International Telecommunication Union

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Recommendation ITU-R BS.1660-9
(12/2022)

Technical basis for planning of terrestrial digital sound broadcasting in the VHF band

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Broadcasting service (sound)

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***Note**: This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

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RECOMMENDATION ITU-R BS.1660-9*

Technical basis for planning of terrestrial digital sound broadcasting in the VHF band

(Question ITU-R 56-3/6)

(2003-02/2005-11/2005-2006-05/2011-12/2011-2012-2015-2019-2022)

Scope

This Recommendation describes the planning criteria that could be used for planning of terrestrial digital sound broadcasting in the VHF band, for Digital Systems A, F, G and C of Recommendation ITU-R BS.1114.

Keywords

Digital Sound Broadcasting, DAB, ISDB-T_{SB}, IBOC, HD Radio, DRM

The ITU Radiocommunication Assembly,

considering

a) Recommendations ITU-R BS.774 and ITU-R BS.1114;

b) ITU-R Digital Sound Broadcasting Handbook – Terrestrial and satellite digital sound broadcasting to vehicular, portable and fixed receivers in the VHF/UHF bands;

c) Report ITU-R BS.2214 – Planning parameters for terrestrial digital sound broadcasting systems in VHF bands,

recommends

that the planning criteria as described in Annex 1 for Digital System A, in Annex 2 for Digital System F, in Annex 3 for Digital System G, and in Annex 4 for Digital System C could be used for planning of terrestrial digital sound broadcasting in the VHF band.

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* The Administration of the Syrian Arab Republic is not in a position to accept the content of this Recommendation, nor for it to be used as a technical basis for the planning of sound broadcasting in the VHF band, at the forthcoming Regional Radiocommunication Conferences planning of the digital terrestrial broadcasting service in parts of Regions 1 and 3.

TABLE OF CONTENTS

Page

Annex 1

Technical basis for planning of terrestrial digital sound broadcasting System A (DAB) in the VHF band

1 General

This Annex describes the planning criteria which could be used for planning the digital sound broadcasting system DAB. Report ITU-R BS.2214 provides further guidance on key elements that are necessary to plan and design a DAB network.

The latest release of the DAB standard, ETSI EN 300 401 V2.1.1, only covers the VHF band, which includes Bands I, II and III. In this Recommendation, only Band III is considered, for which a reference frequency of 200 MHz is used.

The use of the term 'DAB' in this Recommendation applies to both DAB and DAB+ systems. Where there is a difference in the impact on planning criteria between the two systems, this is indicated.

The receiving antenna, which is assumed to be representative for mobile and portable reception, has a height of 1.5 m above ground level, omnidirectional with a gain slightly lower than a dipole.

The field strength prediction method relies on curves for 50% locations, 50% time for the wanted signal and 50% locations, 1% time for the unwanted signal.

For the calculation of tropospheric (1% time) and continuous (50% time) interference, see Recommendation ITU-R BT.655.

The required location percentage for DAB services depends on the reception mode considered.

The propagation curves used for planning relate to a receiving antenna height of 10 m above ground, whereas a DAB service will be planned primarily for mobile reception, i.e. with an effective receiving antenna height of about 1.5 m. A height loss allowance is necessary to convert the minimum required DAB field strength at a vehicle antenna height of 1.5 m to the equivalent value at 10 m.

2 Reception modes and associated *C*/*N* values

Traditionally, radio networks have been planned on the basis of fixed roof top reception with the receive antenna mounted 10 m above the ground. However, this 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 Recommendation, parameters for fixed roof top reception are not provided.

Six reception modes are considered within this recommendation. Table 1 lists these, covering portable and mobile reception scenarios to handheld, kitchen radio and vehicle installed devices. All assume reception at no less than 1.5 m above ground level.

The associated *C*/*N* value to each reception mode is also indicated in Table 1. *C*/*N* values for DAB ensembles intended to carry EEP protected sub channels have been determined by a set of measurements based on arbitrarily chosen DAB+ receivers and two different profiles 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).

TABLE 1

Reception modes and associated *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/suburban/ External antenna (PO-H/Ext)	11.9	TU 12
5	Handheld portable indoor reception/urban/ External antenna (PI-H/Ext)	11.9	TU 12
6	Handheld mobile reception/rural/ External antenna (MO-H/Ext)	12.6	RA 6

3 Antenna gain

Table 2 summarises the antenna gains for DAB receivers in Band III for the reception modes listed in § 2:

– mobile (car) reception using a built-in antenna mounted on the outside of the car;

– portable reception using a stand-alone type of receiver (table top or kitchen radio) with a built-in (folded or telescopic) antenna;

– handheld reception using an external antenna (e.g. wired headset or telescopic);

– handheld reception in a moving vehicle with an external antenna (e.g. telescopic or wired headset).

TABLE 2

Antenna gains G_D

200 MHz		
Reception mode	**Antenna type**	**Antenna gain G_D (dBd)**
Mobile (car) reception (MO)	Adapted antenna	–5 to –10
Portable reception (PO, PI)	Built-in	–8 to –10
Portable and mobile handheld reception (PO-H, PI-H, MO-H)	External (1)	–13

(1) Telescopic or wired headsets

4 Feeder loss

Feeder loss is usually small for reception cases of interest for DAB. It is suggested that a feeder loss of 0 dB should be used for the portable, handheld and mobile reception cases.

5 Allowance for man-made-noise (MMN)

The effect on system performance of man-made noise, MMN, received via the antenna needs to be considered as it impacts the coverage field strength target calculations. Table 3 provides the values for different typical antenna gains and reception scenarios.

TABLE 3

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

Antenna gain (dBd)	**–5**	**–8**	**–13**
Rural	0.9	**0.5**	0.2
Residential/suburban	2.5	**1.5**	0.5
Urban indoor	7.6	**5.3**	2.4

During the last years an increase in man-made noise has been noticed and 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.

6 Coverage prediction height

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). This factor depends on the frequency and receiving environment.

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 in Recommendation ITU-R P.1546.

7 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.

Recently, the issue of building entry loss (BEL) has been revisited. 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. Information on how to calculate BEL is provided in Recommendation ITU-R P.2109.

Recommendation ITU-R P.2109 provides equations to derive distributions for BEL (see Fig. 1) that cover all types of receive environment, from a room with an outside window to a location deep inside a building and different building types. For the purpose of coverage planning, BEL needs to be calculated based on the environment, suburban, urban or others, and whether coverage is planned to a receiver located in a room with an outside window or deep inside a building. Though decisions on BEL to use in planning will depend on local circumstances, the maximum loss for a particular circumstance can be set by limiting the probability. The values of probability provided in Table 4 are considered to be generally applicable for planning.

FIGURE 1

Cumulative Distribution Function (CDF) of BEL based on Recommendation ITU-R P.2109

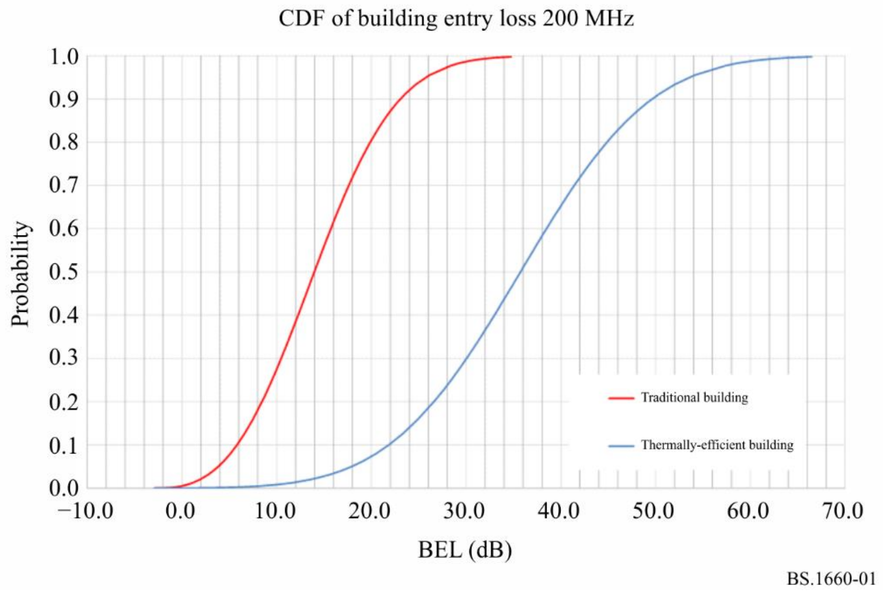

TABLE 4

ITU-R P.2109 Broadcast building entry loss probability for Band III planning

Building type	Environment	Probability building entry loss not exceeded	Max BEL at 200 MHz
Traditional	Suburban	50%	14.0 dB
Traditional	Urban	70%	17.6 dB

8 Vehicle (car) entry loss

A study[1] 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.

9 Location percentages

9.1 Location correction factor

To obtain signal levels for planning, i.e. the minimum field strength needed to provide reception at a higher percentage of locations, a location correction factor C_l has to be applied. In calculating the location correction factor, a log-normal distribution of the received signal with location is assumed.

The location correction factor C_l can be calculated by the equation (1):

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1 Measurements of the vehicle penetration loss characteristics at 800 MHz. *48th IEEE Vehicular technology Symposium, May 1998.*

$$C_l = \mu \times \sigma \qquad (1)$$

where:

σ : standard deviation of the field strength distribution

μ : normal distribution factor.

Values for some often used cases are given below.

TABLE 5

Normal distribution factor values for commonly used % of locations values

Normal distribution factor μ	**Percentage of locations (%)**
0.00	50
0.52	70
1.28	90
1.64	95
2.33	99

Values of μ for other percentages of locations[2] can be found from the normal distribution table in Recommendation ITU-R P.1546.

Depending on the reception mode, different values for μ and for σ have to be applied.

9.2 Location correction factors for different reception modes

In § 2 different reception modes are defined:

MO: Standard mobile reception;

PO: Standard portable outdoor reception;

PI: Standard portable indoor reception;

PO-H/Ext: Handheld portable outdoor reception with external antenna;

PI-H/Ext: Handheld portable indoor reception with external antenna;

MO-H/Ext: Handheld mobile reception with external antenna.

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 vehicle entry loss. When this is the case the resulting standard deviation can be calculated using:

$$\sigma_{res} = \sqrt{(\sigma_{LV}^2 + \sigma_{OL}^2)} \qquad (2)$$

The values used for various reception modes are shown in Table 6. For indoor reception in a building, the values are on the basis of entry loss measured in traditional buildings (see § 7).

2 The Excel function = normsinv(x) where x = a value >0 and <1 will provide values for μ.

TABLE 6

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)[3]	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	0	4.0	95	1.64	6.56	
	Acceptable	4.0	0	4.0	70	0.52	2.08	
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	0	4.0	95	1.64	6.56	
	Acceptable	4.0	0	4.0	70	0.52	2.08	
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

VEL = Vehicle Entry Loss

9.3 Location correction margin

When determining the maximum permissible field strength of an interfering signal both the location variation of the wanted signal and the interfering signal should be taken into account. The amount of protection achieved for a given wanted signal with respect to a given interfering signal is related to the difference of the wanted and interfering field strengths. This difference is a statistical variable that depends on:

– the median values of the two fields, and on

– their location standard deviations,

and which has a standard deviation that can be calculated as follows:

$$\sigma_{res} = \sqrt{(\sigma_{wanted})^2 - 2\rho \times \sigma_{wanted} \times \sigma_{interferer} + \left(\sigma_{interferer}\right)^2} \qquad (3)$$

It is assumed that the wanted and interfering signals are both log-normally distributed and are un-correlated, i.e. correlation factor $\rho = 0$. If they have identical standard deviations, then;

Since $\sigma_{wanted} = \sigma_{interferer}$ and $\rho = 0$,

$$\sigma_{res} = (\sigma_{wanted}) \times \sqrt{2} \qquad (4)$$

The resulting combined location variation standard deviation is used to determine the Location Correction Margin (LCM).

The value of LCM is obtained from the % availability for the wanted field strength, μ, and the combined location variation standard deviation as:

$$\text{LCM} = \mu \times \sigma_{res} \qquad (5)$$

[3] 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.

The median maximum interfering field strength can be derived from:

$$E_I^{Max} = E_W^{Min} - \text{PR} - \text{LCM} \qquad (6)$$

where:

E_I^{Max} : maximum permissible interfering field strength

E_W^{Min} : minimum median wanted field strength

PR : Protection ratio.

Typically, interference situations are calculated for the minimum field strength that is protected; usually the mobile outdoor (MO) reception mode. The availability (percentage locations served) for that reception mode is 99% with the resulting value of μ being 2.33, and hence the value of LCM = $2.33\sigma_{res}$. If a value of 4.0 dB is used for the value of $\sigma_{wanted} = \sigma_{interferer}$ then the resulting value of σ_{res} = 5.66 dB and the value of LCM = 13.19 dB.

