sense of the content of the multiplex. Compared with analogue broadcast radio systems, a DAB transmission is relatively wideband, this extra bandwidth allowing several services to be carried on the transmission. Such a transmission carrying more than one service is known as an ensemble. Originally, the DAB audio coding mechanism, using MPEG Layer II coding, was included in the core specification, ETS 300 401 [34]. Later developments in audio coding efficiency led to the introduction of DAB+ audio coding, based on MPEG 4 AAC coding, which is described in a separate specification, TS 102 563 [58]. With the release of EN 300 401 V2.1.1 [35] the DAB audio coding definition was also transferred into a separate specification, TS 103 466 [59].

DAB is most widely used as a digital radio transmission system for audio services using DAB+ audio coding, with text messages carried as dynamic labels. Additional data can accompany the audio services, visuals via the SlideShow application and logos and programme information via the Service and Programme (SPI) application. The SPI application also allows carriage of other non-audio services such as mobile video services, traffic data and a host of other applications.

Additional standards documents have been created to facilitate additional features, interoperable equipment interfaces, additional transport modes, data applications, etc. A useful guide to the DAB standards is available as ETSI TR 101 495 V2.1.1 [60].

DAB and DAB+: what is the difference?

Some ambiguity surrounds the terms DAB and DAB+, owing to the way that the DAB system has developed over time. Often, DAB+ is used to describe the whole transmission system, although this would more correctly be described as a DAB ensemble with exclusively DAB+ audio services. The coding, modulation and transmission systems are identical whether the ensemble carries DAB audio services, DAB+ audio services, DMB video services, data, or any combination of these.

Today, the majority of DAB ensembles used for digital radio services carry those services using DAB+ audio coding. This is because DAB+ audio is more bandwidth efficient, using around half of the bitrate needed by DAB audio for the same subjective quality, and it is slightly more robust than DAB audio at the same protection level.

DAB audio coding was designed at the same time as the coding, modulation and transmission system. Five levels of Unequal Error Protection (UEP) were specified which provide additional protection to the more sensitive parts of the audio frame. DAB+ audio coding was designed to fit into the existing DAB system, the AAC audio frames are collected into audio super-frames of constant duration and are further protected by a Reed-Solomon (RS) coding. DAB+ audio sub-channels are protected using one of four levels of Equal Error Protection (EEP).

7.1.1 Modulation scheme and guard interval

DAB uses the Orthogonal Frequency Division Multiplexing modulation scheme (OFDM). Since it is not the task of this Report to give an introduction into this modulation technique, the present section is restricted to a short description of those OFDM features that are relevant for planning.

Carrier structure

DAB uses a convolutionally coded D-QPSK OFDM signal. The system is based on the use of 1 536 active carriers with a frequency spacing of 1 kHz. All carriers are transmitted at the same power level. Four DAB frequency blocks fit into a single 7 MHz television channel identified by the letters A, B, C and D, with a 176 kHz guard band between blocks A-B, B-C and C-D. Between blocks D and A there is a wider guard band of 320 or 336 kHz in order to align with a 7 MHz television raster.

Frequency interleaving

The decoding algorithm performs poorly when confronted with bit errors that are all bunched together in the data stream, and because the carriers are subject to fading, bit errors usually do occur in groups when a carrier is in a deep fade. To protect against this, DAB uses frequency interleaving. This mechanism randomly spreads the information across all carriers and thus across the whole bandwidth. This avoids the bundling of bit errors caused by frequency selective fading and significantly improves the performance of the decoder.

Time interleaving

An important property of a broadcast system targeting mobile reception is the use of time interleaving. In a mobile radio propagation channel, errors often appear in bursts. This may happen, for example, when field strength is too low at some reception points on the route along which a mobile receiver is moving.

In this case, use of time interleaving ensures that the errors resulting from these outage points are distributed over several transmission frames allowing the error protection/correction to rectify any errors that may occur. In DAB the interleaving depth is 16 logical frames which is equivalent to 384 ms.

Time interleaving is, however, most effective above a certain speed. In the case of DAB the time interleaving is less effective at speeds below roughly 15 km/h. This means that the portable indoor reception case may be a worst case scenario.

Multipath capability

OFDM, when coupled with appropriate channel coding (error correction coding), can achieve a high level of immunity against multipath propagation and co-channel interference.

In OFDM, the individual carriers are modulated by means of phase shift and amplitude modulation techniques. Each carrier has a fixed phase and amplitude for a certain time duration during which a small portion of the information is carried. This unit of data is called a symbol; the time it lasts is called the symbol duration. At the end of the time period the modulation is changed and the next symbol carries the next portion of information.

A DAB receiver has to cope with the adverse conditions of the broadcast transmission channel. Unless measures are taken, signals arriving at a receiver by different paths will have different time delays which will result in inter-symbol interference (ISI) and a degradation in reception. An OFDM system with a multipath capability allows for the constructive combination of such signals. This is achieved by inserting a guard interval, a cyclic prolongation of the period in which useful information can be extracted from symbol's that are delayed. The FFT-window, i.e. the time period for the OFDM demodulation is then positioned to minimise the inter-symbol interference. The insertion of the guard interval, whilst helping avoid ISI reduces the data capacity because less of the symbol duration is used for "useful" data – the guard interval is a period where the received signal is not used to make received data decisions; it is only used to avoid ISI from the previous symbol due to multipath delays.

All signals with time delays that cannot be absorbed by the guard interval in the way described above introduce a degradation of reception.

OFDM, due to its multicarrier nature, exhibits relatively long symbols. This long symbol period already provides a certain degree of protection against inter-symbol interference caused by multipath propagation. However, as described above, this protection is greatly enhanced by use of the guard interval.

7.1.2 Transmission modes

In the first edition of the DAB standard published in 1995, ETSI ETS 300 401 [34], three transmission modes were defined to allow the DAB system to be used in both terrestrial and satellite network configurations and over a wide range of operating frequencies. A fourth transmission mode was later added. With the latest version of the standard, ETSI EN 300 401 V2.1.1 [35], only Mode I, corresponding to use in the VHF band (30 to 300 MHz) has been retained.

Transmission Mode I is intended to be used for terrestrial Single Frequency Networks (SFN) and local-area broadcasting in Bands I, II and III. It may also be used for cable distribution and for Multiple Frequency Networks (MFN) as well.

TABLE 103

Mode I features

Typical use	Mode I	
	Terrestrial VHF (urban/suburban)	Terrestrial VHF (rural)
Max speed VHF (km/h)	260	390
Number of carriers	1 536	
Carrier spacing (kHz)	1	
Useful symbol duration (μs)	1 000	
Guard interval (μs)	246	
Total symbol duration (μs)	1 246	

7.1.3 Protection levels, coding and net bit rates

Convolutional encoding is applied to each of the data sources feeding the multiplex to ensure reliable reception (see [35] § 11 "Convolutional coding"). The encoding process involves adding deliberate redundancy to the source data. In the ETSI standard specification for the DAB system [35], five Unequal Error Protection (UEP) levels are available (used for DAB audio) and eight Equal Error Protection (EEP) levels are available (used for DAB+ audio and data) that use punctured convolutional coding.

The total capacity of the Main Service Channel (MSC) can be partitioned into several sub-channels. Depending on the number of sub-channels the net bit rate is calculable. Some net bit rates, using the example of 6, 12 and 18 sub-channels carrying DAB audio services, are given in Table 104 for the UEP protection levels.

TABLE 104

Net bit rates per sub-channel

Protection level UEP	Net bit rate (kbit/s)		
	6 sub-channels	12 sub-channels	18 sub-channels
1	128	64	32
2	128	64	48
3	192	96	64
4	192	112	64
5	256	128	80

In the case of the EEP levels, there are two options, each consisting of four different protection levels. For each option, Level 1 represents the strongest and Level 4 the lowest error protection. Option A has sub-channels in multiples of 8 kbit/s and offers the maximum flexibility for segmentation for service providers and is the option generally chosen for DAB+ audio services. In contrast, Option B has sub-channels in multiples of 32 kbit/s and is designed primarily for DMB video services where the greater bit-rate granularity is less important.

Table 105 shows the corresponding code rates for EEP Options A and B:

TABLE 105

Code rates for EEP Options A and B

Protection level	EEP-1A	EEP-2A	EEP-3A	EEP-4A
Code rate	1/4	3/8	1/2	3/4
Protection level	EEP-1B	EEP-2B	EEP-3B	EEP-4B
Code rate	4/9	4/7	4/6	4/5

Table 106 is a table of net bit rates similar to Table 104, but for an ensemble carrying DAB+ audio protected using EEP option A profiles.

TABLE 106

Net bit rates per sub-channel for DAB+

Protection level EEP	**Net bit rate (kbit/s)**		
	12 sub-channels	**18 sub-channels**	**24 sub-channels**
1A	48	32	24
2A	72	48	32
3A	96	64	48
4A	144	96	72

The values shown in Tables 104 and 106 are for the case when all sub-channels have the same bit rate; a situation which will usually result in reduced efficiency. The allocation of different bit rates to each sub-channel (for example, higher bit rates for music and lower for news) enables more efficient use of the spectrum.

7.1.4 Channel models

The *C*/*N* value is a fundamental planning parameter for DAB networks. Generally, the *C*/*N* should ensure acceptable audio quality at a Bit Error Ratio (BER) of 1×10^{-4} after Viterbi.

Previously DAB planning has been based on the WI95 [36] and GE06 [1] agreements. The planning values in these two agreements are mainly based on the EBU planning guideline BPN 003 (issues 1 and 2) [37]. The coverage criteria used has been mobile reception assuming DAB audio coding in a Rayleigh channel, in a rural environment (RA) at a speed of 130 km/h with an associated *C*/*N* of 15 dB (values for a typical urban environment (TU) at a speed of 15 km/h are also given).

Measurements quoted in an early ITU-R Recommendation [38] suggested a Gaussian *C*/*N* value for Mode I at UEP-3 of 7.1 dB. This was simplified to 7 dB for the Wiesbaden planning process. A revision of Recommendation ITU-R BS.1114 [14], gave a value of 7.6 dB for Mode I and 7.4 dB for Modes II and III. The value of 7 dB was adopted in EBU planning guideline BPN 003 [37] for all modes in a Gaussian channel.

The EBU guideline TR 021 [39] considered that for UEP-3 protected sub-channels a *C*/*N* value of 7.4 dB is required to achieve a Bit Error Rate (BER) of 1×10^{-4} after Viterbi decoding in a Gaussian channel. For Rayleigh channels a figure of between 13 and 13.5 dB is quoted, this being based on operational DAB networks. Corresponding DVB-T planning values are then used to extrapolate /

interpolate for all code rates, followed by variable implementation margins for different channel types to derive the results reproduced in Table 107.

TABLE 107

***C/N* values for UEP protection**

Protection level	*C/N* (dB) for BER of 1 × 10^{-4} after Viterbi	
	Gaussian channel	Rayleigh channel – TU 6
UEP-1	5.9	12.1
UEP-2	6.7	12.6
UEP-3	7.4	13.3
UEP-4	8.4	14.9
UEP-5	10.2	18.6

Planning values optimised for ensembles carrying DAB+ audio services are given in TR 025 [40]; these values being based on measurements carried out by the IRT. In these measurements, a Gaussian type channel was assumed for fixed reception, a Rayleigh channel (profile TU 12 at 25 km/h and 178 MHz) and Rural Area 6, RA 6 (speed 120 km/h six taps) for mobile and portable reception was assumed.