10 Receiver properties

10.1 Receiver noise figure

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

10.2 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 § 10.1). 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 in § 11.1 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)

C/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).

Constants:

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

T_0 : Absolute temperature = 290 K.

Formulas used:

$$P_n \text{ (in dBW)} = F_r + 10 \log (k \times T_0 \times B)$$

$$P_{s\,min}\text{ (in dBW)} = P_n + C/N$$

$$U_{s\,min}\text{ (in dB}\mu\text{V)} = P_{s\,min} + 120 + 10\log(Z_i).$$

TABLE 7

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)	–136.10	–136.10
RF signal/noise ratio	C/N (dB)	11.9	12.6
Minimum receiver signal input power	$P_{s\,min}$ (dBW)	–124.20	–123.50
Minimum equivalent receiver input voltage, 75 ohm	$U_{s\,min}$ (dBμV)	14.55	15.25

11 Calculation of signal levels and protection ratio

11.1 Signal levels for planning

In § 10.2 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 § 11.1 minimum median power flux densities and equivalent field strengths are presented which are needed for practical planning considerations.

To calculate the minimum median pfd or equivalent field strength needed to ensure that the minimum values of signal level can be achieved at the required percentage of locations, the following formulas are used:

$$\varphi_{min} = P_{s\,min} - A_a + L_f$$

$$E_{min} = \varphi_{min} + 120 + 10\log_{10}(120\pi) = \varphi_{min} + 145.8$$

$$\varphi_{med} = \varphi_{min} + P_{mmn} + C_l$$ (for portable outdoor reception, mobile reception and, handheld portable outdoor reception and handheld mobile reception)

$$\varphi_{med} = \varphi_{min} + P_{mmn} + C_l + L_b$$ (for portable indoor reception and handheld portable indoor reception)

$$\varphi_{med} = \varphi_{min} + P_{mmn} + C_l + L_v$$ (for handheld mobile reception)

$$E_{med} = \varphi_{med} + 120 + 10\log_{10}(120\pi) = \varphi_{med} + 145.8$$

where:

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

φ_{min} : Minimum pfd at receiving place (dBW/m^2)

E_{min} : Equivalent minimum field strength at receiving place (dBμV/m)

L_f : Feeder loss (dB)

L_b : Building entry loss (dB)

L_v : Vehicle entry loss (dB)

P_{mmn} : Allowance for man-made noise (dB)

C_l : Location correction factor (dB)

φ_{med} : Minimum median pfd, planning value (dBW/m^2)

E_{med} : Minimum median equivalent field strength, planning value (dBμV/m)

A_a : Effective antenna aperture (dBm^2) [$A_a = G_{iso} + 10\log_{10}(\lambda^2/4\pi)$] × G_{iso} is the antenna gain relative to an isotropic antenna.

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

For calculating the location correction factor C_1 a log-normal distribution of the received signal is assumed.

$$C_1 = \mu \times \sigma$$

where:

μ : Distribution factor. See § 9.1

σ : Standard deviation taken as 4.0 dB for outdoor reception. See § 9.2 for σ values appropriate for indoor reception.

While the matters dealt with in this section are generally applicable, additional special considerations are needed in the case of SFNs where there is more than one wanted signal contribution.

11.1.1 Examples of signal levels for planning

This section gives the details of the calculation for the cases listed in Table 1.

In Table 8 the reception height is 1.5 m above ground level (a.g.l.) for all the reception modes. The calculations are performed for one frequency representing Band III (200 MHz) and a bandwidth of 1.7 MHz.

TABLE 8
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
Min. receiver signal input power	$P_{s\ min}$	dBW	-123.50	-124.20	-124.20	-124.20	-124.20	-123.50
Min. 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	dBm^2	-10.32	-13.32	-13.32	-18.32	-18.32	-18.32
Min Power flux density at receiving location	F_{min}	dB(W)/ m^2	-113.18	-110.88	-110.88	-105.88	-105.88	-105.18
Min 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	17.60	0	17.60	8
Standard deviation of the entry loss		dB	0	0	0	0	0	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[4]			4	4	4	4	4	4.47
Location correction factor	C_l	dB	5.12	2.08	2.08	2.08	2.08	5.72
Minimum median power flux density 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)/ m^2	-107.16	-107.30	-85.90	-103.30	-83.80	-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**	**59.90**	**42.50**	**62.0**	**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	4	4.00	4	4.47
Location correction factor	C_l	dB	9.32	6.56	6.56	6.56	6.56	10.42
Minimum median power flux density 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)/ m^2	-102.96	-102.82	-81.42	-98.82	-79.32	-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**	**64.38**	**46.98**	**66.48**	**59.23**

4 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 (see § 9.2).

11.2 Protection ratios

11.2.1 DAB vs DAB

11.2.1.1 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. The required PR is in the range 10 - 14 dB with an average of 12 dB.

11.2.1.2 Adjacent channel protection

The PRs 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. Introducing a new transmitter into a network has the potential to cause interference not only to co-channel usage elsewhere, but also to adjacent channel interference (ACI) in its close vicinity.

In the case of the use of the critical spectrum mask, the adjacent channel protection ratios used for planning should be based upon the values in Table 9.

TABLE 9

Suggested adjacent channel protection ratios (together with critical mask)

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

11.2.2 DAB vs other broadcasting and non-broadcasting systems

11.2.2.1 General remarks

Protection ratios of DAB vs other broadcasting systems and other non-broadcasting systems are well described in documents [13] and [20]. 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 GE06.

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 GE06; 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.

11.2.2.2 DAB vs DVB-T/T2

Protection ratios for DAB vs DVB-T are given in Appendix 3.3 to Annex 2 of GE06, 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 § 11.2.1.

11.2.2.3 DAB vs DRM

The protection ratio for DAB interfered by DRM is 10 dB. This value applies for any frequency offset between both signals within the DAB bandwidth.

The protection ratio for DRM interfered by DAB is given in § 8.2.1.3 of Annex 3.

11.2.2.4 DAB vs other services

Protection ratios for DAB vs Other Services are given in Appendix 4.3 to Annex 2 of GE06, 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 § 11.2.2.1.

12 Unwanted emissions

12.1 Spectrum masks for DAB out-of-band emissions

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 $(10 \times \log_{10}(4 / 1536))$ dB = −26 dB 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. 2 and Table 10. 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.

NOTE – With increasing frequency difference, the attenuation will further increase. However, it is difficult to measure such high values of attenuation. To assist with measurements, it may be necessary to use special notch filters (e.g. at the distress frequency 243 MHz).

FIGURE 2

Spectrum masks for DAB out of band radiation

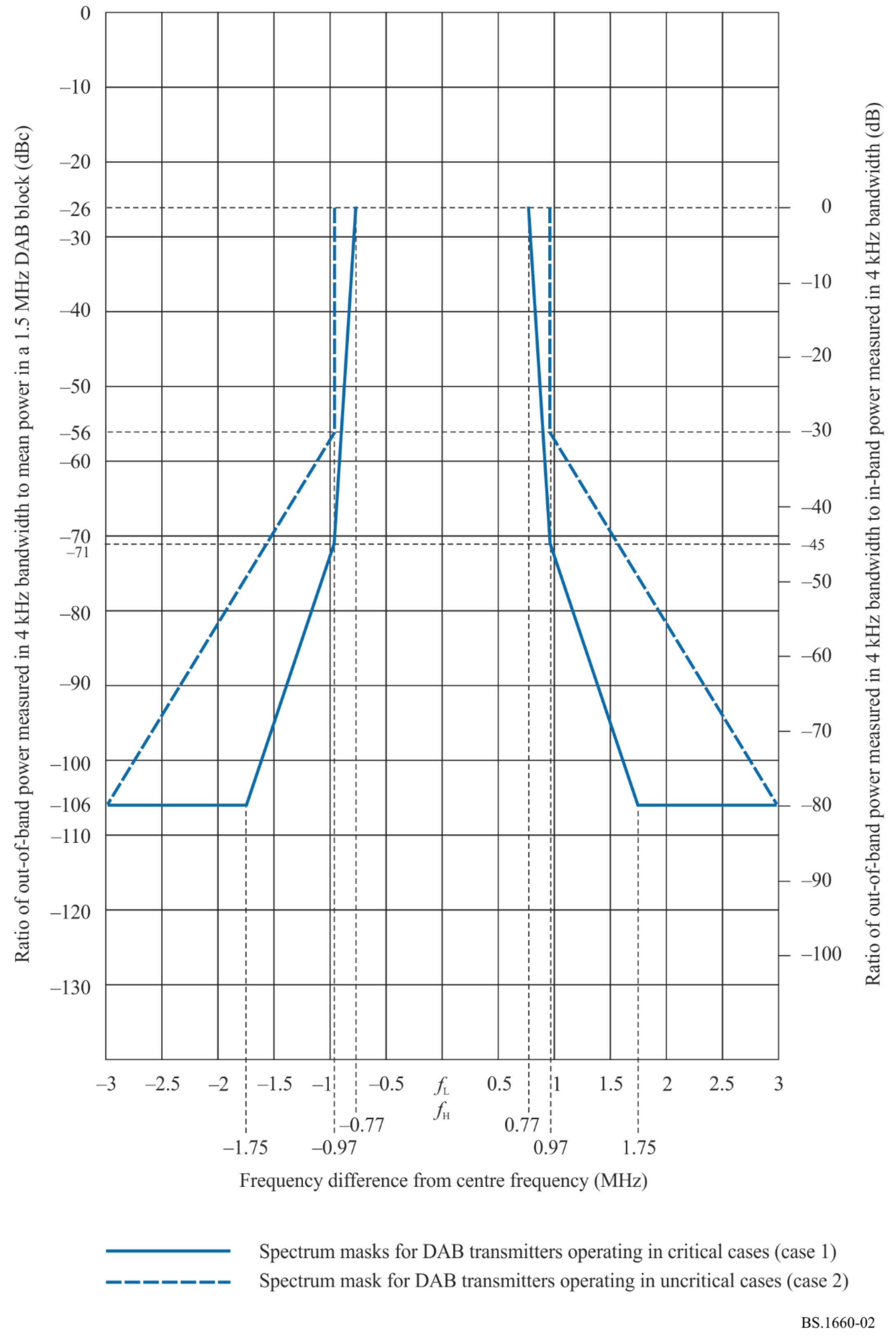


TABLE 10

Break points for spectrum masks in Fig. 2

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

Bibliography

ETSI Specification EN 300 401 – Radio broadcasting systems; Digital Audio Broadcasting (DAB) to mobile, portable and fixed receivers.

Annex 2

Technical basis for planning of terrestrial digital sound broadcasting System F (ISDB-T_{SB}) in the VHF band

1 General

This Annex describes planning criteria for Digital System F (ISDB-T_{SB}) in the VHF band. System F can be assigned to a 6 MHz, 7 MHz, or 8 MHz television channel raster. Segment bandwidth is defined to be a fourteenth of the channel bandwidth, therefore that is 429 kHz (6/14 MHz), 500 kHz (7/14 MHz) or 571 kHz (8/14 MHz). However, the segment bandwidth should be selected in compliance with the frequency situation in each country.

2 Spectrum masks for out-of-band emissions

The radiated signal spectrum should be constrained by the spectrum mask. Table 11 defines the breakpoints of the spectrum mask for *n*-segment transmission for 6/14 MHz, 7/14 MHz, and 8/14 MHz segment system. The spectrum mask is defined as the relative value to the mean power of each frequency. Figure 3 shows the spectrum mask for 3-segment transmission in 6/14 MHz segment system.

TABLE 11

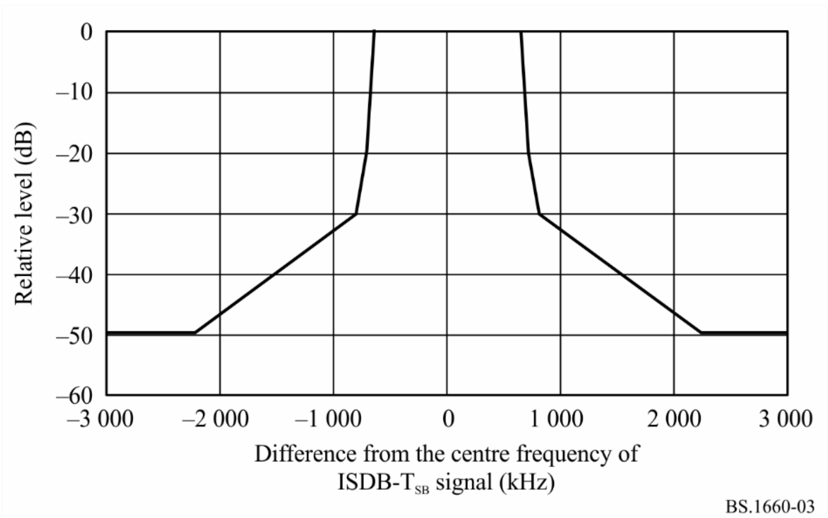
Breakpoints of the spectrum mask
(segment bandwidth (BW) = 6/14, 7/14, or 8/14 MHz)

Difference from the centre frequency of the terrestrial digital sound signal	Relative level (dB)
$\pm\left(\frac{BW\times n}{2}+\frac{BW}{216}\right)$ MHz	0
$\pm\left(\frac{BW\times n}{2}+\frac{BW}{216}+\frac{BW}{6}\right)$ MHz	–20
$\pm\left(\frac{BW\times n}{2}+\frac{BW}{216}+\frac{BW}{3}\right)$ MHz	–30
$\pm\left(\frac{BW\times n}{2}+\frac{BW}{216}+\frac{11\times BW}{3}\right)$ MHz	–50

n: Number of consecutive segments.

FIGURE 3

Spectrum mask for ISDB-T$_{SB}$ transmission signal
(BW = 6/14 MHz, *n* = 3)



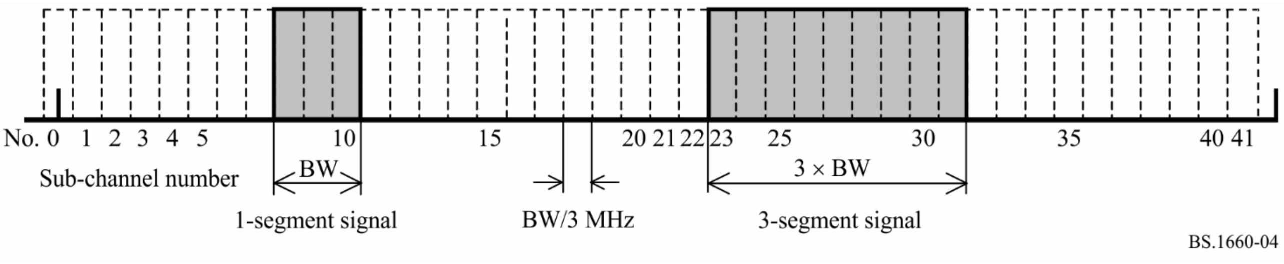
3 Frequency condition

3.1 Definition of sub-channel

In order to indicate the frequency position of the ISDB-T$_{SB}$ signal each segment is numbered using a sub-channel number 0 through 41. The sub-channel is defined as one third of the BW (see Fig. 4). For example, the frequency positions of 1-segment and 3-segment signal shown in Fig. 4 are defined as the 9th and 27th sub-channels respectively in the analogue television channel.

FIGURE 4

Definition of sub-channel

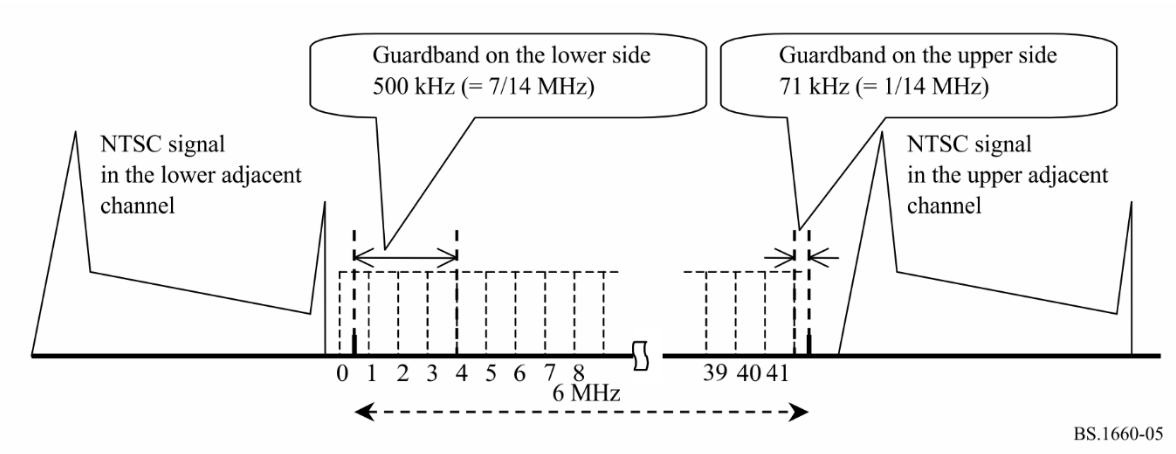


3.2 Guardbands

From the results of subjective evaluation on NTSC interfered with by ISDB-T_{SB}, guardbands are determined at both sides of the NTSC signal. As shown in Fig. 5, the guardbands are 500 kHz (= 7/14 MHz) on the lower side within the channel and 71 kHz (= 1/14 MHz) on the upper side. Accordingly, the sub-channels that can be used for digital sound broadcasting are from sub-channel Nos. 4 to 41. Within a 6 MHz television channel, a maximum of 12 segments can be allocated, excluding the guardbands.

FIGURE 5

Guardbands to coexist with adjacent analogue television signal



4 Minimum usable field strength

Link budgets for the three cases of fixed reception, portable reception and mobile reception at the frequencies of 100 MHz and 200 MHz are presented in Table 12. Required field strengths for the 1-segment and the 3-segment are described in the 22nd row and the 24th row respectively. The values are for the case of 6/14 MHz segment system, and can be converted for the case of 7/14 MHz or 8/14 MHz segment system according to the bandwidth.

TABLE 12

Link budgets for ISDB-T$_{SB}$

(a) 100 MHz

	Element	Mobile reception			Portable reception			Fixed reception		
	Frequency (MHz)	100			100			100		
	Modulation scheme	QPSK	QPSK	16-QAM	QPSK	QPSK	16-QAM	QPSK	QPSK	16-QAM
	Coding rate of the inner code	1/2	2/3	1/2	1/2	2/3	1/2	1/2	2/3	1/2
1	Required *C*/*N* (QEF after error correction) (dB)	4.9	6.6	11.5	4.9	6.6	11.5	4.9	6.6	11.5
2	Implementation degradation (dB)	2	2	2	2	2	2	2	2	2
3	Interference margin (dB)	2	2	2	2	2	2	2	2	2
4	Multipath margin (dB)	–	–	–	1	1	1	1	1	1
5	Fading margin (temporary fluctuation correction) (dB)	9.4	9.4	8.1	–	–	–	–	–	–
6	Receiver required *C*/*N* (dB)	18.3	20	23.6	9.9	11.6	16.5	9.9	11.6	16.5
7	Receiver noise figure, *NF* (dB)	5	5	5	5	5	5	5	5	5
8	Noise bandwidth (1-segment), *B* (kHz)	429	429	429	429	429	429	429	429	429
9	Receiver intrinsic noise power, N_r (dBm)	–112.7	–112.7	–112.7	–112.7	–112.7	–112.7	–112.7	–112.7	–112.7
10	External noise power at the receiver input terminal, N_0 (dBm)	–98.1	–98.1	–98.1	–98.1	–98.1	–98.1	–99.1	–99.1	–99.1
11	Total receiver noise power N_t (dBm)	–98.0	–98.0	–98.0	–98.0	–98.0	–98.0	–98.9	–98.9	–98.9
12	Feeder loss, *L* (dB)	1	1	1	1	1	1	2	2	2
13	Minimum usable receiver input power (dBm)	–79.7	–78.0	–74.4	–88.1	–86.4	–81.5	–89.0	–87.3	–82.4
14	Receiver antenna gain, G_r (dBi)	–0.85	–0.85	–0.85	–0.85	–0.85	–0.85	–0.85	–0.85	–0.85
15	Effective antenna aperture (dB/m^2)	–2.3	–2.3	–2.3	–2.3	–2.3	–2.3	–2.3	–2.3	–2.3
16	Minimum usable field strength, E_{min} (dB(μV/m))	39.4	41.1	44.7	31.0	32.7	37.6	31.1	32.8	37.7
17	Time-rate correction (dB)	0.0	0.0	0.0	0.0	0.0	0.0	4.3	4.3	4.3

TABLE 12 (*continued*)

	Element	Mobile reception			Portable reception			Fixed reception		
18	Location rate correction (dB)	12.8	12.8	12.8	2.9	2.9	2.9	–	–	–
19	Wall penetration loss value (dB)	–	–	–	10.1	10.1	10.1	–	–	–
20	Required field strength (1-segment) at antenna, *E*(dB(μV/m))	52.2	53.9	57.5	44.0	45.7	50.6	35.4	37.1	42.0
	Assumed antenna height, h_2 (m)	1.5	1.5	1.5	1.5	1.5	1.5	4.0	4.0	4.0
21	Height correction to 10 m (dB)	10.0	10.0	10.0	10.0	10.0	10.0	7.0	7.0	7.0
22	Required field strength (1-segment, h_2 = 10 m), *E*(dB(μV/m))	62.2	63.9	67.5	54.0	55.7	60.6	42.4	44.1	49.0
23	Conversion from 1-segment to 3-segment (dB)	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
24	Required field strength (3-segment, h_2 = 10 m), *E*(dB(μV/m))	67.0	68.7	72.3	58.8	60.5	65.4	47.2	48.9	53.8

(b) 200 MHz

	Element	Mobile reception			Portable reception			Fixed reception		
	Frequency (MHz)	200			200			200		
	Modulation scheme	DQPSK	16-QAM	64-QAM	DQPSK	16-QAM	64-QAM	DQPSK	16-QAM	64-QAM
	Coding rate of the inner code	1/2	1/2	7/8	1/2	1/2	7/8	1/2	1/2	7/8
1	Required *C*/*N* (QEF after error correction) (dB)	6.2	11.5	22.0	6.2	11.5	22.0	6.2	11.5	22.0
2	Implementation degradation (dB)	2.0	2.0	3.0	2.0	2.0	3.0	2.0	2.0	3.0
3	Interference margin (dB)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
4	Multipath margin (dB)	–	–	–	1.0	1.0	1.0	1.0	1.0	1.0
5	Fading margin (temporary fluctuation correction) (dB)	9.5	8.1	(1)	–	–	–	–	–	–
6	Receiver required *C*/*N* (dB)	19.7	23.6	(1)	11.2	16.5	28.0	11.2	16.5	28.0
7	Receiver noise figure, *NF* (dB)	5	5	–	5	5	5	5	5	5

TABLE 12 (*continued*)

	Element	Mobile reception			Portable reception			Fixed reception		
8	Noise bandwidth (1-segment), B (kHz)	429	429	–	429	429	429	429	429	429
9	Receiver intrinsic noise power, N_r (dBm)	–112.7	–112.7	–	–112.7	–112.7	–112.7	–112.7	–112.7	–112.7
10	External noise power at the receiver input terminal, N_0 (dBm)	–107.4	–107.4	–	–107.4	–107.4	–107.4	–107.4	–107.4	–107.4
11	Total receiver noise power, N_t (dBm)	–106.3	–106.3	–	–106.3	–106.3	–106.3	–106.3	–106.3	–106.3
12	Feeder loss, L (dB)	2.0	2.0	–	2.0	2.0	2.0	2.0	2.0	2.0
13	Minimum usable receiver input power (dBm)	–86.6	–82.7	–	–95.1	–89.8	–78.3	–95.1	–89.8	–78.3
14	Receiver antenna gain, G_r (dBi)	–0.85	–0.85	–	–0.85	–0.85	–0.85	–0.85	–0.85	–0.85
15	Effective antenna aperture (dB/m^2)	–8.3	–8.3	–	–8.3	–8.3	–8.3	–8.3	–8.3	–8.3
16	Minimum usable field strength, E_{min} (dB(μV/m))	39.5	43.4		31.0	36.3	47.8	31.0	36.3	47.8
17	Time-rate correction (dB)	0.0	0.0	–	0.0	0.0	0.0	6.2	6.2	6.2
18	Location rate correction (dB)	12.8	12.8	–	2.9	2.9	2.9	–	–	–
19	Wall penetration loss value (dB)	–	–	–	10.1	10.1	10.1	–	–	–
20	Required field strength (1-segment) at antenna, E(dB(μV/m))	52.3	56.2		44.0	49.3	60.8	37.2	42.5	54.0
	Assumed antenna height, h_2 (m)	1.5	1.5	–	1.5	1.5	1.5	4	4	4
21	Height correction to 10 m (dB)	12	12	–	12	12	12	10	10	10
22	Required field strength (1-segment, h_2 = 10 m), E(dB(μV/m))	64.3	68.2	–	56.0	61.3	72.8	47.2	52.5	64.0

TABLE 12 (*end*)

	Element	Mobile reception			Portable reception			Fixed reception		
23	Conversion from 1-segment to 3-segment (dB)	4.8	4.8	–	4.8	4.8	4.8	4.8	4.8	4.8
24	Required field strength (3-segment, h_2 = 10 m), E(dB(μV/m))	69.1	73.0		60.8	66.1	77.6	52.0	57.3	68.8

(1) Not usable in fading environment.

1) Required *C*/*N*

The required *C*/*N* for modulation schemes and coding rates are shown in Table 13.