Most recent *C*/*N* values for DAB ensembles intended to carry EEP protected sub channels have been determined by a set of measurements carried out by the IRT and Rai Way. These measurements were based on nineteen arbitrarily chosen DAB+ receivers and three different profiles, one for fixed reception and two for mobile and portable reception. The two Rayleigh profiles are Typical Urban 12, TU 12 (speed 25 km/h twelve taps), and Rural Area 6, RA 6 (speed 120 km/h six taps). The results, shown in Table 106, are the averages of the minimum values of the proper operation of the receivers.

TABLE 108

***C/N* values for EEP-A protection**

Protection level	Corresponding code rate	*C/N* (dB)			Approximate bit-rate (Mbit/s)
		Gaussian channel (FX)	TU 12	RA 6	
EEP-1A	1/4	3.7	7.8	7.8	0.58
EEP-2A	3/8	4.4	9.7	9.9	0.86
EEP-3A	**1/2**	**5.6**	**11.9**	**12.6**	**1.15**
EEP-4A	3/4	8.6	18.1	20.7	1.73

For both UEP and EEP, the differences between the *C*/*N* values of the various protection levels are not constant and the measurements show that the higher code rate, which results in lower protection, requires significantly more *C*/*N* to achieve reliable reception. Moreover, in EBU TR 021 [39] it is stated that the Protection Level 5 does not work for the mobile high-speed worst-case reception situation. This was confirmed by the tests made with DAB+ audio which proved that some receivers are not able to lock the signal when using the RA 6 profile with EEP-4A. The *C/N* values for EEP-3A, highlighted in bold in Table 106 have been used in the link budget calculations.

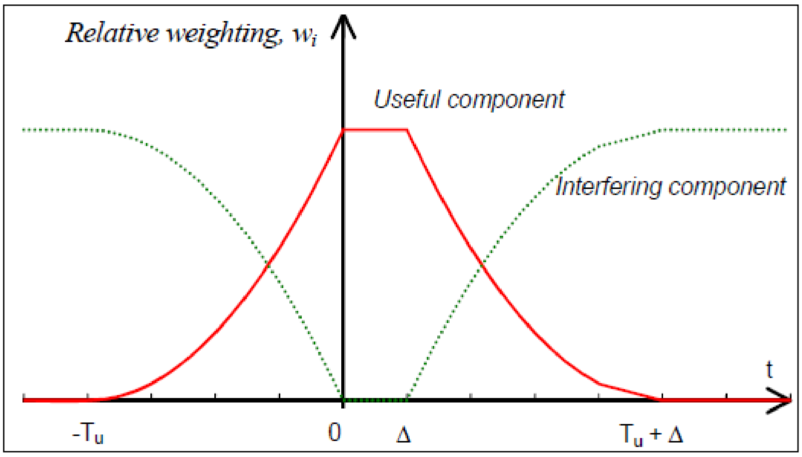
7.1.5 SFN performance

7.1.5.1 Theoretical evaluation of SFN performance

In Single Frequency Networks (SFNs) transmitters are required to radiate the same OFDM symbol at the same time. This comes from the fact that "echoes" generated by co-channel transmitters shall be confined within the guard interval period: outside the guard interval a part of the echo power is associated with the same OFDM symbol as the primary signal, and which therefore contributes positively to the total useful signal power; differently another part of the echo power is associated with the previous or subsequent OFDM symbol and produces inter-symbol interference (ISI), which has a similar effect to uncorrelated Gaussian noise interference. In Fig. 8 the splitting of a generic signal power into useful and interfering components is shown, where Δ is the guard interval length and T_u is the useful symbol length [47].

FIGURE 8

DAB model - splitting of a generic signal power into useful and interfering components



For DAB, the rule for splitting the signal power into a useful component and an interfering component is expressed as follows:

$$w_i = \begin{cases} 0 & if \quad t \leq -T_u \\ \left(\frac{T_u+t}{T_u}\right)^2 & if \quad -T_u < t \leq 0 \\ 1 & if \quad 0 < t \leq \Delta \\ \left(\frac{(T_u+\Delta)-t}{T_u}\right)^2 & if \quad \Delta < t \leq T_u + \Delta \\ 0 & if \quad t > T_u + \Delta \end{cases} \tag{47}$$

$$C = \sum_i w_i \times C_i \tag{48}$$

$$I = \sum_i (1 - w_i) \times C_i \tag{49}$$

where:

C_i	power contribution from the i-th signal at the receiver input
C	total power of the effective useful signal
I	total effective interfering power
w_i	weighting coefficient for the i-th component
T_u	useful symbol length
Δ	guard interval length

t signal arrival time.

It must be borne in mind that, the total effective interfering power, is weighted by the established DAB-to-DAB protection ratio when being regarded as a source of interference in a coverage calculation.

The OFDM receiver has to setup a time window during which it samples the on-air OFDM signal. The objective is to synchronize this time window with the useful period of the OFDM symbol. If the transmitters deliver the same OFDM symbol at the same instant, or with a sufficiently small time delay, the differential propagation path delay to the OFDM receiver will remain inside the guard interval period. Accordingly, the sum of the received signals will be constructive because they constitute the same OFDM symbol (with no ISI).

In the design of SFNs the inter-transmitter distance is proportional to the maximum echo delay acceptable by the transmission system, which depends on the guard interval. Actual transmitter spacing can be increased beyond that defined by the guard interval with network optimization in terms of static delays, antenna patterns and power of transmitters.

As an example, considering a 2-path scenario with power $P_1 = P$ for signal 1 and power $P_2 = aP$ for signal 2; the requirement for an allowed delay of signal 2 is given by:

$$\frac{P_1 + w \times P_2}{(1-w) \times P_2} = \frac{P + w \times aP}{(1-w) \times aP} = \gamma \qquad (50)$$

where:

γ: required protection ratio for the considered service

w: weighting function

a: allowed power of signal 2, expressed as a percentage of the power of signal 1.

w is a function of t, the relative delay of signal 2. All quantities are expressed in linear scale.

The value of the parameter a is sought as a function of the delay t. It is independent of the particular value of P; it can therefore be written as:

$$a(t) = \frac{1}{\gamma - (1+\gamma) \times w(t)} \qquad (51)$$

Table 109 gives the results for a protection ratio γ = 13.5 dB and a guard interval Δ = 246 µs.

TABLE 109

Theoretical values of the required difference in power for a delayed signal

Relative delay (µs)	***w***	***a***	**Required difference between P_1 and P_2 → 10 log(a) (dB)**
$0 \le t \le 246$ (i.e. inside the guard interval)	1	1	0 (i.e. not required)
300	0.8949	0.6859	1.64
335	0.8299	0.3358	4.74
365	0.7762	0.2362	6.27
400	0.7157	0.1770	7.52
t > 1246	0	$1/\gamma$ = 0.0447	13.5

It has been found that practical SFN performance (§ 7.1.5.2) aligns quite well with the theoretical considerations based on equations (47) to (49) and shown in Fig. 8 (see also § 2.6 of EBU TR 021 [39]).

The effective planning of the required radiated power and the optimization of static delays at the secondary site(s) will improve SFN performance as well and provide the effective management to eliminate most potential interference problems.

7.1.5.2 Practical SFN performance

In some countries, large area SFNs will need to be considered due to frequency constraints. For this reason, an experimental verification of the behaviour of DAB receivers in presence of signals beyond the guard interval is required, in order to optimize the setup of this kind of network.

Rai Way performed several tests on this issue in the laboratory and in a sample service area.

In both cases a number of models of commercial receivers sold in Italy (Continental, Blaupunkt and Pure) were tested. The transmission Mode I was considered as a reference as it is used in real DAB+ networks deployment in the VHF band in Italy. The theoretical value of the guard interval, Δ, used was 246 µs.

Tests were specifically focused on the identification of the "minimal condition" which allows the commercial receivers to correctly demodulate the content when one or more echoes are beyond the guard interval, taking into account the power levels of the signals and their relative delays. These tests showed that far beyond the guard interval the difference in the signal levels of transmitters at the receiving point represents the discriminating factor which guarantees (or not) a good reception quality, in line with the theoretical analysis of § 7.1.5.1. Therefore, this difference has been named as the required protection ratio ζ to make the reception feasible in presence of signals beyond the guard interval. It is important to notice that the parameter γ (introduced in the previous section) and ζ have a different meaning: ζ expresses the difference in the signal levels of transmitters at the receiving point (only in SFN mode) which might guarantee a good reception quality. Therefore, it does not have a fixed value, but rather a value which varies and depends on the relative delay among the SFN echoes. For this reason, ζ cannot be considered in the same way as γ, although if a specific condition arises in the considered SFN network (see Table 110) the value of the two parameters corresponds.

The behaviour shown by commercial receivers in the service area was very similar to that seen in the laboratory tests. From the results of these studies, Rai Way derived the values in Table 110; the conditions required in a DAB+ SFN in order that commercial receivers may correctly demodulate the audio content with good quality.

TABLE 110

Conditions to be respected by DAB signals in SFN configuration (transmission Mode I) to make audio reception feasible with good quality on commercial receivers

Required protection ratio ζ	Relative delay
0 (i.e. not required)	$0 \leq t \leq 246$ µs (i.e. inside the guard interval)
5 dB	$246 < t \leq 350$ µs
13.5 dB	$t > 350$ µs

It is important to notice that for the range 0 µs to ~350 µs the values of Table 109 fit quite well with the figures of Table 110. In the range beyond 400 µs the degradation as reflected in Table 110 is faster than the one derived from the theoretical equation presented in § 7.1.5.1. On the other hand, the conditions shown in Table 110 are quite conservative and might be slightly adjusted after further tests are performed on commercial receivers. Also, a more complex mathematical function that better describes the real behaviour of receivers in presence of echoes beyond the guard interval could be derived.

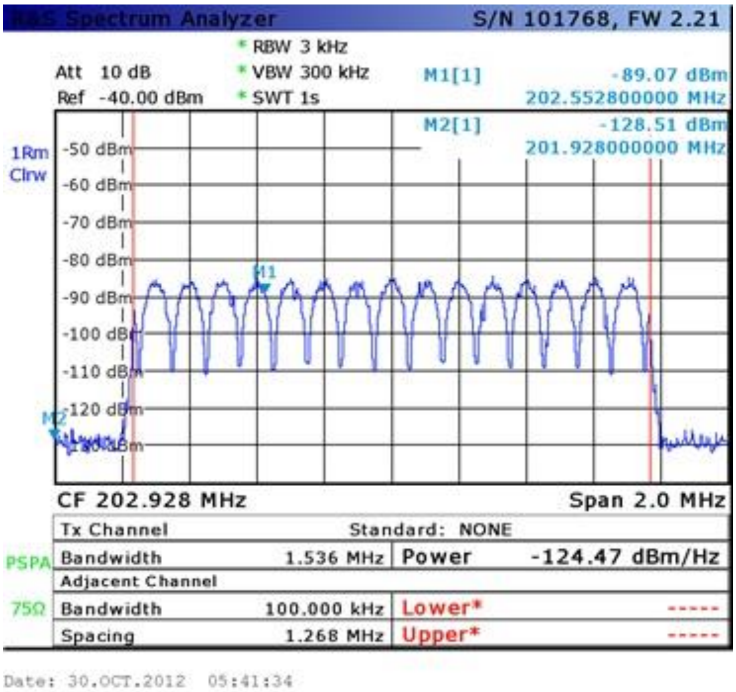
Additional tests should be performed for case of pre-echoes those “in advance” of the time window, i.e. for $t < 0$. Unless otherwise demonstrated, planning analysis should not rely on the symmetry of the theoretical DAB model with respect to the time axis, as shown in Fig. 8 (for $t < 0$ a *protection ratio* ζ of about 13.5 dB should be considered).

In Annex H of [45], all the details and the results of the tests performed by Rai Way on SFN performance, both in the laboratory and in a sample service area, are reported.

Laboratory and field testing by CRA has shown situations where SFN performance could be degraded under certain conditions even though the reception of two SFN signals is within the guard band, i.e. less than 246 µs apart. This particular situation occurs when the signals from both transmitters are very close in power, e.g. less than 1 dB difference - the ‘zero dB’ echo case. The two signals are combined at the input to the antenna non-coherently and consequently the relative phase of each sub-carrier in the OFDM symbol will determine the resulting power. This is shown in Fig. 9 where the delay between the two equal power signals is 10 µs. The result is that there are several sub-carriers in the symbol which are significantly reduced in power, in this case by over 20 dB relative to the peak sub-carrier power. The impact of this ‘scalloping’ is a reduction in receiver performance when the received signal power is less than approximately 20 dB above the minimum received signal power threshold. This reduction is due to the poor C/N for the specific sub-carriers in the symbol which effectively propagate through the receiver signal processing as errors and can result in an effective increase in the noise floor. The result can be to raise the minimum receive signal power by typically between 3 and 6 dB for FEC code rate EEP-3A, dependent on the second path delay and the receiver implementation.

FIGURE 9

The spectrum of two equal power DAB signals combined with 10 µs delay



This situation typically will only occur when the receiver is in a situation where the signal received from both transmitters is not only equal power but also ‘clean’, that is there are no significant multipath signal components present. As the power difference between the two received signals increases the performance is dominated by the stronger signal. Also, the presence of multipath components helps ‘dilute’ the effect by adding further non-coherent signal components that can reduce the depth of some notches.

7.2 Receiver parameters

7.2.1 Receiver noise figure

A noise factor of 7 dB has been used since the early days of DAB. This value is also suggested by the EBU in their DAB planning guideline document [37]. However, some receivers, in particular mobile DAB receivers, are likely to perform better, i.e. having a noise figure of about 5 dB or better.

IRT has made measurements of the receiver noise figure [41] and found that values lay in the range 4.7 dB to 6.4 dB. On the basis of these tests and experience with modern receivers, a noise figure of 6 dB is regarded as a reasonable compromise to cover different receiver types.

It is suggested that a noise figure of 6 dB should be used for planning.

7.2.2 Minimum receiver signal input levels

To illustrate how the *C*/*N* influences the minimum signal input level to the receiver, the latter has been calculated for representative *C*/*N*, including the implementation margin. For other values simple linear interpolation can be applied.

The receiver noise figure has been chosen as 6 dB (see § 7.2.1). The noise figure is given for all the frequencies within Band III and thus the minimum receiver input signal level is independent of the transmitter frequency. If other noise figures are used in practice, the minimum receiver input signal level will change correspondingly by the same amount.

The minimum receiver input signal levels calculated here are used to derive the minimum power flux densities and corresponding minimum median equivalent field strength values for various reception modes.

Definitions:

B : Receiver noise bandwidth (Hz)

S/N : RF signal-to-noise ratio required by the system (dB)

F_r : Receiver noise figure (dB)

P_n : Receiver noise input power (dBW)

$P_{s\,min}$: Minimum receiver signal input power (dBW)

$U_{s\,min}$: Minimum equivalent receiver input voltage into Z_i (dBμV)

Z_i : Receiver input impedance (75 Ω)

k : Boltzmann's constant = 1.38×10^{-23} Ws/K

T_0 : Absolute temperature = 290 K

Equations:

$$P_n = F_r + 10 \log(kT_0B)$$

$$P_{s\,min} = P_n + C/N$$

$$U_{s\,min} = P_{smin} + 120 + 10 \log(Z_i)$$

TABLE 111

Minimum required input signal levels for different *C*/*N* values

Band III – 7 MHz channels			
Channel model		TU 12	RA 6
Equivalent noise bandwidth	*B* (Hz)	1.536×10^6	1.536×10^6
Receiver noise figure	F_r (dB)	6	6
Corresponding receiver noise input power	P_n (dBW)	−136.1	−136.1
Signal-to-noise ratio	*S*/*N* (dB)	11.9	12.6
Minimum receiver signal input power	$P_{s\ min}$ (dBW)	−124.2	−123.5
Minimum equivalent receiver input voltage, 75 ohm	$U_{s\ min}$ (dBW)	14.55	15.25

7.3 Additional considerations for DAB planning

7.3.1 Coverage prediction height

Two main mechanisms give rise to variations in field strength with height.

The first is simply that diffraction losses will tend to fall as an antenna is raised above the level of surrounding clutter.

The second effect leading to variation of field strength with height is one due to interference between direct and reflected waves, this effect is dependent on polarisation and overall path geometry such as possible ground reflected wave in open/rural environments, however reflected waves are not normally taken into account in prediction models.

Historically radio services were received at rooftop level (clear of the clutter), typically 10 m above ground level (a.g.l.) and hence propagation prediction methods provided field-strength values at 10 metres. This was necessary since receiver performance was relatively poor compared to today’s standards. However, using modern receivers, listening is now predominantly carried out on mobile and indoor portable receivers and a representative height of typically 1.5 m is assumed. An adjustment to 1.5 m would therefore have to be applied.

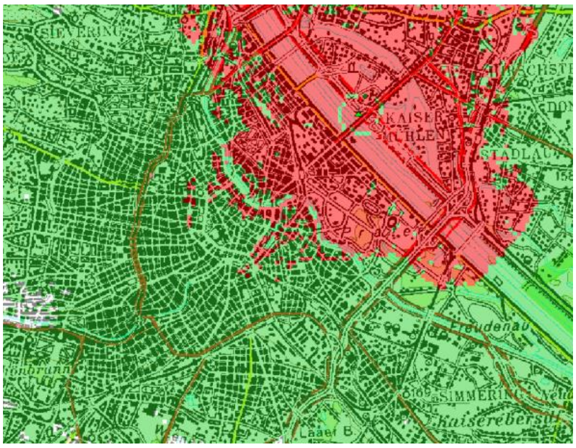
The alternative prediction approach is to construct the propagation geometry from the transmitter to the receiver on the basis of the required receiver height, i.e. direct to 1.5 m a.g.l.

Advances in computing power and storage and the availability of affordable fine resolution clutter data (density and heights of buildings, trees etc.) for large areas, allows for predictions to be made directly to the intended receiver height. This method is recommended when developing or updating deterministic prediction tools.

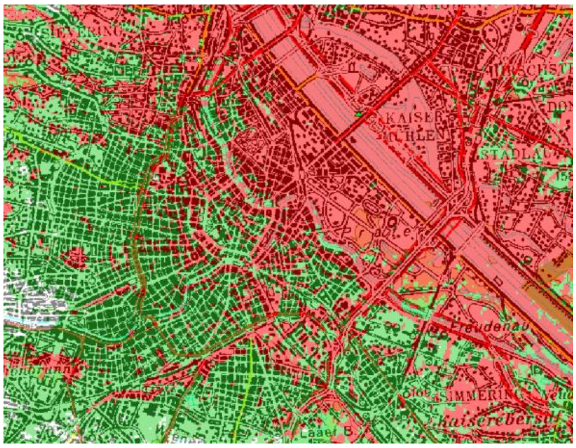
FIGURE 10

Examples of clutter resolution when comparing predictions at 1.5 m a.g.l. with a prediction at 10 m a.g.l. with fixed height loss. The terrain data resolutions matched to the clutter resolution.

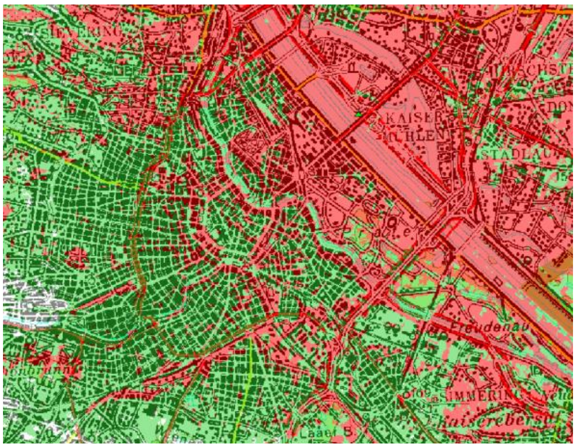
These maps have been produced with a low transmit power to demonstrate the differences



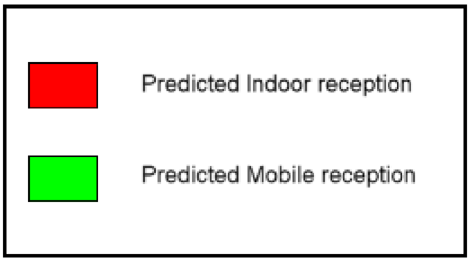
a) 100 m resolution prediction at 10 m a.g.l.
and fixed height loss of 12.4 dB (Low Urban)



b) 50 m resolution prediction to 1.5 m a.g.l.



c) 25 m resolution prediction to 1.5 m a.g.l.



Key to maps

As the resolution of clutter data becomes finer, the difference in 10 m predictions using a height loss factor compared to a prediction directly to 1.5 m becomes more apparent. Figure 10 compares a 10 m fixed height loss prediction with predictions to 1.5 m at different clutter data resolutions. It demonstrates that the finer resolutions can show more detail in the coverage which otherwise may have been overlooked. The terrain data resolution should be matched to the clutter data resolution and defines the minimum pixel size used in the predictions. The finer the detail of the predictions the more computational power and storage is required. By predicting direct to the receiver height, the need to set height loss values, either a fixed value or by receiving environment, is avoided.

If clutter data of a suitable resolution is not available or computational power or storage is limited then predictions to 10 m a.g.l. with a height loss correction factor, L_h (dB), being applied are suggested. This height loss correction factor is the method used in the ITU-R published empirical based propagation models. The height loss relative to 10 m a.g.l. or the ‘representative clutter height’ can be calculated.

For long distance interference analysis, the deterministic models used for coverage planning may not provide accurate results due to the extended range that interference travels and the impact of tropospheric conditions such as ducting. In this case, the interfering field strength calculations can still be based on empirical models, typically Recommendation ITU-R P.1546 [18].