TABLE 13

Required *C*/*N*

Modulation	Coding rate for convolutional coding (dB)				
	1/2	2/3	3/4	5/6	7/8
DQPSK	6.2	7.7	8.7	9.6	10.4
QPSK	4.9	6.6	7.5	8.5	9.1
16-QAM	11.5	13.5	14.6	15.6	16.2
64-QAM	16.5	18.7	20.1	21.3	22.0

2) Implementation degradation

The amount of equivalent *C*/*N* degradation expected in equipment implementation.

3) Interference margin

The margin for the equivalent *C*/*N* degradation caused by interference such as those from analogue broadcasting.

NOTE – Long-distance propagation over sea paths or other environments may cause interference in some circumstances. Although it is not practical to include such special cases in the calculation of link budgets, attention should be paid to this type of interference.

4) Multipath margin for portable reception or fixed reception

The margin for the equivalent *C*/*N* degradation caused by multipath interference.

5) Fading margin for mobile reception

The margin for the equivalent *C*/*N* degradation caused by temporary fluctuation in the field strength.

The *C*/*N* required in the fading channel is shown in Table 14. Fading margins are shown in Table 15.

TABLE 14

Required *C*/*N*
(Mode 3, Guard 1/16, and GSM typical urban fading model)

			Maximum Doppler frequency (f_D)(1)		
Modulation	**Coding rate**	**Gaussian noise (dB)**	**2 Hz**	**7 Hz**	**20 Hz**
DQPSK	1/2	6.2	15.7 dB	11.4 dB	9.9 dB
QPSK	1/2	4.9	14.3 dB	10.8 dB	10.4 dB
16-QAM	1/2	11.5	19.6 dB	17.4 dB	19.1 dB
64-QAM	1/2	16.5	24.9 dB	22.9 dB	>35 dB

(1) When velocity of vehicle is 100 km/h, maximum Doppler frequency is up to 20 Hz in the VHF high channel (170-220 MHz).

TABLE 15

Fading margins
(Temporary field-strength fluctuation margin)

Modulation	**Coding rate**	**VHF (up to f_D = 20 Hz) (dB)**
DQPSK	1/2	9.5
QPSK	1/2	9.4
16-QAM	1/2	8.1
64-QAM	1/2	–

6) Receiver required *C*/*N*

= (1: required *C*/*N*) + (2: implementation degradation) + (3: interference margin) + (4: multipath margin) + (5: fading margin).

7) Receiver noise figure, *NF*

= 5 dB.

8) Noise bandwidth, *B*

= 1-segment signal transmission bandwidth.

9) Receiver thermal noise power, N_r

= 10 × log ($k\ T\ B$) + *NF*

$k = 1.38 \times 10^{-23}$ (the Boltzmann constant), T = 290 K.

10) External noise power, N_0

The external noise power (lossless antenna) in the 1-segment bandwidth based on the median values of man-made noise power for business (curve A) category in Recommendation ITU-R P.372 at each of the frequencies of 100 MHz and 200 MHz is as follows:

N_0 = –96.3 dBm – (12: feeder loss) + G_{cor} for 100 MHz,

N_0 = –104.6 dBm – (12: feeder loss) + G_{cor} for 200 MHz,

$G_{cor} = G_r$ ($G_r < 0$), 0 ($G_r > 0$).

NOTE – G_{cor} is a correction factor for the received external noise power by a receiving antenna. A receiving antenna with a minus gain ($G_r < 0$) receives both desired signals and external noise with the minus gain ($G_{cor} = G_r$). On the other hand, a receiving antenna with a plus gain ($G_r > 0$) receives desired signals in the direction of the main beam with the plus gain but receives external noise omnidirectionally without a gain ($G_{cor} = 0$).

11) Total received noise power, N_t

= the power sum of (9: receiver intrinsic noise power) and (10: external noise power at the receiver input terminal)

= $10 \times \log (10^{(N_r/10)} + 10^{(N_0/10)})$.

12) Feeder loss, L

L = 1 dB at 100 MHz for mobile and portable reception

L = 2 dB at 100 MHz for fixed reception

L = 2 dB at 200 MHz for mobile, portable and fixed reception.

13) Minimum usable receiver input power

= (6: receiver required C/N) + (11: total receiver noise power)

= $C/N + N_t$

14) Receiver antenna gain, G_r

= –0.85 dBi, assuming a $\lambda/4$ monopole antenna.

15) Effective antenna aperture

= $10 \times \log (\lambda^2/4\pi)$ + (14: receiving antenna gain) (dBi).

16) Minimum usable field strength, E_{min}

= (12: feeder loss) + (13: minimum receiver input power) – (15: effective antenna aperture) + 115.8 (power flux-density (dBm/m^2) to field strength (dB(μV/m)) conversion).

17) Time-rate correction

For fixed reception, the time-rate correction value is determined by Recommendation ITU-R P.1546. The value from 50% to 1% is 4.3 dB at 100 MHz and 6.2 dB at 200 MHz, respectively. The propagation condition is as follows:

– Path:	Land paths
– Transmitting/base antenna height:	250 m
– Distance:	70 km.

18) Location rate correction

According to Recommendation ITU-R P.1546, standard deviation of location variation σ is 5.5 dB for digital broadcasting signal.

In the case of mobile reception, the location correction value from 50% to 99%[5] is 12.9 dB (2.33 σ).

In the case of portable reception, the location correction value from 50% to 70%[5] is 2.9 dB (0.53 σ).

19) Wall penetration loss

For indoor reception, the signal loss due to passing through walls is considered. The average penetration loss is 8 dB with a standard deviation of 4 dB. Assuming the location rate of 70% (0.53 σ) for portable receivers, the value is as follows.

= 8 dB + 0.53 × 4 dB = 10.1 dB.

20) Required field strength at antenna

= (16: minimum field strength, E_{min}) + (17: time rate correction) + (18: location rate correction) + (19: wall penetration loss).

21) Height correction

According to Recommendation ITU-R P.1546, the height correction values are derived as shown in Table 16.

TABLE 16

Height correction values

(a) Suburban, 100 MHz

	4 m above ground level (dB)	**1.5 m above ground level (dB)**
Difference in field strength from height of 10 m above ground level	–7	–10

(b) Suburban, 200 MHz

	4 m above ground level (dB)	**1.5 m above ground level (dB)**
Difference in field strength from height of 10 m above ground level	–10	–12

22) Required field strength at receiving height of 10 m above ground level

= (20: required field strength at antenna) + (21: reception height correction).

23) Conversion from 1-segment signal to 3-segment signal

noise bandwidth conversion value

= 10 × log (3/1) = 4.8 dB.

24) Required field strength (h_2 = 10 m) for 3-segment signal

= (22: required field strength (h_2 = 10 m)) + (23: conversion from 1-segment signal to 3-segment signal).

[5] Different percentages may be used according to the service criteria in each country.

5 Protection of ISDB-T_{SB}

5.1 ISDB-T_{SB} interfered with by ISDB-T_{SB}

5.1.1 Required *D*/*U* in fixed reception

The *D*/*U* between 1-segment ISDB-T_{SB} signals are measured at a BER of 2×10^{-4} after decoding the inner code, and are shown for each guardband in Table 17. The guardband means a frequency spacing between spectrum edges.

In the case where the spectra overlap each other, interference is considered as co-channel interference.

TABLE 17

Required *D*/*U* (dB) between 1-segment ISDB-T_{SB} signals (fixed reception)

Modulation	Coding rate	Co-channel	Guardband (MHz)							
			0/7	1/7	2/7	3/7	4/7	5/7	6/7	7/7 or above
DQPSK	1/2	4	–15	–21	–25	–28	–29	–36	–41	–42
16-QAM	1/2	11	–6	–12	–21	–24	–26	–33	–38	–39
64-QAM	7/8	22	–4	–10	–10	–11	–13	–19	–23	–24

5.1.2 Required *D*/*U* in mobile reception

In mobile reception, the standard deviation of a location variation of digital broadcasting signal is 5.5 dB according to Recommendation ITU-R P.1546. The field-strength values for wanted and unwanted signals are assumed to be uncorrelated. To protect wanted ISDB-T_{SB} signals for 99% of locations against interference from other ISDB-T_{SB} transmissions, a propagation correction is 18 dB ($\approx 2.33 \times 5.5 \times 1.414$). The *D*/*U* including the total margins are listed in Table 18.

TABLE 18

Required *D*/*U* (dB) between 1-segment ISDB-T_{SB} signals (mobile reception)

Modulation	Coding rate	Co-channel	Guardband (MHz)							
			0/7	1/7	2/7	3/7	4/7	5/7	6/7	7/7 or above
DQPSK	1/2	22	3	–3	–7	–10	–11	–18	–23	–24
16-QAM	1/2	29	12	6	–3	–6	–8	–15	–20	–21

5.1.3 Resultant protection ratios for ISDB-T_{SB} interfered with by ISDB-T_{SB}

The protection ratios are defined as the highest values taken from Tables 17 and 18 to apply to every reception condition. The resultant protection ratios are shown in Table 19.

TABLE 19

Protection ratios for ISDB-T$_{SB}$ interfered with by ISDB-T$_{SB}$

Desired signal	Interference signal	Frequency difference	Protection ratio
ISDB-T$_{SB}$ (1-segment)	ISDB-T$_{SB}$ (1-segment)	Co-channel	29 dB
		Adjacent	Table 20
	ISDB-T$_{SB}$ (3-segment)	Co-channel	24 dB
		Adjacent	Table 20
ISDB-T$_{SB}$ (3-segment)	ISDB-T$_{SB}$ (1-segment)	Co-channel	34 dB
		Adjacent	Table 20
	ISDB-T$_{SB}$ (3-segment)	Co-channel	29 dB
		Adjacent	Table 20

NOTE – For protection ratios for ISDB-T$_{SB}$, fading margin for mobile reception is taken into account. The values in the Table include the fading margin of 18 dB.

TABLE 20

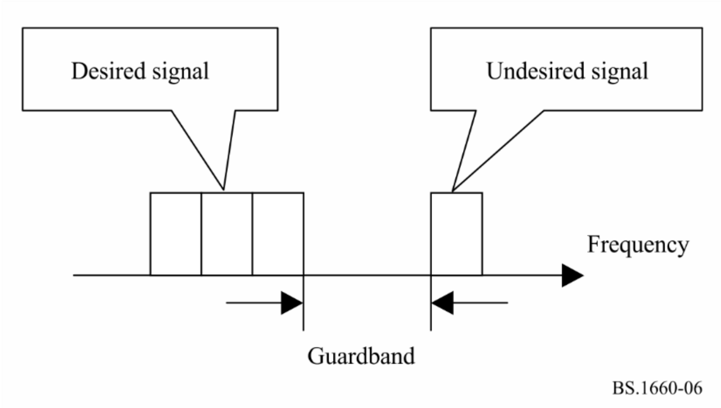
Protection ratios (dB) depending on guardbands

Desired signal	Interference signal	Guardband (MHz)							
		0/7	1/7	2/7	3/7	4/7	5/7	6/7	7/7 or above
ISDB-T$_{SB}$ (1-segment)	ISDB-T$_{SB}$ (1-segment)	12	6	–3	–6	–8	–15	–20	–21
	ISDB-T$_{SB}$ (3-segment)	7	1	–8	–11	–13	–20	–25	–26
ISDB-T$_{SB}$ (3-segment)	ISDB-T$_{SB}$ (1-segment)	17	11	2	–1	–3	–10	–15	–16
	ISDB-T$_{SB}$ (3-segment)	12	6	–3	–6	–8	–15	–20	–21

NOTE 1 – The values in the Table include the fading margin of 18 dB. The guardband between ISDB-T$_{SB}$ signals is as shown in Fig. 6.

FIGURE 6

Guardband and arrangement of the signals



5.2 ISDB-T_{SB} interfered with by analogue television (NTSC)

5.2.1 Required *D*/*U* in fixed reception

The *D*/*U* required for 1-segment ISDB-T_{SB} signal interfered with by NTSC are listed in Table 21. The *D*/*U* are measured at the BER of 2×10^{-4} after decoding the inner code. The guardbands between ISDB-T_{SB} signal and NTSC signal in adjacent channel interference are as shown in Fig. 5.

TABLE 21

Required *D*/*U* for 1-segment ISDB-T_{SB} interfered with by analogue television (NTSC) (fixed reception)

Modulation	Coding rate	Interference		
		Co-channel (dB)	Lower-adjacent channel (dB)	Upper-adjacent channel (dB)
DQPSK	1/2	2	–57	–60
16-QAM	1/2	5	–54	–56
64-QAM	7/8	29	–38	–38

5.2.2 Required *D*/*U* in mobile reception

In mobile reception, both the desired signal and interference signal experience field-strength fluctuation due to Rayleigh fading. The standard deviation of a location variation of digital broadcasting signal is 5.5 dB and that of analogue broadcasting signal is 8.3 dB according to Recommendation ITU-R P.1546. The field-strength values for wanted and unwanted signals are assumed to be uncorrelated. To protect wanted ISDB-T_{SB} signals for 99% of locations against interference from NTSC signals, the propagation correction is 23 dB.