The height loss correction factor from 10 m to 1.5 m can be taken directly from the Final Acts of GE06, § 3.2.2.1 of Chapter 3 of Annex 2 (Considerations on height loss) [1]. This factor depends on the frequency and receiving environment.

Some example calculated values at 200 MHz have been populated in Table 112, based on UK and Austrian clutter samples. The Austrian examples represent the clutter categories seen in the map in Fig. 10.

For planning purposes height loss values can be calculated using relevant clutter heights for the country or area in question and based on ITU method [18], some example calculations have been reproduced in Annex D in [45].

TABLE 112

(a and b) Calculated height loss examples for some different environment classes in the UK and Austria

Band III at 200 MHz	**Typical UK clutter height**	**Rec. 1546 Calculated height loss**
Urban	18 m	17.6 dB
Suburban	9 m	11.4 dB
Low Suburban	6 m	7.9 dB
Rural	6 m	7.9 dB

Band III at 200 MHz	**Typical Austrian clutter height**	**Rec. 1546 Calculated height loss**
Dense Urban	30 m	21.7 dB
Low Urban	10 m	12.4 dB
Suburban	10 m	12.4 dB
Rural	0 m	Not applicable

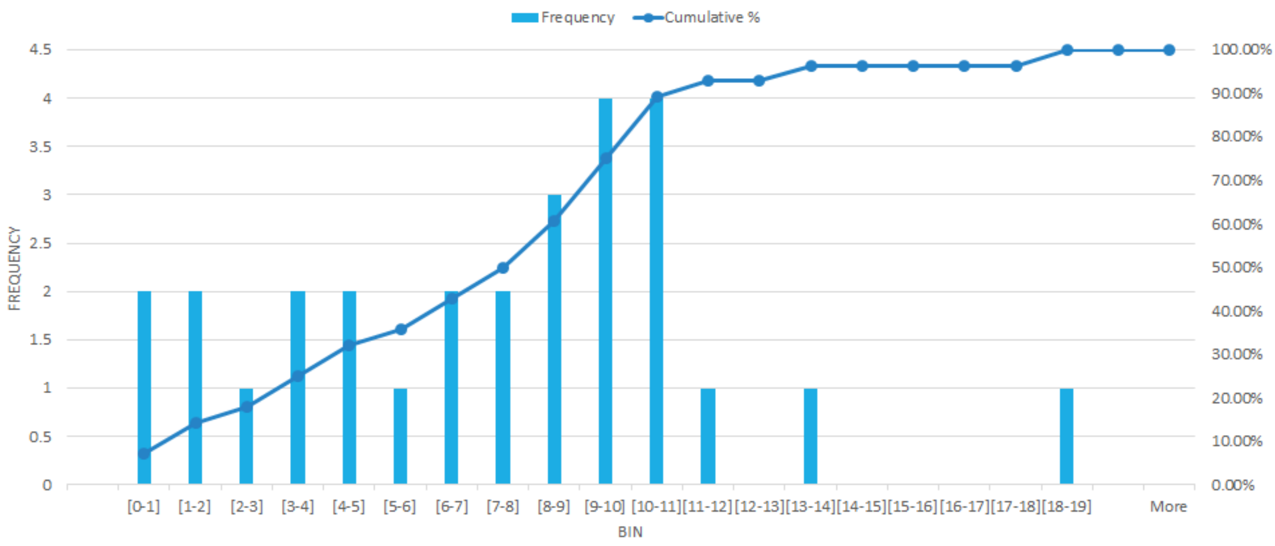
Table 112a shows some example calculated height loss values for the UK and Table 112b shows some for Austria which have been used in the map of Figure 10a. These examples show that height loss decreases with lower clutter heights.

In Australia a measurement campaign has been carried out to obtain a better understanding of height loss. Commercial Radio Australia in conjunction with the Australian Broadcast Corporation undertook measurements in a range of different environments from line-of-sight to various shadowed environments from high to low field strengths. All measurements were taken in Canberra where there is a single medium power (3.1 kW ERP) high tower transmission, and hence there is no influence from SFN transmissions which tend to reduce the height loss due to multiple sources of received signal. The results are shown in Fig. 11.

The measurement results at 25 out of the 28 measurement sites, i.e. 90%, had height loss values of less than 10.5 dB, and the average height loss value was between 7 and 8 dB.

FIGURE 11

Height loss measurement results



The measurement results provide a basis for the height loss value used in 10 m to 1.5 m prediction methods, where 90% of values will be less than 10.5 dB, hence Australia has opted for a value of 10 dB as being appropriate, the same value is used in the UK where similar results were found during early Band III DAB survey measurements.

Due to the differences in building types, spacing and construction methods between countries or even areas, it is pragmatic to carry out survey and analysis work when calibrating a prediction model for 1.5 m reception. For predictions based on 10 m a.g.l. and including a height loss factor it is recommended to classify typical environments (such as urban, suburban) with a height loss value for each category. To calibrate and validate a prediction model measurements should be considered in areas where co-channel interference is at a minimum and there is a single wanted signal, they should be carried out at 10 m a.g.l. (or clear of local clutter) and also at the target receiver height of 1.5 m. Once below the clutter height and diffraction path an omnidirectional receive antenna should be used for measuring due to the much greater importance of reflections. As mobile measurements using a nominally omnidirectional receive antenna are fairly quick and easy to make compared to 10 m measurements, the validation of predictions direct to 1.5 m receiver height can be made much quicker.

Typically, when planning for indoor reception, the urban and dense urban areas which may represent a small percentage of the overall area whilst exhibiting higher building entry loss, will be targeted first and served with high field strengths from one or more transmitters and any increase in height loss becomes less noticeable in the predictions. For these reasons and evidence from survey measurements, the examples of Australia and the UK use a single value representing the Suburban environment. It should be stipulated that these values are examples provided as guidance for the inclusion of height loss in the development of coverage predictions.

7.3.1.1 Height loss values for planning

For planning purposes height loss values can be calculated using the methodology proposed in Recommendation ITU-R P.1546 [18] for different receiving environments and some typical clutter heights for the country or the area under examination as shown in Table 113.

TABLE 113

Height loss for different environment classes and typical clutter heights

Receiving environment	Reference frequency (MHz)	Representative clutter height (m)	Height loss L_h from ITU-R P.1546 methodology (dB)
Dense urban	200	30	22
Urban	200	20	19
Suburban	200	10	12
Rural	200	10	12

7.3.2 Building and vehicle entry loss

7.3.2.1 Building entry loss

Portable reception can take place at both outdoor and indoor locations. For indoor locations, depending on the materials, the construction and orientation of the building, the field strength can be significantly attenuated. The ratio between the mean field strength inside a building at a given height above ground level and the mean field strength outside the same building at the same height above ground level expressed in (dB) is the mean building entry loss.

For Band III, in many planning documents, such as [1], [44], [2], [39], the mean building entry loss L_b was set to 9 dB and standard deviation σ_b to 3 dB.

ITU-R WP 3K has compiled measurement data on building entry loss [43] and Teracom have made additional measurements and have developed a more sophisticated model for building entry loss (see Annex E in [45]).

For example, [42] proposes for 200 MHz a median building entry loss of 10.5 dB for traditional buildings and 34.4 dB for thermally efficient buildings, as calculated in Table 114 below.

TABLE 114

Example of calculation of median building entry loss
The value of the coefficients *u* and *v* are given in Table 1 of [42]

	Traditional building	Thermally-efficient building
Frequency, f	0.2 GHz	0.2 GHz
Model coefficient, r	12.64	28.19
Model coefficient, s	3.72	−3.00
Model coefficient, t	0.96	8.48
Median loss for horizontal paths $L_h = r + s \log(\mathrm{f}) + t [\log(f)]^2$	10.5	34.4
Correction for elevation angle of the path at the building façade $L_e = 0.212 \lvert\theta\rvert$ where θ is the elevation angle	~ 0	~ 0
Median building entry loss, $L_h + L_e$	10.5 dB	34.4 dB
$\sigma_1 = u + \mathrm{v} \log(f)$	8.2 dB	10.8 dB

In addition, for both cases the standard deviation σ_1, is much higher than the standard deviation given in the previous planning documents. Detailed values may be calculated by the formula given in [42].

This large difference between traditional buildings and thermally efficient buildings and the much higher spread of the building entry loss values is confirmed by the Teracom measurements.

The values given in previous planning documents, L_b = 9 dB and σ_b = 3 dB, represent a reference from which DAB networks have been planned for indoor reception. However, with building regulations changing to provide more thermally efficient buildings which in turn leads to extremely high median value for the building entry loss (Table 114), achieving reliable indoor RF coverage may, in future, be challenging. Network designers may need to consider alternative means for providing a service indoors within thermally efficient buildings.

7.3.2.2 Vehicle (car) entry loss

A study presented in [46] shows in-car entry losses of 8 dB with an associated standard deviation of 2 dB, based on measurements at 800 MHz. Due to the lack of investigations concerning the car entry loss and its variation with the frequency, the same value is taken for Band III. Furthermore, it is expected that the value of 8 dB will not be sufficient for estimating entry loss into trains.

7.3.3 Location percentages

7.3.3.1 Location statistics within a pixel and prediction error

Slow fading effects are due to ground cover variations, which are important for pixel sizes substantially greater than the relevant morphography. Since the local distribution of morphographic influences within the pixel will usually be homogenous and their effects occur in a multiplicative way along the path, the loss due to slow fading fits a log-normal distribution, independent of the signal’s bandwidth, and consequently slow fading is often called “Log-normal Fading”. Measurements validate this assumption.

Due to the log-normal distribution of the slow fading, the logarithm of the field strength (including slow fading only) fits a normal distribution. The field strength is characterized by a median value and its standard deviation within the area of one pixel.

More information on the location variation of field strength and its implementation for coverage prediction is given in Annex F in [45].

In many frequency planning documents, e.g. [1], a standard deviation for wideband signals of 5.5 dB is used.

Recent studies ([48], [49], [50], [51]), where a large number of measurements have been taken, show that the standard deviation of the field strength distribution within a pixel of between 20 × 20 m to 100 × 100 m in size is, depending on the clutter and also the size of the pixel, between about 2 and 4 dB. The larger the pixel size, the higher the standard deviation of the field strength distribution.

The minimum median field strength values calculated in § 7.4.1 use a standard deviation value of 4.0 dB as being a representative value.

7.3.3.2 Location correction factors for different reception modes

In many cases the location correction factor is influenced not only by the location variation but also by the standard deviation of additional losses such as building entry loss or vehicle entry loss as explained in § 7.3.2.

The values used for various DAB reception modes are shown in Table 115. For indoor reception in a building, the values are on the basis of entry loss measured in traditional buildings (see § 7.3.2.1).