The *D*/*U* including a margin required for mobile reception are listed in Table 22.

TABLE 22

Required *D*/*U* for 1-segment ISDB-T_{SB} interfered with by analogue television (NTSC) (mobile reception)

Modulation	Coding rate	Interference		
		Co-channel (dB)	Lower-adjacent channel (dB)	Upper-adjacent channel (dB)
DQPSK	1/2	25	–34	–37
16-QAM	1/2	28	–31	–33

5.2.3 Resultant protection ratios for ISDB-T_{SB} interfered with by analogue television (NTSC)

The protection ratios are defined as the highest values taken from Tables 21 and 22 to apply to every reception condition. For the 3-segment transmission, it is necessary to correct the protection ratios by 5 dB (≈ 4.8 dB = 10 × log (3/1)). The resultant protection ratios are shown in Table 23.

TABLE 23

Protection ratios for ISDB-T_{SB} interfered with by analogue television (NTSC)

Desired signal	Interference		Protection ratio (dB)
	Interference signal	Frequency difference	
ISDB-T_{SB} (1-segment)	NTSC	Co-channel	29
		Lower-adjacent	–31
		Upper-adjacent	–33
ISDB-T_{SB} (3-segment)		Co-channel	34
		Lower-adjacent	–26
		Upper-adjacent	–28

NOTE – For protection ratios for ISDB-T_{SB}, fading margin for mobile reception is taken into account. The values in the Table include the fading margin of 23 dB.

5.3 Analogue television (NTSC) interfered with by ISDB-T_{SB}

Protection ratios are defined as *D*/*U* at which subjective evaluations resulted in an impairment score of 4 (5-grade impairment scale). The evaluation experiments were conducted according to the double-stimulus impairment scale method described in Recommendation ITU-R BT.500.

In the case of adjacent interference, the guardbands between NTSC signal and ISDB-T_{SB} signal are as shown in Fig. 5. For the 3-segment transmission, it is necessary to correct the protection ratios by 5 dB (≈ 4.8 dB = 10 × log (3/1)). The resultant protection ratios are shown in Table 24.

TABLE 24

Protection ratios for analogue television (NTSC) interfered with by ISDB-T_{SB}

Desired signal	Interference		Protection ratio (dB)
	Interference signal	Frequency difference	
NTSC	ISDB-T_{SB} (1-segment)	Co-channel	57
		Lower-adjacent	11
		Upper-adjacent	11
		Image channel	–9
	ISDB-T_{SB} (3-segment)	Co-channel	52
		Lower-adjacent	6
		Upper-adjacent	6
		Image channel	–14

5.4 ISDB-T_{SB} interfered with by services other than broadcasting

The maximum interfering field-strength density below 108 MHz to avoid interference by services other than broadcasting is shown as follows:

TABLE 25

Maximum interfering field strength density interfered with by services other than broadcasting

Parameter	Value	Unit
Maximum interfering field-strength density	4.6	dB(μV/(m · 100 kHz))

NOTE – For derivation, see Attachment 1 to Annex 2.

Attachment 1 to Annex 2

Derivation of maximum interfering field strength density interfered with by services other than broadcasting

Parameter	Symbol	Value	Unit
Frequency	*f*	108	MHz
Bandwidth	*B*	429×10^3	Hz
Receiver antenna gain	*Gr*	–0.85	dBi
Feeder loss	*L*	1	dB
NF	*NF*	5	dB

Parameter	Symbol	Value	Unit
Receiver intrinsic noise power	Nr	–112.7	dBm
Median value of man-made noise power as described in § 5 of Recommendation ITU-R P.372-10	F_{am}	20.5	dB
External noise power to the receiver input power	N_0	–99.0	dBm
Total receiver noise power	N_t	–98.8	dBm
Effective antenna aperture	A_{eff}	–3.0	dB · m^2
Total noise field strength	E_t	21.0	dB(μV/m)
Maximum interfering field strength (in 429 kHz)	E_i	11.0	dB(μV/m)
Maximum interfering field strength density	E_{is}	4.6	dB(μV/(m · 100 kHz))

Receiver intrinsic noise power:

$$N_r = 10 \times \log (k\,T\,B) + NF + 30 \qquad \text{(dBm)}$$

Median value of man-made noise power as described in § 5 of Recommendation ITU-R P.372-9:

$$F_{am} = c - d \times \log f \qquad \text{(dB)}$$

(c = 76.8 and d =27.7 for the city area)

External noise power to the receiver input power:

$$N_o = 10 \times \log (k\,T\,B) - L + 30 + F_{am} + G_{cor} \qquad \text{(dBm)}$$

$$G_{cor} = G_r\,(G_r < 0),\ 0\ (G_r > 0)^6$$

Total receiver noise power:

$$N_t = 10 \times \log \left(10^{(N_r/10)} + 10^{(N_0/10)}\right) \qquad \text{(dBm)}$$

Effective antenna aperture:

$$A_{eff} = 10 \times \log(\lambda^2/4\pi) + G_r \text{ (dB} \cdot \text{m}^2)$$

Total noise field strength:

$$E_t = L + N_t - A_{eff} + 115.8 \text{ (dB(μV/m))}$$

6 G_{cor} is a correction factor for the received external noise power by a receiving antenna. A receiving antenna with a minus gain ($G_r < 0$) receives both desired signals and external noise with the minus gain ($G_{cor} = G_r$). On the other hand, a receiving antenna with a plus gain ($G_r > 0$) receives desired signals in the direction of the main beam with the plus gain but receives external noise omnidirectionally without a gain ($G_{cor} = 0$).

Maximum interfering field strength:

$$E_i = E_t + I/N \ (\text{dB}(\mu\text{V/m}))$$

Data:

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

T: Absolute temperature = 290 K

I/N: I/N for inter-service sharing = −10 (dB).

Annex 3

Technical basis for planning of terrestrial digital sound broadcasting System G (DRM) in the VHF bands

1 General

This Annex contains relevant DRM system parameters and network concepts for planning broadcasting networks with DRM in all VHF bands, considering 254 MHz as the international top boundary of the VHF broadcasting spectrum[7].

To calculate the relevant planning parameter minimum median field strength and protection ratios, the receiver and transmitter characteristics, system parameters, and transmission aspects as a common basis for concrete DRM transmission network planning are first determined.

2 Reception modes

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.

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

2.2 Portable reception

In general, portable reception means a reception where a portable receiver is used outdoors or indoors at no less than 1.5 m above ground level. A location probability of 95% in a suburban area is assumed to obtain a good reception situation.

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[7] ITU Radio Regulations for Region 1, Footnote **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 RR No. **9.21**.

Two receiving locations will be distinguished:

– **Indoor 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.

– **Outdoor 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.

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

– **Portable outdoor reception (PO) and portable indoor reception (PI)**: This situation models the reception situation in a suburban area with good reception conditions for both situations indoors and outdoors, respectively, and a receiver with an omnidirectional VHF antenna pattern.

– **Portable outdoor handheld reception (PO-H) and portable indoor handheld reception (PI-H)**: This situation models the reception situation in an urban area with bad reception conditions and a receiver with an external antenna (for example, telescopic antennas or the cable of wired headsets).

2.3 Mobile reception

Mobile reception (MO) is defined as reception in a rural area with hilly terrain by a receiver in motion also at high speed with a matched antenna situated at no less than 1.5 m above ground level or floor level.

3 Correction factors for field-strength predictions

The wanted field-strength level values predicted with Recommendation ITU-R P.1546-4 refer always to the median value at a receiving location with a receiving antenna in 10 m height above ground level. Otherwise the wanted field-strength values are predicted at the average construction or vegetation height at the receiving location. To take into account the given different receiving modes and circumstances in network planning, correction factors have to be included to carry the minimum field-strength level over to the median minimum field-strength level for predictions with Recommendation ITU-R P.1546-4.

3.1 Reference frequencies

The planning parameters and correction factors in this document are calculated for the reference frequencies given in Table 26.

TABLE 26

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) refers to a half-wave dipole and is given for the different receiving modes in Table 27.

TABLE 27

Antenna gains G_D

Frequency (MHz)		65	100	200
Antenna gain G_D	for fixed reception (FX) (dBd)	0	0	0
	for portable and mobile reception (PO, PI, MO) (dBd)	−2.2	−2.2	−2.2
	for portable handheld reception (PO-H, PI-H) (dBd)	−22.76	−19.02	−13.00

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 is given with 2 dB for 10 m cable length. Herewith the frequency-dependent cable attenuation per unit length L'_f can be calculated and is given in Table 28.

TABLE 28

Feeder loss L'_f per unit length

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

The cable length l for the different reception modes are given in Table 29 and the herewith calculated feeder losses L_f for different frequencies and reception modes are given in Table 30.

TABLE 29

Cable length l for reception modes

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

TABLE 30

Feeder loss L_f for different reception modes

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

3.4 Height loss correction factor

For portable and mobile reception, a receiving antenna height of 1.5 m 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 as given in Table 31.

TABLE 31

Height loss correction factor L_h for different reception modes

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

3.5 Building entry loss

Information on how to calculate BEL is provided in Recommendation ITU-R P.2109.

Recommendation ITU-R P.2109 provides equations to derive distributions for BEL that cover all types of receive environment, from a room with an outside window to a location deep inside a building and different building types. For the purpose of coverage planning, BEL needs to be calculated based on the environment, suburban, urban, etc, and whether coverage is planned to a receiver located in a room with an outside window or deep inside a building. Though decisions on BEL to use in planning will depend on local circumstances, the maximum loss for a particular circumstance can be set by limiting the probability. The values of probability provided in Table 32 are considered to be generally applicable for planning. The building entry loss in a suburban environment for traditional buildings is shown in Table 33.

TABLE 32

ITU-R P.2109 building entry loss probability

Building type	Environment	Probability building entry loss not exceeded
Traditional	Suburban	50%
Traditional	Urban	70%

TABLE 33

Building entry loss L_b suburban environment traditional building type

Frequency (MHz)	65(1)	100	200
Building entry loss L_b (dB)	14.5	14.2	14

(1) Recommendation ITU-R P.2109 stops at about 80 MHz – the value for 65 MHz is based on the formulas supplied but is outside the nominal working range i.e. is an extrapolation.

3.6 Allowance for man-made noise

The allowance for man-made noise, MMN (dB), takes into account the effect of man-made noise 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).

Recommendation ITU-R P.372-8 gives the legal values to calculate the allowance of man-made 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. For all reception modes the residential area (Curve B) is assumed.

Taking into account a receiver noise figure F_r of 7 dB for DRM, the MMN can be computed for fixed, portable and mobile reception. The results are shown in Table 34.

TABLE 34

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

Frequency (MHz)	65	100	200
Allowance for man-made noise (dB) for fixed (FX), portable (PO, PI) and mobile (MO) reception (F_r = 7 dB)	15.38	10.43	3.62

The value of the decile location variations (10% and 90%) in residential area is given by 5.8 dB. Therefore the standard deviation of MMN for fixed, portable and mobile reception σ_{MMN} = 4.53 dB, see Table 35.

TABLE 35

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

Frequency (MHz)	65	100	200
Standard deviation of MMN σ_{MMN} (dB) for fixed (FX), portable (PO, PI) and mobile (MO) reception	4.53	4.53	4.53

Due to a very low antenna gain for portable handheld reception the MMN for this reception mode is negligible and therefore assumed to be 0 (dB), see Table 36.

TABLE 36

Allowance for man-made noise for portable handheld reception

Frequency (MHz)	65	100	200
Allowance for man-made noise (dB) for portable handheld reception (PO-H, PI-H)	0	0	0

3.7 Implementation loss factor

Implementation loss of the non-ideal receiver is considered in the calculation of the minimum receiver input power level with an additional implementation loss factor L_i of 3 dB, see Table 37.

TABLE 37

Implementation loss factor L_i

Frequency (MHz)	65	100	200
Implementation loss factor L_i (dB)	3	3	3

3.8 Correction factors for location variability

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:

$$E(p) \text{ (dB(μV/m))} = E_{med} \text{ (dB(μV/m))} + C_l(p) \text{ (dB)} \qquad \text{for } 50\% \leq p \leq 99\% \qquad (7)$$

where:

$C_l(p)$: 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:

$$C_l(p) \text{ (dB)} = \mu(p) \cdot \sigma_c \text{ (dB)} \qquad (8)$$

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 38.