TABLE 115

Location Correction value calculations for various reception modes

Reception mode	Service quality	Location variation σ_{LV} (dB)	Variation of other losses σ_{OL} (dB)	Composite location variation SD σ_{res} (dB)	Location probability %	Distribution factor value μ	Location correction factor C_l (dB) (1)	Comments
1. MO (rural)	Good	4.0	0	4.0	99	2.33	9.32	
	Acceptable	4.0	0	4.0	90	1.28	5.12	
2. PO (suburban)	Good	4.0	0	4.0	95	1.64	6.56	
	Acceptable	4.0	0	4.0	70	0.52	2.08	
3. PI (urban)	Good	4.0	8.2	9.12	95	1.64	14.96	BEL
	Acceptable	4.0	8.2	9.12	70	0.52	4.74	BEL
4. PO-H/Ext (suburban)	Good	4.0	0	4.0	95	1.64	6.56	
	Acceptable	4.0	0	4.0	70	0.52	2.08	
5. PI-H/Ext (urban)	Good	4.0	8.2	9.12	95	1.64	14.96	BEL
	Acceptable	4.0	8.2	9.12	70	0.52	4.74	BEL
6. MO-H/Ext (rural)	Good	4.0	2	4.47	99	2.33	10.42	VEL
	Acceptable	4.0	2	4.47	90	1.28	5.72	VEL

BEL = Building entry loss VEL = Vehicle entry loss

(1) The values in the Location correction factor column do not have any rounding as may be found by using the base numbers in this Table which are shown as having only two decimal places.

7.4 Planning parameters

7.4.1 Minimum median field strength

In § 7.2.2 the minimum signal levels to overcome noise are given as the minimum receiver input power and the corresponding minimum equivalent receiver input voltage. No account is taken of any propagation effect. However, it is necessary to consider propagation effects when considering reception in a practical environment.

In defining coverage, it is indicated that due to the very rapid transition from near perfect to no reception at all, it is necessary that the minimum required signal level is achieved at a high percentage of locations. These percentages have been set at 95% for “good” and 70% for “acceptable” portable reception. For mobile reception the percentages defined were 99% and 90%, respectively.

In this section, minimum median power flux-densities and equivalent field strengths are presented which are needed for practical planning considerations. Six different reception modes are described which are listed in Table 116. The *C*/*N* values are those described in Table 108 for protection level EEP-3A associated with the reception modes defined in § 2.

TABLE 116

Reception modes, *C*/*N* values

	Reception mode	***C*/*N* (dB)**	**Channel model**
1	Mobile reception / rural (MO)	12.6	RA 6
2	Portable outdoor reception / suburban (PO)	11.9	TU 12
3	Portable indoor reception / urban (PI)	11.9	TU 12
4	Handheld portable outdoor reception / External antenna (PO-H)	11.9	TU 12
5	Handheld portable indoor reception / External antenna (PI-H)	11.9	TU 12
6	Handheld mobile reception / External antenna (MO-H)	12.6	RA 6

Results of calculation according to § 3.10 are provided in Table 117.

TABLE 117

DAB+ in Band III

			1. (MO) Mobile / rural	2. (PO) Portable outdoor /suburban	3. (PI) Portable indoor / urban	4. (PO-H/Ext) Handheld portable outdoor / suburban / External antenna	5. (PI-H/Ext) Handheld portable indoor / urban / External antenna	6. (MO-H/Ext) Handheld mobile / rural / External antenna
Frequency	Freq	MHz	200	200	200	200	200	200
Minimum *C/N* required by system	*C/N*	dB	12.6	11.9	11.9	11.9	11.9	12.6
Receiver noise figure	F_r	dB	6	6	6	6	6	6
Equivalent noise bandwidth	*B*	MHz	1.54	1.54	1.54	1.54	1.54	1.54
Receiver noise input power	P_n	dBW	−136.10	−136.10	−136.10	−136.10	−136.10	−136.10
Minimum receiver signal input power	$P_{s\,min}$	dBW	−123.50	−124.20	−124.20	−124.20	−124.20	−123.50
Minimum equivalent receiver input voltage, 75 Ω	U_{min}	dBμV	15.25	14.55	14.55	14.55	14.55	15.25
Feeder loss	L_f	dB	0	0	0	0	0	0
Antenna gain relative to half dipole	G_d	dB	−5	−8	-8	−13	−13	−13
Effective antenna aperture	A_a	dBm²	−10.32	−13.32	−13.32	−18.32	−18.32	−18.32
Minimum pfd at receiving location	Φ_{min}	dB(W)/m²	−113.18	−110.88	−110.88	−105.88	−105.88	−105.18
Minimum equivalent field strength at receiving location	E_{min}	dBμV/m	32.62	34.92	34.92	39.92	39.92	40.62
Allowance for man-made noise	P_{mmn}	dB	0.90	1.50	5.30	0.50	2.40	0.20
Entry loss (building or vehicle)	L_b, L_v	dB	0	0	10.50	0	10.50	8
Standard deviation of the entry loss		dB	0	0	8.20	0	8.20	2
Location probability		%	90	70	70	70	70	90
Distribution factor			1.28	0.52	0.52	0.52	0.52	1.28
Standard deviation (1)			4	4	9.12	4	9.12	4.47
Location correction factor	C_l	dB	5.12	2.08	4.74	2.08	4.74	5.72
Minimum median pfd at 1.5 m a.g.l.; 50% time and 50% locations (for a location probability of 90 or 70% as indicated)	Φ_{med}	dB(W)/m²	−107.16	−107.30	−90.34	−103.30	−88.24	−91.26
Minimum median equivalent field strength at 1.5 m a.g.l.; 50% time and 50% locations (for a location probability of 90 or 70% as indicated)	E_{med}	dBμV/m	**38.64**	**38.50**	**55.46**	**42.50**	**57.56**	**54.54**
Location probability		%	99	95	95	95	95	99
Distribution factor			2.33	1.64	1.64	1.64	1.64	2.33
Standard deviation			4	4	9.12	4.00	9.12	4.47
Location correction factor	C_l	dB	9.32	6.56	14.96	6.56	14.96	10.42
Minimum median pfd at 1.5 m a.g.l.; 50% time and 50% locations (for a location probability of 99 or 95% as indicated)	Φ_{med}	dB(W)/m²	−102.96	−102.82	−80.12	−98.82	−78.02	−86.57
Minimum median equivalent field strength at 1.5 m a.g.l.; 50% time and 50% locations (for a location probability of 99 or 95% as indicated)	E_{med}	dBμV/m	**42.84**	**42.98**	**65.68**	**46.98**	**67.78**	**59.23**

(1) The minimum median field strength values calculated use a standard deviation value of 4 dB as being a representative value. However, when making field strength predictions for a particular pixel it is suggested to add the prediction error and therefore to use a standard deviation value of 5.5 dB.

7.4.2 Transmitter spectrum mask

Outside the 1.5 MHz wide COFDM spectrum, the signal contains natural sidebands, attenuated relative to the main signal by some 40-50 dB. Although a high degree of linearity is employed, commonly used power amplifiers produce intermodulation products that increase the level of the sidebands, in some cases to only 30 dB below the main signal. These sidebands are unwanted, are considered spurious signals and should as far as possible be suppressed to allow optimum usage of the frequency spectrum. This attenuation (also called shoulder attenuation) is of importance because it allows adjacent DAB frequency blocks to be used in adjacent service areas.

The DAB signal spectrum is measured in a 4 kHz bandwidth. Inside the 1.5 MHz block the power level therefore reduces by (10 × log(4 / 1 536)) dB = −26 dB (see [54]) relative to the total power of the signal. The (shoulder) attenuation of the sidebands (out-of-band signals) is expressed in dB relative to this value.

The out-of-band radiated signal spectrum in any 4 kHz band shall be constrained by one of the masks defined in Fig. 12 and Table 118. The solid line mask shall apply to DAB transmitters in critical areas for adjacent channel interference. The dotted line mask shall apply to DAB transmitters in other circumstances for suppression of adjacent channel interference.

FIGURE 12

Spectrum mask for DAB out-of-band radiation

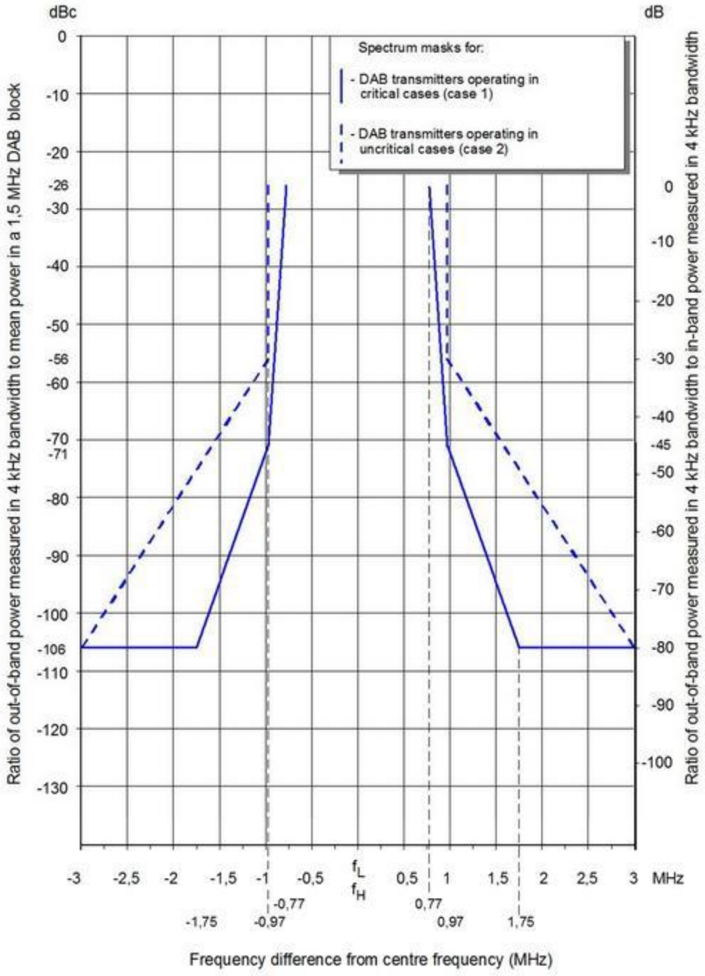


TABLE 118

Break points for spectrum masks in Fig. 12

Frequency relative to the block centre frequency (MHz)	Case 1 (critical cases) relative level (dB)	Case 2 (uncritical cases) relative level (dB)
±0.77	−26	−26
±0.97	−71	−56
±1.75	−106	n.a.
±3.00	−106	−106

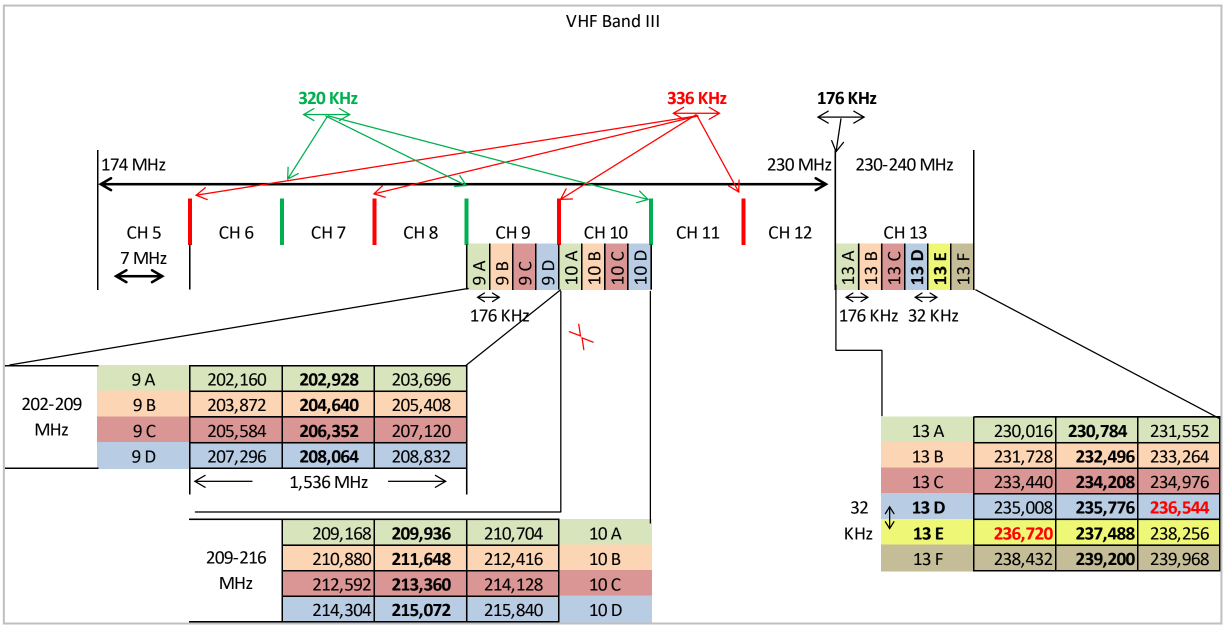
7.4.3 DAB frequency block raster and bandwidth

A DAB block is a frequency channel 1.536 MHz wide. A 176 kHz guard band separates adjacent DAB blocks. DAB in VHF has been introduced in the pre-existing 7 MHz raster of analogue TV; therefore 4 DAB blocks fit into one TV channel with a guard band of 320 kHz or 336 kHz between TV channel limits. The blocks are designated according to their TV channel position in Band III (channels 5 to 12) and labelled A through D for each TV channel, e.g. 5A for the lowest DAB block in VHF Band III.

Channel 13 (230 MHz - 240 MHz), which is not covered by GE06 [1] and retains to WI95revCO07 [52], contains 6 DAB blocks with a guard band of 176 kHz. There also remains a plan entry in Band I, labelled 4A.

FIGURE 13

DAB frequency blocks in Band III



7.4.4 Protection ratios

7.4.4.1 DAB versus DAB

7.4.4.1.1 Co- channel protection ratios

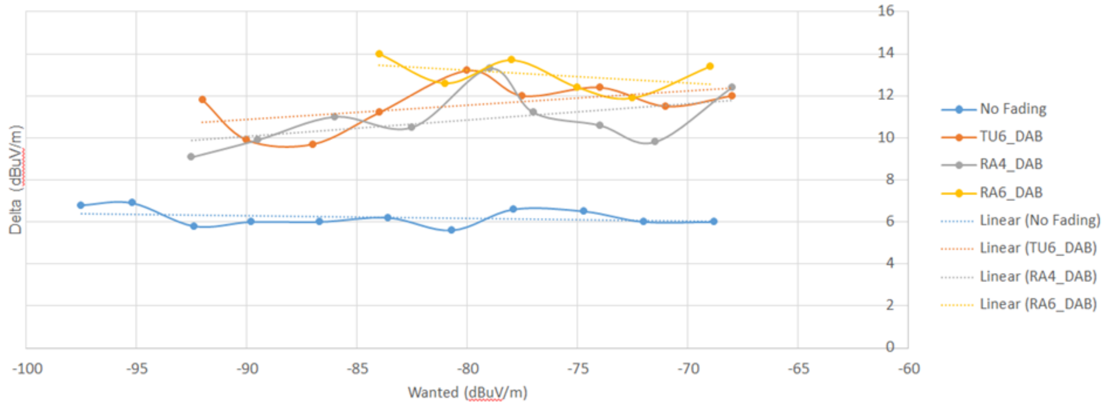
The Co-Channel Interference (CCI) Protection Ratio (PR) is used to plan DAB services on the same channel block or frequency. Generally, though the two transmissions on the same frequency should be from distant locations there will be some 'residual' signal power which propagates between the two areas.

To calculate the maximum allowed interference power in a specific area we must define the minimum power ratio between the wanted and interfering signal. As DAB uses COFDM the interfering signal appears to be AWG Noise added at the front end of the receiver. Consequently, it is reasonable to set the protection ratio at the same value as that used for Rayleigh fading, i.e. a *C*/*N* which is generally between 12 and 13 dB.

CRA undertook a number of bench tests to determine the current PR required by modern receivers. Figure 14 shows the results for a very commonly used table top receiver implementation (2016). The results show the power difference to support non-errored audio for a range of input equivalent field strengths and channel types.

FIGURE 14

Protection ratio requirements for a range of channel types



The first observation is that the AWGN result is around 6 dB across the input range of −95 to −70 dBµV/m. This can be compared to the commonly used AWGN reference *C*/*N* of 7.4 dB and the results may indicate that the required AWGN *C*/*N* is less than the standard allowance.

The results for the fading channels show that the required PR is in the range 10-14 dB with an average of 12 dB.

7.4.4.1.2 Adjacent channel protection

The Protection Ratios for adjacent channel use are very important as they will have a large impact upon the design of the DAB network, in particular when adding other non co-located services on an adjacent frequency.

National, regional and local broadcast coverage requirements will typically differ leading to alternative network implementations in an area. Introducing a new transmitter into a network has the potential to cause interference not just to co-channel usage elsewhere, but also adjacent channel interference (ACI) in its close vicinity. The level of ACI impact will depend on many factors such as, the new transmitter power, antenna pattern - both horizontal radiation pattern (HRP) and vertical radiation pattern (VRP), antenna height, whether the new transmitter is in a highly populated area or next to a busy road, and the frequency separation between the new service and the affected service. The level of impact will also depend on the robustness of the affected service and its field strength level in the area around the new transmitter site.

Impact predictions for non co-sited proposed transmitters should be carried out. These predictions must consider the relevant adjacent channel protection ratio plus the additional margin needed to serve the required percentage locations (forming the Protection Margin). Such impact predictions will identify if the existing services are protected to their planned service level.

A field strength measurement survey can be made for the existing services to validate the coverage prediction. BER measurements should also be taken as an indication of the quality of service. These measurements will be a record of the existing service performance.

The predicted field strength difference between the services in each pixel will indicate areas where the protection margin is exceeded, this method will include pixels that would not actually hear any audible interference and therefore it is essentially very restrictive to new services.

Adjacent channel interference can be regarded as degrading the affected service within a certain area around the additional transmitter (so-called “hole punching”), in which case the impact may be better represented by counting the proportion of users in each pixel that may be affected. This method examines the existing services predicted percentage locations served in each pixel before and after the proposed new service, the drop in predicted percentage locations multiplied by the number of households in that pixel will indicate the severity and number of households likely to be affected. If the coverage in a pixel drops below 50% locations served then receiver blocking can be assumed and all households in that pixel should be counted as lost. Assessment of many ACI situations in the UK has identified these predicted estimates to align closely with reality.

In many cases this proportional counting, combined with careful consideration of the design of the new transmitter, will reduce the predicted impact to a level that the affected broadcaster will find acceptable and hence allow the new non co-sited service to launch.

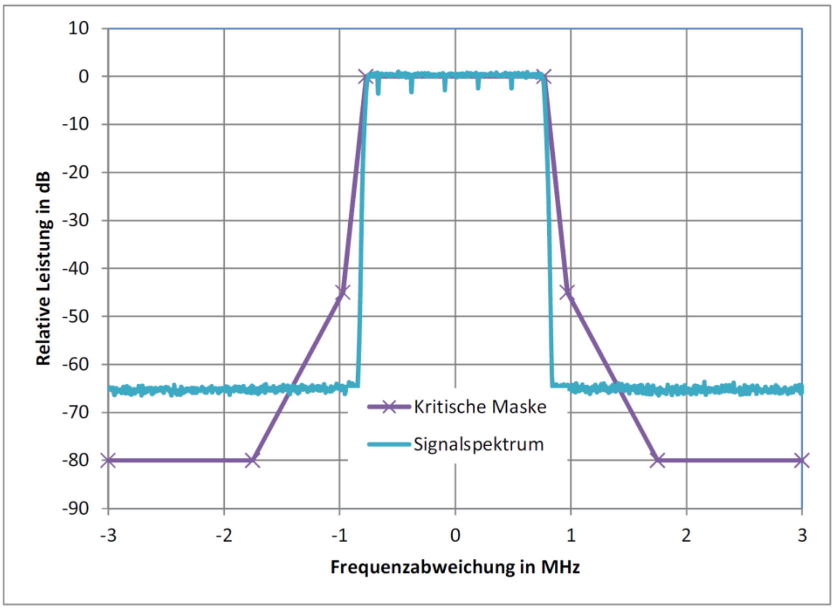
When the new transmitter is brought to air, drive survey measurements can be taken of both services to validate the impact assessment. The proportion of measurement points within a pixel that exceed the relevant protection ratio (from Table 119) should be used to calculate the proportional impact. These results can also be scaled to represent indoor coverage impacts (only counted where the affected service provides enough field strength for an indoor service before the addition of the new transmitter). BER measurements of the affected service should again be taken to indicate where uncorrected errors have increased and to validate the field strength difference results. Annex I in [45] provides a worked example of such an ACI assessment carried out in the UK.

The critical and non-critical spectrum masks for DAB were specified to allow a reasonable degree of overlap between service areas using adjacent channels. In deciding the masks, it was important to provide sufficient filtering reducing Out-of-Band (OOB) emissions from DAB transmissions into adjacent channels, without making filters too expensive. As such the DAB receiver’s adjacent selectivity itself is generally the main limitation when operating non co-sited transmitters.

The IRT has carried out a number of measurements of adjacent channel protection ratios [53] during the last few years. The measurements show that these protection ratios strongly depend upon the spectrum of the interfering signal. Measurements were carried out using three differently filtered interfering signals: fulfilling the non-critical spectrum mask, the critical spectrum mask and using an undistorted signal, shown below in Fig. 15.

FIGURE 15

Undistorted signal considered in IRT studies [53]



Based on BBC experience (see Annex I in [45]) and the IRT's measurements it is suggested that, in the case of the use of the critical spectrum mask, the adjacent channel protection ratios used for planning should be based upon the following values (Table 119):

TABLE 119

Suggested adjacent channel protection ratios (together with critical mask)

Interfering DAB block	Protection ratio (dB)
N ± 1	-40
N ± 2	-45
N ± 3	-45

7.4.4.2 DAB vs other broadcasting and non-broadcasting systems

7.4.4.2.1 General remarks

Protection ratios of DAB vs other broadcasting systems and other non-broadcasting systems are well described in several ITU-R documents: [1], [44], [55]. For Europe, a relevant exception is DVB-T2 since this is a relatively new system for which no or only very few measurements exist.

The situation is different with regard to DAB+. Apart from intra-system measurements (DAB+ vs DAB+), practically no figures are available for protection ratios of DAB+ vs other broadcasting systems and other non-broadcasting systems.