TABLE 38

Distribution factor μ

Percentage of receiving locations p (%)	70	95	99
Reception mode	Fixed (FX)	Portable (PO, PI, PO-H, PI-H)	Mobile (MO)
Distribution factor μ	0.524	1.645	2.326

3.8.2 Combined standard deviation

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

$$\sigma_c(\text{dB}) = \sqrt{\sigma_m^2 + \sigma_{MMN}^2} \qquad (9)$$

The values of the standard deviation σ_m (dB) of the wanted field-strength level are dependent on frequency and environment, and empirical studies have shown a considerable spread. Representative values and the equation to calculate the standard deviation σ_m (dB) of the wanted field-strength level are given by Recommendation ITU-R P.1546-4. The calculation of the standard deviation σ_m (dB) of the wanted field-strength level values take into account only the effects of slow fading, but not the effects of fast fading. For DRM it had be ensured that the determination of the minimum *C*/*N* value of DRM consider the effects of the fast fading, therefore no additional correction margin is needed here.

The following fixed values are given by Recommendation ITU-R P.1546-4:

Broadcasting, analogue (i.e. FM at 100 MHz): $\sigma_m = 8.3$ dB

Broadcasting, digital (more than 1 MHz bandwidth, i.e. DAB at 200 MHz): $\sigma_m = 5.5$ dB

The computed standard deviations σ_m (dB) with the equations given by Recommendation ITU-R P.1546-4 for DRM in urban and suburban areas as well as in rural areas are given in Table 39.

TABLE 39

Standard deviation for DRM $\sigma_{m,DRM}$

Frequency (MHz)		65	100	200
Standard deviation for DRM $\sigma_{m,DRM}$	in urban and suburban areas (dB)	3.56	3.80	4.19
	in rural areas (dB)	2.86	3.10	3.49

To calculate the combined standard deviation σ_c (dB) for the different reception modes more or less parts of the given particular standard deviations have to be taken into account. The values for the standard deviation of MMN are given in § 3.6, and those for the standard deviation of the field strength σ_m (dB) are given in Table 35.

The results of the calculations of the combined standard deviation σ_c (dB) for the respective reception modes are given in Table 40.

TABLE 40

Combined standard deviation σ_c for the different reception modes

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)	5.76	5.91	6.17
	portable handheld indoor (PI-H) (dB)	3.56	3.80	4.19

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* in (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.

$$PR(p) \text{ (dB)} = PR_{basic} \text{ (dB)} + CF(p) \text{ (dB)} \qquad \text{for } 50\% \le p \le 99\% \qquad (10)$$

with:

$$CF(p)\ (\text{dB}) = \mu(p)\sqrt{\sigma_w^2 + \sigma_n^2}\ (\text{dB}) \tag{11}$$

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

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.

4 DRM system parameters for field-strength predictions

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

4.1 Modes and 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 41:

– **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 41

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 approximately	49.7 kbit/s	149.1 kbit/s

4.2 Propagation-related OFDM parameters

The propagation-related OFDM parameters of DRM are given in Table 42.

TABLE 42

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
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

4.3 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-interference depends on the length of the OFDM guard interval. Since the length T_g of the DRM guard interval is 0.25 ms, the maximum echo delay, and therefore the maximum transmitter distance, yields 75 km.

5 Minimum receiver input power level

For having cost effective DRM receiver solutions the receiver noise figure F is assumed to be $F_r = 7$ dB.

With $B = 100$ kHz and $T = 290$ K, the thermal receiver noise input power level for DRM Mode E yields $P_n = -146.98$ (dBW).

The DRM standard gives a required $(C/N)_{min}$ to achieve an average coded bit error ratio BER = $1 \cdot 10^{-4}$ (bit) after the channel decoder for different channel models. Effects of the narrow-band system, such as fast fading, are included in the channel models and therefore in calculated values of the $(C/N)_{min}$.

Three channel models have been allocated to the given reception modes that give the respective required $(C/N)_{min}$, see Table 43.

TABLE 43

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

		$(C/N)_{min}$ (dB) for	
Reception mode	**Channel model**	**4-QAM, R = 1/3**	**16-QAM, R = 1/2**
Fixed reception (FX)	Channel 7 (AWGN)	1.3	7.9
Portable reception (PO, PI, PO-H, PI-H)	Channel 8 (urban@60 km/h)	7.3	15.4
Mobile reception (MO)	Channel 11 (hilly terrain)	5.5	12.8

Based on the above given values and including the implementation loss factor, the minimum receiver input power level at the receiving location has been calculated for both 16-QAM and 4-QAM, see Tables 44 and 45.

TABLE 44

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 ratio	$(C/N)_{min}$ (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 45

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 ratio	$(C/N)_{min}$ (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

6 Minimum wanted field strength used for planning

6.1 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 by the following steps 1 to 5:

1) Determine the receiver noise input power level P_n

$$P_n \text{ (dBW)} = F \text{ (dB)} + 10 \log_{10} (k \cdot T_0 \cdot B) \qquad (12)$$

with:

- F: receiver noise figure (dB)
- k: Boltzmann’s constant, $k = 1.38 \times 10^{-23}$ (J/K)
- T_0: absolute temperature (K)
- B: receiver noise bandwidth (Hz).

2) Determine the minimum receiver input power level $P_{s,\,min}$

$$P_{s,\,min} \text{ (dBW)} = (C/N)_{min} \text{ (dB)} + P_n \text{ (dBW)} \qquad (13)$$

with:

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

3) Determine the minimum pfd (i.e. the magnitude of the Poynting vector) at receiving place φ_{min}

$$\varphi_{min}\ (\text{dBW/m}^2) = P_{s,\,min}\ (\text{dBW}) - A_a\ (\text{dBm}^2) + L_f\ (\text{dB}) \tag{14}$$

with:

L_f: feeder loss (dB)

A_a: effective antenna aperture (dBm^2).

$$A_a\ (\text{dBm}^2) = 10 \cdot \log\left(\frac{1.64}{4\pi}\left(\frac{300}{f\ (\text{MHz})}\right)^2\right) + G_D\ (\text{dB}) \tag{15}$$

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

$$E_{min}\ (\text{dB}(\mu\text{V/m})) = \varphi_{min}\ (\text{dBW/m}^2) + 10\log_{10}\left(Z_{F0}\right)(\text{dB}\Omega) + 20\log_{10}\left(\frac{1V}{1\mu V}\right) \tag{16}$$

with:

$$Z_{F0} = \sqrt{\frac{\mu_0}{\varepsilon_0}} \approx 120\pi\ (\Omega) \qquad \text{the characteristic impedance in free space} \tag{17}$$

resulting in:

$$E_{min}\,(\text{dB}\mu\,\text{V/m}) = \varphi_{min}\,(\text{dBW/m}^2) + 145.8\ \ (\text{dB}\Omega) \tag{18}$$

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: $E_{med} = E_{min} + P_{mmn} + Cl$ (19)

for portable outdoor and mobile reception: $E_{med} = E_{min} + P_{mmn} + C_l + L_h$ (20)

for portable indoor reception: $E_{med} = E_{min} + P_{mmn} + C_l + L_h + L_b$ (21)

Based on these equations, the minimum median field-strength level for the respective reception modes have been calculated for both 16-QAM and 4-QAM, for VHF Bands I, II and III, see Tables 46 to 49.

6.2 Minimum median field-strength level for VHF Band I

TABLE 46

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 pfd 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 entry loss	L_b (dB)	0.00	14.5	14.5	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*
Location correction factor	C_l (dB)	3.02	9.45	5.84	9.47	5.85	12.46
Minimum median field-strength level	E_{med} (dB(μV/m))	18.2	54.2	62.7	39.7	48.3	41.1

TABLE 47

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 pfd 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 entry loss	L_b (dB)	0.00	14.5	14.5	0.00	0.00	0.00
Location probability	%	*70*	*95*	*95*	*95*	*95*	*99*

TABLE 47 (*end*)

DRM modulation		16-QAM. R = 1/2					
Receiving situation		FX	PI	PI-H	PO	PO-H	MO
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*
Location correction factor	C_l (dB)	3.02	9.45	5.84	9.47	5.85	12.46
Minimum median field-strength level	E_{med} (dB(μV/m))	24.8	62.3	70.8	47.8	56.4	48.4

6.3 Minimum median field-strength level for VHF Band II

TABLE 48

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 pfd 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
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 entry loss	L_b (dB)	0.00	14.2	14.2	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*
Location correction factor	C_l (dB)	3.10	9.70	6.23	9.73	6.25	12.77
Minimum median field-strength level	E_{med} (dB(μV/m))	17.3	54.9	64.8	40.7	50.7	42.3

TABLE 49

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 pfd 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 entry loss	L_b (dB)	0.00	14.2	14.2	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*
Location correction factor	C_l (dB)	3.10	9.70	6.23	9.73	6.25	12.77
Minimum median field-strength level	E_{med} (dB(μV/m))	23.9	63.0	72.9	48.8	58.8	49.6

6.4 Minimum median field-strength level for VHF Band III

TABLE 50

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 pfd 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 entry loss	L_b (dB)	0.00	14.00	14.00	0.00	0.00	0.00

TABLE 50 (*end*)

DRM modulation		4-QAM. R = 1/3					
Receiving situation		FX	PI	PI-H	PO	PO-H	MO
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*
Location correction factor	C_l (dB)	3.24	10.12	6.87	10.15	6.89	13.31
Minimum median field-strength level	E_{med} (dB(μV/m))	17.3	56.3	67.3	42.4	53.3	44.1

TABLE 51

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

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	−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 pfd 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 entry loss	L_b (dB)	0.00	14.00	14.00	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*
Location correction factor	C_l (dB)	3.24	10.12	6.87	10.15	6.89	13.31
Minimum median field-strength level	E_{med} (dB(μV/m))	23.9	64.4	75.4	50.5	61.4	51.4

7 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.

For 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. The DRM system is designed to be used with this raster.

For 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.

8 Unwanted emissions

8.1 Out-of-band spectrum mask

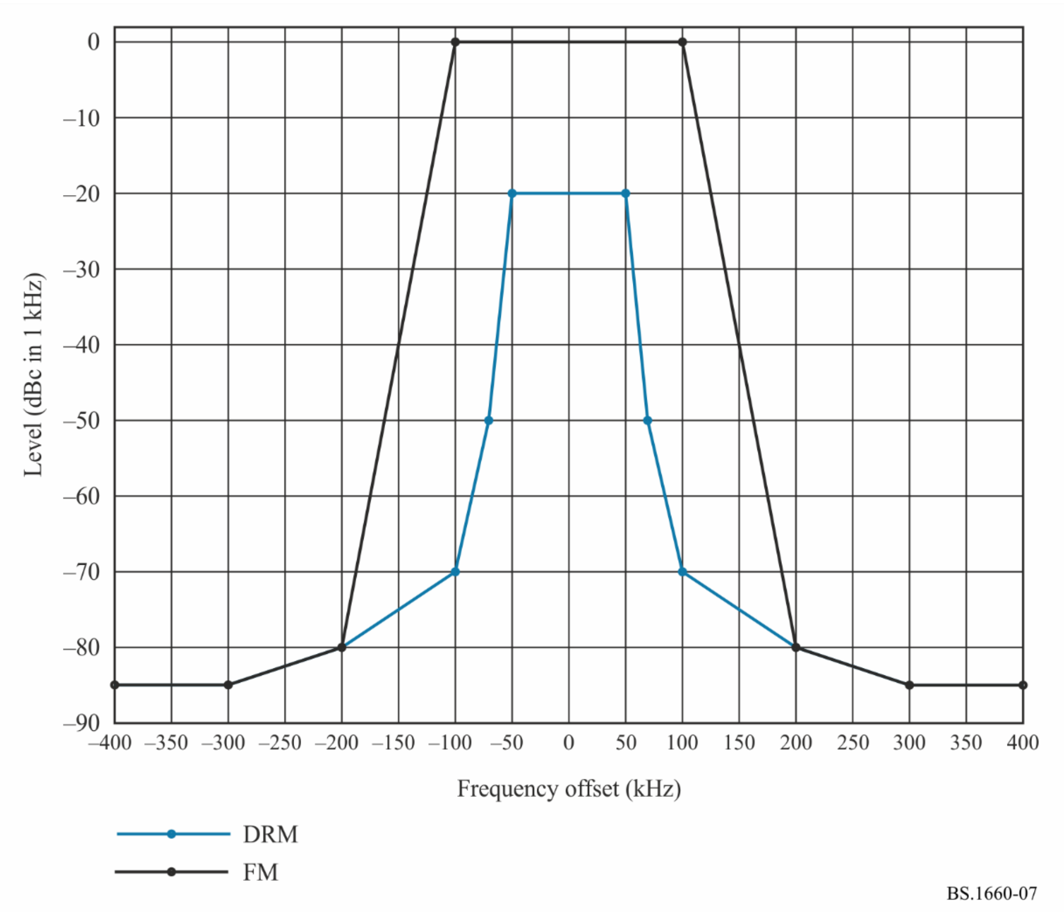
The power density spectrum at the transmitter output is important to determine the adjacent channel interference.