This is not very critical, however, since in most cases an extrapolation from DAB to DAB+ is possible as well as an extrapolation from DVB-T to DVB-T2. The basic ideas for these extrapolations are the following:

a) All cases where DAB+ interferes with other broadcasting or non-broadcasting systems can be treated in the same way as DAB, since both DAB and DAB+ have the same RF characteristics, being OFDM interferers, with the same bandwidth, the same carrier structure, etc.

b) For DVB-T2 being interfered with by DAB/DAB+, it is proposed that the protection ratios of a corresponding DVB-T mode (modulation scheme + code rate) be used; in this case, corresponding means having the same (or a similar) C/N value.

c) For DAB+ being interfered with by DVB-T/DVB-T2, it is proposed that the C/N of DAB+ vs. DAB+ minus 6 dB be used, since the ratio of DAB+ and DVB-T/T2 bandwidths is 1/4. Non fully overlapping DAB+ and DVB-T/T2 channels should be treated according to Tables A.3.3-13/14 of [1].

d) For DAB+ being interfered with by other services, it is proposed to use the following procedure:
The PR for DAB vs the other service (OS) exists: $PR_{DAB\text{-}OS}$, as well as the C/N of DAB: C/N_{DAB}.
These values can be taken from [1] or [37]; typically DAB mode 'Protection Level 3' is chosen.

The quantity $\Delta_{OS} = C/N_{DAB} - PR_{DAB\text{-}OS}$ is defined.

It is assumed that Δ_{OS} is representative for all protection levels, also for DAB+.

The PR for DAB+ being interfered with by OS is then given by:

$$PR_{DAB+\text{-}OS} = C/N_{DAB+} - \Delta_{OS}$$

This procedure is a pragmatic but qualitative approach, in view of the lack of measurement results. It may be replaced in the future when results of DAB+ measurements become available.

7.4.4.2.2 DAB vs DVB-T/T2

Protection ratios for DAB vs DVB-T are given in Appendix 3.3 to Annex 2 of [1], Tables A.3.3-13 - 22.

Protection ratios for DAB vs DVB-T2 and DAB+ vs DVB-T/T2 may be derived by applying the procedure described in § 7.4.4.2.1.

7.4.4.2.3 DAB vs other services

Protection ratios for DAB vs Other Services are given in Appendix 4.3 to Annex 2 of [1], Tables A.4.3-2 to A.4.3-5.

PRs for DAB+ vs Other Services may be derived by applying the procedure described in § 7.4.4.2.1.

Annex 1

Symbols and abbreviations

For the purposes of the present Report, the following symbols and abbreviations apply:

φ_{min}	Minimum power flux-density at receiving place (dBW/m^2)
A_a	Effective antenna aperture (dBm^2)
B	Receiver noise bandwidth (Hz)
BEL	Building entry loss
CF	Combined location correction factor (dB)
C_l	Location correction factor (dB)
c_0	Velocity of light in free space (km/s)
d	Antenna directivity
DAB/DAB+	Digital audio broadcasting
$D_{echo(max)}$	Maximum echo delay distance (km)
DRM+	DRM mode E
E	RMS field-strength level (dB)
E_{min}	Equivalent minimum RMS field-strength level at receiving place (dB(μV/m))
E_{med}	Equivalent median RMS field-strength level, planning value (dB(μV/m))
F_a	Antenna noise figure (dB)
$F_{a,med}$	Antenna noise figure mean value (dB)
F_r	Receiver noise figure (dB)
F_s	System equivalent noise figure (dB)
FM	Frequency modulation
f_a	Antenna noise factor
f_r	Receiver noise factor
g	Linear antenna gain (dB)
G	Antenna gain (dB)
G_D	Antenna gain with reference to half-wave dipole (dBd)
ΔG	Antenna gain variation (dB)
η	Antenna efficiency
k	Boltzmann’s constant (J/K)
K	Correction factor for the macro-scale standard deviation σ_m (dB)
l	Cable length (m)
λ	Wavelength (m)
L_b	Mean building entry loss (dB)
L_f	Feeder loss (dB)
L'_f	Feeder loss per unit length (dB/m)
L_h	Height loss correction factor (10 m a.g.l. to 1.5 m. a.g.l.) (dB)
μ	Distribution factor

MMN	Allowance for man-made noise
MSC	Main service channel
N_s	Number of symbols per frame in DRM mode E (ms)
OFDM	Orthogonal Frequency Division Multiplexing
p	Percentage of receiving locations (location probability) (%)
PL	Protection level in DRM mode E
P_{mmn}	Man-made noise level (dB)
P_n	Receiver noise input power (dBW)
PR	Protection ratio (dB)
PR_{basic}	Basic protection ratio (dB)
$P_{s,min}$	Minimum receiver signal input power (dBW)
QAM	Quadrature amplitude modulation
QPSA	Quadrature phase shift keying
R	Code rate
R_L	Antenna loss resistance (Ω)
R_r	Antenna radiation resistance (Ω)
σ_b	Building entry loss standard deviation (dB)
σ_c	Combined standard deviation (dB)
σ_m	Macro-scale standard deviation (dB)
$\sigma_{m,DRM}$	Macro-scale standard deviation for DRM (dB)
$\sigma_{m,\mathrm{DAB}}$	Macro-scale standard deviation for DAB (dB)
$\sigma_{m,\mathrm{FM}}$	Macro-scale standard deviation for FM (dB)
σ_{MMN}	Man-made noise standard deviation (dB)
SDC	Service description channel
SFN	Single frequency network
T	Elementary time period of DRM mode E (ms)
T_f	Duration of transmission frame of DRM mode E (ms)
T_g	Duration of guard interval of DRM mode E (ms)
T_s	Duration of OFDM symbol of DRM mode E (ms)
T_u	Duration of useful (orthogonal) part of DRM mode E (ms)
T_0	Absolute temperature (K)
VEL	Vehicle entry loss
VHF	very high frequency
Z_{F0}	Characteristic impedance in free space (Ω).

Annex 2

Technical references

1 Position of DRM frequencies

1.1 VHF Band II

The DRM centre frequencies are positioned in 100 kHz distance according to the FM frequency grid and ETSI-DRM [6]. The nominal carrier frequencies are, in principle, integral multiples of 100 kHz [5], see Table 120. A 50 kHz channel spacing is considered.

TABLE 120

Position of DRM frequencies in VHF Band II (87.5-108 MHz)

DRM channel centre frequency f_C (MHz)	DRM channel number	DRM channel centre frequency f_C (MHz)	DRM channel number	DRM channel centre frequency f_C (MHz)	DRM channel number	DRM channel centre frequency f_C (MHz)	DRM channel number
87.6	1	92.7	52	97.8	103	102.9	154
87.7	2	92.8	53	97.9	104	103.0	155
87.8	3	92.9	54	98.0	105	103.1	156
87.9	4	93.0	55	98.1	106	103.2	157
88.0	5	93.1	56	98.2	107	103.3	158
88.1	6	93.2	57	98.3	108	103.4	159
88.2	7	93.3	58	98.4	109	103.5	160
88.3	8	93.4	59	98.5	110	103.6	161
88.4	9	93.5	60	98.6	111	103.7	162
88.5	10	93.6	61	98.7	112	103.8	163
88.6	11	93.7	62	98.8	113	103.9	164
88.7	12	93.8	63	98.9	114	104.0	165
88.8	13	93.9	64	99.0	115	104.1	166
88.9	14	94.0	65	99.1	116	104.2	167
89.0	15	94.1	66	99.2	117	104.3	168
89.1	16	94.2	67	99.3	118	104.4	169
89.2	17	94.3	68	99.4	119	104.5	170
89.3	18	94.4	69	99.5	120	104.6	171
89.4	19	94.5	70	99.6	121	104.7	172
89.5	20	94.6	71	99.7	122	104.8	173
89.6	21	94.7	72	99.8	123	104.9	174
89.7	22	94.8	73	99.9	124	105.0	175

TABLE 120 (*end*)

DRM channel centre frequency f_C (MHz)	DRM channel number	DRM channel centre frequency f_C (MHz)	DRM channel number	DRM channel centre frequency f_C (MHz)	DRM channel number	DRM channel centre frequency f_C (MHz)	DRM channel number
89.8	23	94.9	74	100.0	125	105.1	176
89.9	24	95.0	75	100.1	126	105.2	177
90.0	25	95.1	76	100.2	127	105.3	178
90.1	26	95.2	77	100.3	128	105.4	179
90.2	27	95.3	78	100.4	129	105.5	180
90.3	28	95.4	79	100.5	130	105.6	181
90.4	29	95.5	80	100.6	131	105.7	182
90.5	30	95.6	81	100.7	132	105.8	183
90.6	31	95.7	82	100.8	133	105.9	184
90.7	32	95.8	83	100.9	134	106.0	185
90.8	33	95.9	84	101.0	135	106.1	186
90.9	34	96.0	85	101.1	136	106.2	187
91.0	35	96.1	86	101.2	137	106.3	188
91.1	36	96.2	87	101.3	138	106.4	189
91.2	37	96.3	88	101.4	139	106.5	190
91.3	38	96.4	89	101.5	140	106.6	191
91.4	39	96.5	90	101.6	141	106.7	192
91.5	40	96.6	91	101.7	142	106.8	193
91.6	41	96.7	92	101.8	143	106.9	194
91.7	42	96.8	93	101.9	144	107.0	195
91.8	43	96.9	94	102.0	145	107.1	196
91.9	44	97.0	95	102.1	146	107.2	197
92.0	45	97.1	96	102.2	147	107.3	198
92.1	46	97.2	97	102.3	148	107.4	199
92.2	47	97.3	98	102.4	149	107.5	200
92.3	48	97.4	99	102.5	150	107.6	201
92.4	49	97.5	100	102.6	151	107.7	202
92.5	50	97.6	101	102.7	152	107.8	203
92.6	51	97.7	102	102.8	153	107.9	204

1.2 VHF Band III

The frequency band of a DAB block has a bandwidth of 1.536 MHz with lower and upper guard channels to fit into the 7 MHz channels of VHF Band III. The DRM centre frequencies are positioned in 100 kHz distance beginning by 174.05 MHz and integral multiples of 100 kHz up to 229.95 MHz, see Table 121.

The nomenclature of the DRM channel identifier is given by:

(No. of the VHF channel) – (No. of the DRM channel suffix in the VHF channel), e.g. for the first DRM channel in this Table the identifier is “5-1”.