8.1.1 VHF Band I and VHF Band II

An out-of-band spectrum mask for DRM in VHF Band I and VHF Band II, respectively, is given in Fig. 7 and Table 52, together with the vertices of the symmetric out-of-band spectrum mask for FM transmitters[8] as minimum transmitter requirement, defined for a resolution bandwidth (RBW) of 1 kHz.

FIGURE 7

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



8 Given in this Recommendation, Annex 1, Table 11.

TABLE 52

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

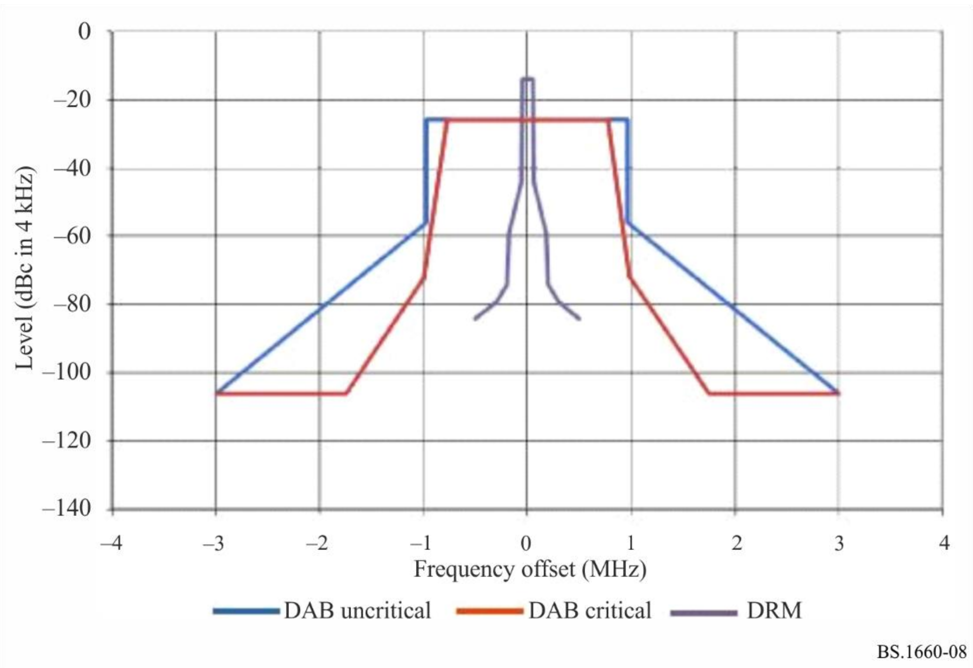
Spectrum mask (100 kHz channel)/ relative level for FM		Spectrum mask (100 kHz channel)/ relative level for DRM	
Frequency offset (kHz)	**Level (dBc)/(1 kHz)**	**Frequency offset (kHz)**	**Level (dBc)/(1 kHz)**
0	0	0	−20
±50	0	±50	−20
±70	0	±70	−50
±100	0	±100	−70
±200	−80	±200	−80
±300	−85	±300	−85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

8.1.2 VHF Band III

An out-of-band spectrum mask for DRM in VHF Band III is given in Fig. 8 and Table 53, together with the vertices of the symmetric out-of-band spectrum masks for DAB transmitters[9] as minimum transmitter requirement, defined for a resolution bandwidth (RBW) of 4 kHz. Thus the value of −14 dBr results for DRM.

FIGURE 8

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



9 Given in Recommendation ITU-R BS.1660-3 – Technical basis for planning of terrestrial digital sound broadcasting in the VHF band.

TABLE 53

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

Spectrum mask (100 kHz channel)/ relative level for DRM (in 4 kHz)	
Frequency offset (kHz)	**Level (dBc)**
0	–14
±50	–14
±60	–44
±181.25	–59
±200	–74
±300	–79
±500	–84

8.2 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.

– 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 than 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, and the combined location correction factor *CF*°(dB) which is therefore required.

8.2.1 Protection ratios for DRM

8.2.1.1 DRM interfered with by DRM

The basic protection ratio PR_{basic} for DRM is valid for all VHF bands (see Table 54). Since the standard deviation of DRM differs in the respective VHF bands, the corresponding protection ratios *PR*(*p*) (see Table 55 for 4-QAM and Table 56 for 16-QAM) are different in the respective VHF bands.

TABLE 54

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 55

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

Reference frequency band		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		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		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 56

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

Reference frequency band		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		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 56 (*end*)

Reference frequency band		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

8.2.1.2 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 57. The values for the corresponding protection ratios *PR*(*p*), are given in Table 58 for 4-QAM and in Table 59 for 16-QAM, respectively.

TABLE 57

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 58

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 59

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

8.2.1.3 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 60. The values for the corresponding protection ratios $PR(p)$, are given in Table 61 for 4-QAM and in Table 62 for 16-QAM, respectively.

TABLE 60

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 61

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 62

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

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

Since the impact mechanism 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.

To correct for the lower power spectral density of a DVB-T signal of same field strength compared to a DAB signal, the following correction factors should be applied to the e.r.p. of the interfering signals prior to calculating its field strength:

– 6.4 dB for a 7 MHz DVB-T signal;

– 6.9 dB for an 8 MHz DVB-T signal.

8.2.2 Protection ratios for broadcasting systems interfered with by DRM

8.2.2.1 Protection ratios for FM in VHF Band II

The FM signal parameters are given in Recommendation ITU-R BS.412-9. In its Annex 5, it is indicated 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 distance has also to be taken into account when planning OFDM systems into VHF Band II. Therefore not only the protection ratios PR_{basic} in the range of 0 kHz to ±400 kHz are given in Table 63, but also those for ±500 kHz and ±1000 kHz. The values for 600 kHz to 900 kHz can be interpolated therefrom.

TABLE 63

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

Frequency offset (kHz)		0	±100	±200	±300	±400	±500	±1000
Basic protection ratio for FM (stereo)	PR_{basic} (dB)	49	30	3	−8	−11	−13	−21

8.2.2.2 Protection ratios for DAB in VHF band III

The DAB signal parameters are given in Annex 1 to this Recommendation.

Bibliography

ETSI EN 201 980; Digital Radio Mondiale (DRM); System Specification.

Annex 4

Technical basis for planning of terrestrial digital sound broadcasting System C (HD Radio) in the VHF band II

1 Introduction

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 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, as mentioned previously, is known as In-Band On-Channel (IBOC) and 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 Annex 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.

2 Configurations and definitions

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 Annex in conjunction with the provided planning parameters and deployment aspects.

2.1 HD radio 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 64.

TABLE 64

Characteristics of various HD radio system operating modes

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

(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 65.

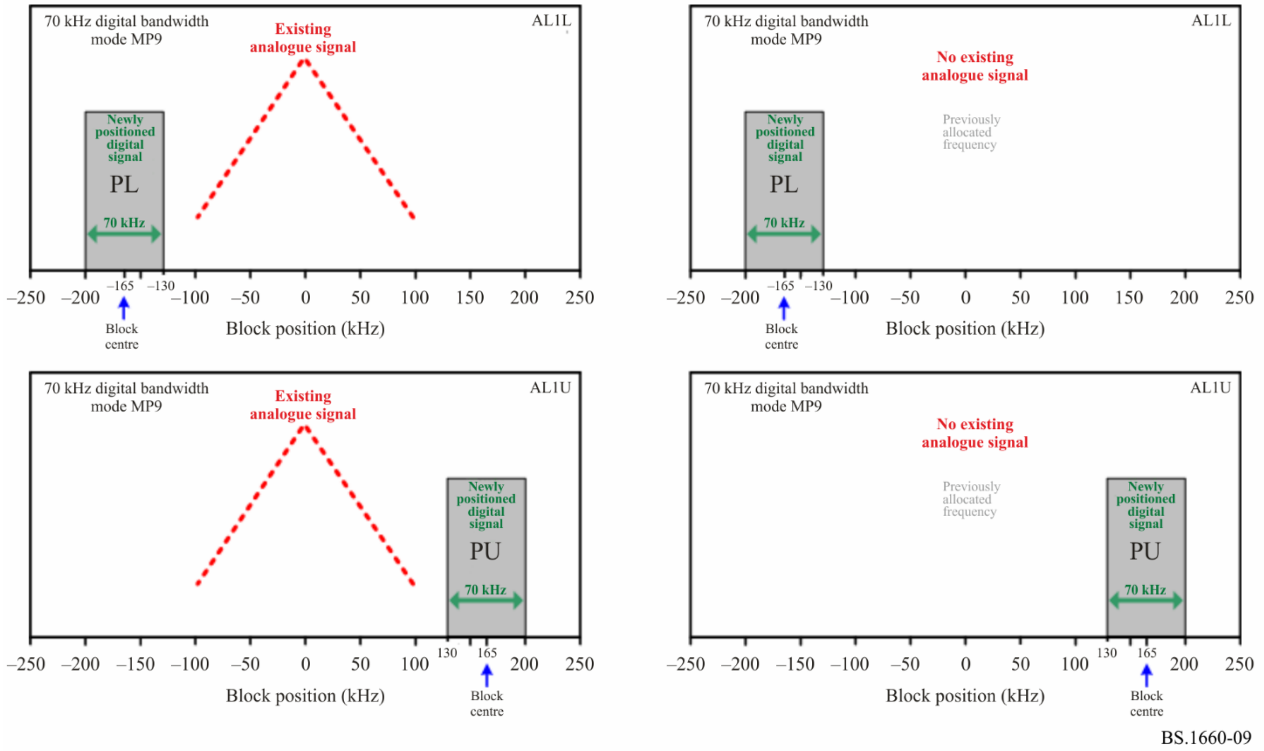
TABLE 65

HD radio system physical layer parameters

Parameter name	Computed value (rounded)
Cyclic Prefix Width α	0.1586 ms
Symbol Duration (with prefix) *Ts*	2.902 ms
Number of symbols in a block	32
Block Duration Tb	9.288 ms
Number of blocks in a frame	16
Frame Duration T_f	1.486 s
OFDM Subcarrier Spacing Δf	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 9

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.

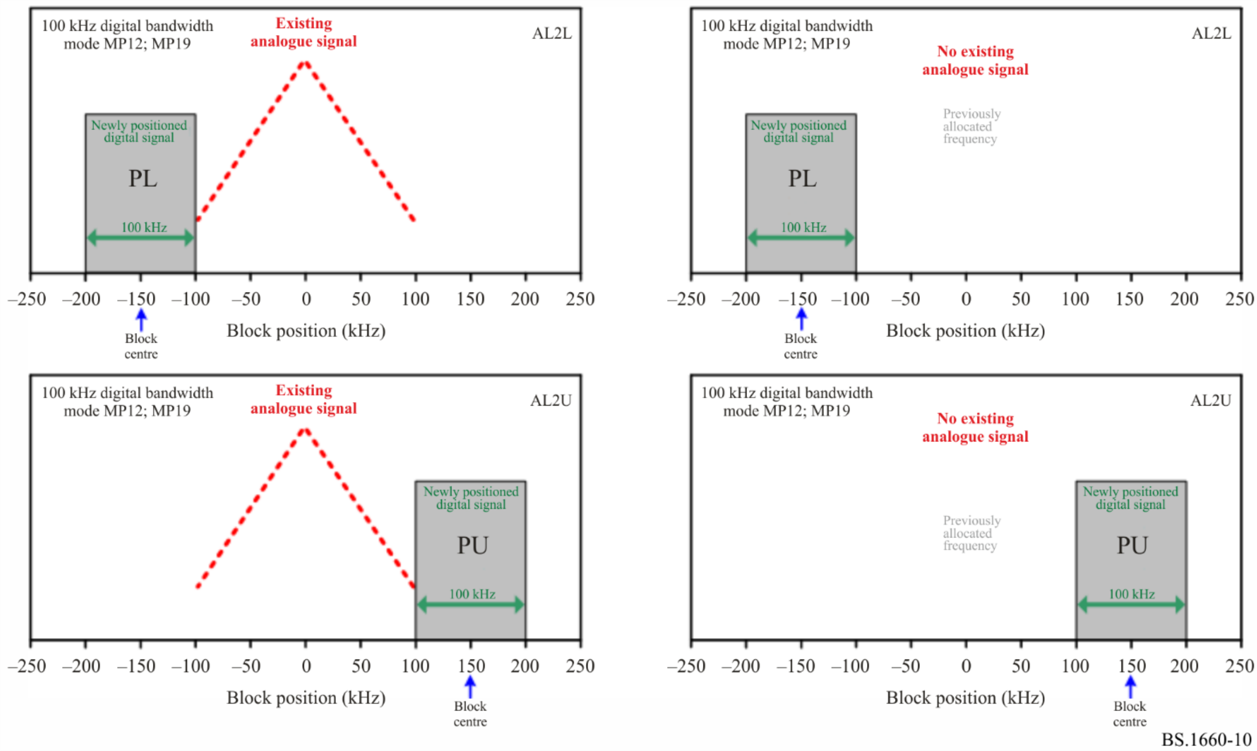
In the United States of America, the fundamental channel raster in VHF Band II is based on 200-kHz spacing. The HD Radio system presumes that the digital signal blocks are at pre-defined positions. As can be seen from the diagrams in Figs 9 and 10, these positions are not centred on the 200 kHz raster 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 center 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. 11, or two digital signal blocks of 100 kHz each, as shown in Fig. 12, are employed jointly for providing more options for trade-off between throughput (net bit rate) and robustness.