TABLE 121

Position of DRM frequencies in VHF Band III (174-230 MHz)

DRM channel suffix	**DRM channel centre frequency f_C (MHz) in VHF channel (number)**							
	5	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	174.050	181.050	188.050	195.050	202.050	209.050	216.050	223.050
2	174.150	181.150	188.150	195.150	202.150	209.150	216.150	223.150
3	174.250	181.250	188.250	195.250	202.250	209.250	216.250	223.250
4	174.350	181.350	188.350	195.350	202.350	209.350	216.350	223.350
5	174.450	181.450	188.450	195.450	202.450	209.450	216.450	223.450
6	174.550	181.550	188.550	195.550	202.550	209.550	216.550	223.550
7	174.650	181.650	188.650	195.650	202.650	209.650	216.650	223.650
8	174.750	181.750	188.750	195.750	202.750	209.750	216.750	223.750
9	174.850	181.850	188.850	195.850	202.850	209.850	216.850	223.850
10	174.950	181.950	188.950	195.950	202.950	209.950	216.950	223.950
11	175.050	182.050	189.050	196.050	203.050	210.050	217.050	224.050
12	175.150	182.150	189.150	196.150	203.150	210.150	217.150	224.150
13	175.250	182.250	189.250	196.250	203.250	210.250	217.250	224.250
14	175.350	182.350	189.350	196.350	203.350	210.350	217.350	224.350
15	175.450	182.450	189.450	196.450	203.450	210.450	217.450	224.450
16	175.550	182.550	189.550	196.550	203.550	210.550	217.550	224.550
17	175.650	182.650	189.650	196.650	203.650	210.650	217.650	224.650
18	175.750	182.750	189.750	196.750	203.750	210.750	217.750	224.750
19	175.850	182.850	189.850	196.850	203.850	210.850	217.850	224.850
20	175.950	182.950	189.950	196.950	203.950	210.950	217.950	224.950
21	176.050	183.050	190.050	197.050	204.050	211.050	218.050	225.050
22	176.150	183.150	190.150	197.150	204.150	211.150	218.150	225.150
23	176.250	183.250	190.250	197.250	204.250	211.250	218.250	225.250
24	176.350	183.350	190.350	197.350	204.350	211.350	218.350	225.350
25	176.450	183.450	190.450	197.450	204.450	211.450	218.450	225.450
26	176.550	183.550	190.550	197.550	204.550	211.550	218.550	225.550
27	176.650	183.650	190.650	197.650	204.650	211.650	218.650	225.650
28	176.750	183.750	190.750	197.750	204.750	211.750	218.750	225.750
29	176.850	183.850	190.850	197.850	204.850	211.850	218.850	225.850
30	176.950	183.950	190.950	197.950	204.950	211.950	218.950	225.950
31	177.050	184.050	191.050	198.050	205.050	212.050	219.050	226.050
32	177.150	184.150	191.150	198.150	205.150	212.150	219.150	226.150

TABLE 121 (*end*)

DRM channel suffix	DRM channel centre frequency f_C (MHz) in VHF channel (number)							
	5	6	7	8	9	10	11	12
33	177.250	184.250	191.250	198.250	205.250	212.250	219.250	226.250
34	177.350	184.350	191.350	198.350	205.350	212.350	219.350	226.350
35	177.450	184.450	191.450	198.450	205.450	212.450	219.450	226.450
36	177.550	184.550	191.550	198.550	205.550	212.550	219.550	226.550
37	177.650	184.650	191.650	198.650	205.650	212.650	219.650	226.650
38	177.750	184.750	191.750	198.750	205.750	212.750	219.750	226.750
39	177.850	184.850	191.850	198.850	205.850	212.850	219.850	226.850
40	177.950	184.950	191.950	198.950	205.950	212.950	219.950	226.950
41	178.050	185.050	192.050	199.050	206.050	213.050	220.050	227.050
42	178.150	185.150	192.150	199.150	206.150	213.150	220.150	227.150
43	178.250	185.250	192.250	199.250	206.250	213.250	220.250	227.250
44	178.350	185.350	192.350	199.350	206.350	213.350	220.350	227.350
45	178.450	185.450	192.450	199.450	206.450	213.450	220.450	227.450
46	178.550	185.550	192.550	199.550	206.550	213.550	220.550	227.550
47	178.650	185.650	192.650	199.650	206.650	213.650	220.650	227.650
48	178.750	185.750	192.750	199.750	206.750	213.750	220.750	227.750
49	178.850	185.850	192.850	199.850	206.850	213.850	220.850	227.850
50	178.950	185.950	192.950	199.950	206.950	213.950	220.950	227.950
51	179.050	186.050	193.050	200.050	207.050	214.050	221.050	228.050
52	179.150	186.150	193.150	200.150	207.150	214.150	221.150	228.150
53	179.250	186.250	193.250	200.250	207.250	214.250	221.250	228.250
54	179.350	186.350	193.350	200.350	207.350	214.350	221.350	228.350
55	179.450	186.450	193.450	200.450	207.450	214.450	221.450	228.450
56	179.550	186.550	193.550	200.550	207.550	214.550	221.550	228.550
57	179.650	186.650	193.650	200.650	207.650	214.650	221.650	228.650
58	179.750	186.750	193.750	200.750	207.750	214.750	221.750	228.750
59	179.850	186.850	193.850	200.850	207.850	214.850	221.850	228.850
60	179.950	186.950	193.950	200.950	207.950	214.950	221.950	228.950
61	180.050	187.050	194.050	201.050	208.050	215.050	222.050	229.050
62	180.150	187.150	194.150	201.150	208.150	215.150	222.150	229.150
63	180.250	187.250	194.250	201.250	208.250	215.250	222.250	229.250
64	180.350	187.350	194.350	201.350	208.350	215.350	222.350	229.350
65	180.450	187.450	194.450	201.450	208.450	215.450	222.450	229.450
66	180.550	187.550	194.550	201.550	208.550	215.550	222.550	229.550
67	180.650	187.650	194.650	201.650	208.650	215.650	222.650	229.650
68	180.750	187.750	194.750	201.750	208.750	215.750	222.750	229.750
69	180.850	187.850	194.850	201.850	208.850	215.850	222.850	229.850
70	180.950	187.950	194.950	201.950	208.950	215.950	222.950	229.950

2 Computations of correction factors

2.1 Computation of the antenna gain for portable handheld reception

The antenna (linear) gain g is the product of directivity d and efficiency η [4].

$$g = \eta \cdot d \tag{52}$$

For lossless antennas the efficiency equals one and the gain equals the directivity.

Portable handheld reception antennas are very lossy, and therefore the gain is much lower than directivity. They are also short linear antennas, with small dimensions compared to wavelength, and have a constant directivity of about 1.5 (1.8 dBi or –0.4 dBd). The gain changes with frequency only due to efficiency.

To estimate the efficiency change with frequency a transmitting antenna is considered. That leads to the values for a receiving antenna also, because antennas are reciprocal; their directivity, efficiency and gain are the same as receiving or transmitting antenna [4].

To transfer the maximum energy from a port to an antenna or vice versa the antenna has to be matched to the port impedance. A matched antenna has an equivalent series circuit with radiation resistance R_r, antenna loss resistance and a matching circuit loss resistance. We consider the reactive part of the serial impedance as zero. The radiation resistance is small and the transmitted energy is dissipated mostly in the antenna loss resistance and the matching circuit. Only the energy in R_r is radiated. Combining all losses in R_L the antenna efficiency:

$$\eta = \frac{R_r}{R_r + R_L} \approx \frac{R_r}{R_L} \tag{53}$$

R_r can be neglected in the denominator, because R_r is much lower than R_L.

For the antenna length l << λ the radiation resistance magnitude is proportional to the square of the antenna length l relative to wavelength λ [4]:

$$R_r = k \cdot \left(\frac{l}{\lambda}\right)^2 = k' \cdot (l \cdot f)^2 \ (\Omega) \tag{54}$$

where λ was substituted by c/f, with c the light velocity.

If the antenna dimension is not changed, and it is considered that the losses in the antenna and the matching circuit does not change significantly in the frequency range of interest, the efficiency η_2 at a frequency f_2, compared to the efficiency η_1 at a frequency f_1, changes as follows:

$$\frac{\eta_2}{\eta_1} = \left(\frac{f_2}{f_1}\right)^2 = \frac{G_2}{G_1} \tag{55}$$

The same is true for the gain G (dB), since the directivity does not change.

Changing the frequency from f_1 to f_2 the gain changes with:

$$\Delta G = 20 \log_{10}\left(\frac{f_2}{f_1}\right) \quad \text{(dB)} \tag{56}$$

2.2 Computation of man-made noise allowance from the antenna noise factor

Definition of the antenna noise factor

An antenna for terrestrial communications with efficiency one receives from its environment, no matter what shape its receiving diagram has, thermal noise with a power n:

$$n = kTB$$

where:

- k : Boltzmann's constant (J/K)
- T : environment temperature (K)
- B : bandwidth (Hz).

If the antenna receives in the same bandwidth B Gaussian noise like man-made noise with a power i, the total power received is:

$$p_a = n + i$$

We can define an antenna noise factor f_a as:

$$f_a = \frac{p_a}{n} = \frac{n+i}{n} = 1 + \frac{i}{n}$$

and an antenna noise figure F_a given in dB [4]:

$$F_a = 10 \log_{10}(f_a)$$

The man-made noise allowance for coverage calculations

In a link budget used for coverage calculations, the receiver is taken into account by its noise figure F_r. It can be shown, that the effect of the man-made noise i received by the antenna is equivalent to an increase of the receiver noise figure F_r by an amount MMN in dB, called man-made noise allowance.

If the antenna does not receive man-made noise, the total equivalent noise at a receiver input is:

$$p = p_r + n$$

with:

- p : power sum (W)
- p_r : receiver noise corresponding to the noise figure and the bandwidth (W)
- n : thermal noise (kTB) (W)

f_r : receiver noise factor calculated from the noise figure $\left(f_r = 10^{\frac{F_r}{10}} \right)$.

The receiver noise factor is defined as:

$$f_r = \frac{p}{n} = \frac{p_r + n}{n} = 1 + \frac{p_r}{n}$$

If man-made noise *i* is received, the power at the receiver input is:

$$p = p_r + n + i$$

The interference power is increased by a factor *mmn*:

$$mmn = \frac{p_r + n + i}{p_r + n} = 1 + \frac{i}{p_r + n} = 1 + \frac{\frac{i}{n}}{1 + \frac{p_r}{n}}$$

but:

$$\frac{p_r}{n} = f_r - 1$$

and

$$\frac{i}{n} = f_a - 1$$

The factor *mmn* can be expressed as a function of f_r and f_a:

$$mmn = 1 + \frac{f_a - 1}{f_r}$$

or in dB, the allowance for man-made noise *MMN*:

$$MMN = 10 \log \left(1 + \frac{f_a - 1}{f_r} \right)$$

The system equivalent noise figure to be used for coverage calculations is increased to:

$$F_s = F_r + MMN$$

Special case with antenna gain below 1.8 dBi

The antenna gain is the product of directivity and efficiency. The lowest realistic directivity is the one of a short dipole (length << λ) and it has the value 1.5 (1.8 dBi). Any gain lower than 1.8 dBi (−0.4 dBd) is due to an antenna efficiency η lower than 1.

If the antenna efficiency is η, from the received wanted signal w only η*w reaches the receiver, but the Gaussian noise and the man-made noise getting into the receiver are also reduced to η*n and η*i.

The interference power at the receiver input is increased due to man-made noise interference i by the factor mmn:

$$mmn = \frac{p_r + n + \eta_i}{p_r + n} = 1 + \frac{\eta_i}{p_r + n} = 1 + \frac{\frac{\eta_i}{n}}{1 + \frac{p_r}{n}}$$

$$MMN = 10\log\left(1 + \eta\frac{f_a - 1}{f_r}\right)$$

The efficiency η can be calculated from the antenna gain G_D, for gains lower than −0.4 dBd:

$$\eta = 10^{\frac{G_D + 0.4}{10}}$$

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