FIGURE 10

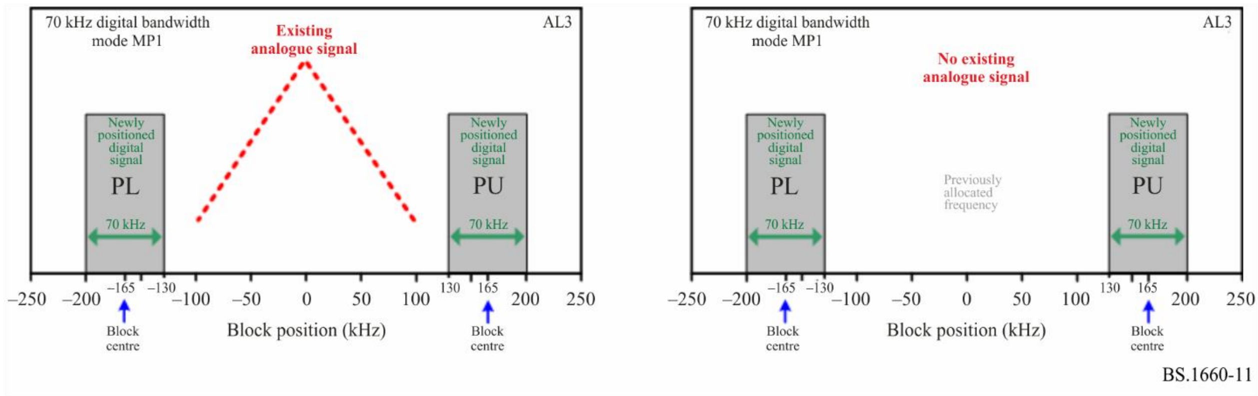
HD Radio System 100-kHz Digital Block Positioning examples



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 11

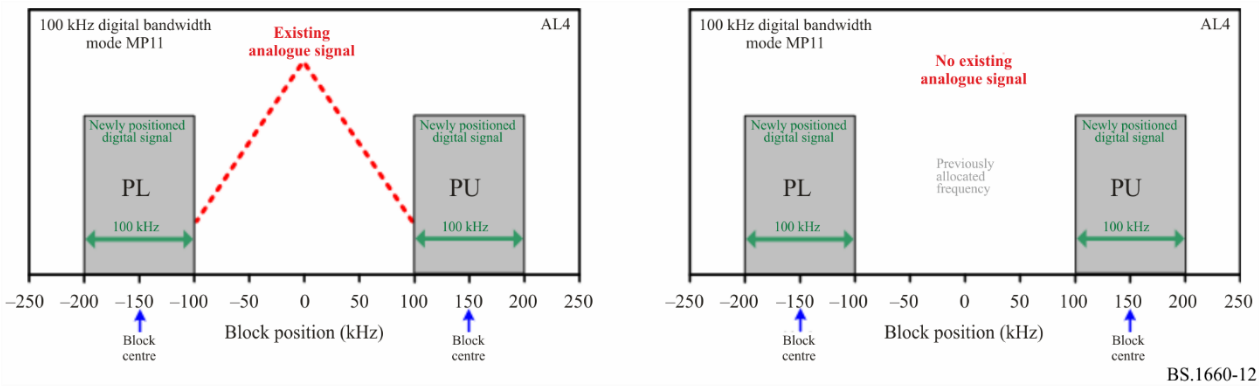
HD Radio System 2 x 70-kHz digital block positioning examples



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 12

HD Radio System 2 x 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.

3 Analysis Parameters

The performance is provided for several scenarios and reception conditions. The conditions are related to the signal path, the specific reception scenario and the receiving device category.

In order to properly analyse reception performance of the different receiving modes and circumstances, certain correction factors have to be applied to the calculations of required (median) minimum field strength, as reflecting the received signal power. The foundations for such corrections are established in [5]. However, certain adjustments for scenarios that are not addressed in [5], are devised from related technologies and environments, as indicated where applicable.

The correction factors may be divided into two groups. One group is related to the signal path and the reception location, and is independent of specific receiver implementation. The second group may be related to specific receiver design methodology and needs to be analysed accordingly.

3.1 Reception modes

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

Reception availability as addressed by ITU in [5] and [2] 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.

3.1.1 Fixed reception (FX)

Fixed reception is defined as reception where a roof level mounted receiving antenna is used (i.e., fixed antenna reception). For calculating the required field strength levels for fixed antenna reception, a receiving antenna height of 10 m above ground level is assumed, following [5] and [2]. However, the location probability of 50% as often indicated in [5] is considered insufficient. Instead, a location probability of 70% is assumed to obtain ‘acceptable’ reception situation as suggested in [13] and [12].

3.1.2 Portable reception

Portable reception is defined as reception where a portable receiving device is used. Such portable device may also be hand-held. That implies the use of portable, smaller, limited performance antenna, at limited elevation above ground level. As indicated in [13] and [12], different combinations of antenna and locations may be translated to different reception modes.

A distinction is made over location in association with speed and the employed antenna:

- Portable/Hand-held outdoor reception
  - At 1.5 m or more above ground level, at rest or at very low speed
  - With external antenna (i.e. telescopic, wired headset, etc.) or integrated antenna
- Portable/Hand-held indoor reception
  - At 1.5 m or more above ground level, at rest or at very low speed
  - With external antenna (i.e. telescopic, wired headset, etc.) or integrated antenna
  - On the ground floor, in a room with window in an external wall
- A distinction is made over location and perceived/desired reception quality:
- Quasi-static
  - Approximately 0.5 m × 0.5 m, with antenna moving up to 0.5 m
  - 99% reception
- Small area
  - Approximately 100 m × 100 m
  - 95% reception
- Large area
  - Consists of sum of small areas

3.1.3 Mobile reception

Mobile reception 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. While not specifically addressed in [5] 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 [13] and [12].

In order to cover all of the indicated combinations by using as few cases as possible while providing realistic reception scenarios, only six reception modes are analysed, as indicated in Table 66.

TABLE 66

Definition of reception modes for performance analysis

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

3.2 Reception location related correction factors

This section provides the basis and the calculations for correction factors that are only related to signal path and reception location.

3.2.1 Reference frequency

The correction factors and related analysis are done for a reference frequency of f = 100 MHz.

3.2.2 Feeder loss

The feeder loss L_f represents the signal attenuation from the receiving antenna to the receiver's RF input. This is not covered by [5] but is specifically addressed in [13] for f = 200 MHz. Since it is indicated to be proportional to f_2, it is then adjusted for the reference frequency and indicated Table 67.

TABLE 67

Feeder loss versus Reception mode

	FX	**MO**	**PO, PI, PO-H, PI-H**
Cable length (m)	10	2	0
Feeder loss, L_f (dB)	1.4	0.3	0

3.2.3 Height loss

The effective receiving antenna height depends on the reception mode. For mobile reception and for portable reception, a receiving antenna height of 1.5 m above ground level (outdoor) or above floor level (indoor) is assumed. The common propagation prediction methods typically provide 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. Height loss in VHF Band II can be calculated using [5]. However, the proposed correction may apply to specifically situated antenna, which may be considered acceptable for certain portable reception cases. This may not be properly representing other cases such as hand-held devices, where the antenna situation (spatial orientation) varies and impacts the effective height. More realistic scenario and applicable losses for VHF Band II are indicated in [12]. The resulting height loss correction factor L_h for all reception modes is provided in Table 68.

TABLE 68

Height loss correction factor

	FX, MO, PO, PI	**PO-H, PI-H**
Height loss, L_h (dB)	10	17

3.2.4 Building penetration loss

Building penetration loss reflects the mean ratio between the mean field strength inside a building and the mean field strength outside the building, at the same height above ground level. No direct recommendations were provided by ITU regarding applicable penetration loss values for VHF Band II. More recent activities and documents [13] and [12] have resulted in recommended values for VHF Band III. As indicated in [13], these values are applicable to the wide range of frequencies over VHF Band III. Therefore, it is assumed that these values are also applicable to VHF Band II, and are provided in Table 69.

TABLE 69

Building penetration loss factors

Building penetration loss, L_b (dB)	**Building penetration loss standard deviation, σ_b (dB)**
9	3

3.2.5 Implementation loss

Implementation loss, as indicated in this Recommendation, 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, Lim, for such receivers are considered to be 5 dB. The implementation losses per reception mode are provided in Table 70.

TABLE 70

Implementation loss factor

	FX, MO, PO, PI	**PO-H, PI-H**
Implementation loss, L_{im} (dB)	3	5

3.2.6 Location variability correction factor

Location variability loss is often defined as reflecting the excess path loss over the service area of a transmitter, due to terrain effects and obstacles, in addition to more local shadowing. The variability discussions refer to the terrain as a finite area, typically represented by a square with a side length of 100 m to 1 km.

Field strength predictions are typically provided for 50% of time and 50% of locations. In order to derive the field strength value that is required for higher location probability, a location correction factor has applied, according to ITU recommendations as indicated in [5].

3.2.6.1 Location standard deviation

As indicated in [5], values of the standard deviation of the signal strength at a location are dependent on frequency and environment, and empirical studies have shown a considerable spread. Representative values for areas of 500 m-x-500 m are given by the following expression in equation (22):

$$\sigma_L = K + 1.3\log(f) \qquad (22)$$

where:

σ_L : standard deviation of the Gaussian distribution of the local means in the study area (dB)

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 location deviation has been calculated according to equation (22). Excess effects that may be differently resulting from different mobility scenarios, and may be potentially differently mitigated by different receivers, are accounted for by separate calculation for each channel model, thus not added here. The calculated standard deviation is provided in Table 71.

TABLE 71

Location standard deviation

Standard deviation for digital broadcasting, σ_L (dB)	
In urban and suburban locations	3.8
In rural locations	3.1

3.2.6.2 Location distribution factor

The distribution factor is defined as "inverse complementary cumulative normal distribution as a function of probability". It is used to correct the standard deviation for the desired location probability. For the location probabilities as indicated for each reception mode, the applicable distribution factor, as recommended in [5] is provided in Table 72.

TABLE 72

Location distribution factor

	FX	**MO**	**PO**	**PI**	**PO-H**	**PI-H**
Reception percentage	70%	99%	95%	99%	95%	99%
Distribution factor, μ	0.52	2.33	1.64	2.33	1.64	2.33

It is noted that the HD Radio system's approach to signal reception considers 99% for 'good' indoor reception, while certain other approaches may require only 95%. This higher requirement (of 99%) results in a higher distribution factor of 2.33 as opposed to a distribution factor of only 1.64 for 95% indoor reception.

3.2.6.3 Adjusted location deviation

The location deviation, which has been calculated for outdoor locations, has to be adjusted for the desired location probability and for any environment that is other than outdoor.

The reception modes include indoor reception environment. The excess variations (i.e. beyond the outdoor location variation) of the signal impeding on the quasi-static indoor antenna are assumed to be affected solely by the building penetration deviation; thus the antenna location deviation is assumed to be the same as the building penetration deviation. The outdoor field strength and the building penetration are assumed to be statistically independent, and both follow log-normal distribution. Similarly to the calculations in [13], their combined deviation may be calculated as follows in equation (23):

$$\sigma_C = \sqrt{(\sigma_L^2 + \sigma_b^2)} \tag{23}$$

where:

σ_c : combined standard deviation (dB).

Then, adjusting the deviation with the distribution factor according to [5] is calculated as follows in equation (24):

$$\sigma_S = \mu \cdot \sqrt{(\sigma_L^2 + \sigma_b^2)} \tag{24}$$

where:

σ_S : The adjusted location deviation (dB)

σ_L : Outdoor location deviation (dB)

σ_r : Antenna location deviation (dB). For outdoor reception $\sigma_r = 0$. For indoor reception $\sigma_r = \sigma_b$.

In order to reduce the number of calculations, all reception modes are either defined in urban and suburban areas or otherwise performance are assumed to be a larger interest in these areas over rural areas. Therefore, a location correction of $\sigma_L = 3.8$ dB is used for all cases, ignoring the ‘lower’ correction of 3.1 dB which applies only to rural areas, according to [5]. The calculated adjusted location deviation is provided in Table 73.

TABLE 73

Adjusted location deviation

Reception mode	FX	MO	PO	PI	PO-H	PI-H
Reception percentage	70%	99%	95%	99%	95%	99%
Distribution factor, μ	0.52	2.33	1.64	2.33	1.64	2.33
Standard deviation, σ_L	3.8	3.8	3.8	3.8	3.8	3.8
Specific antenna location deviation, σ_r	0	0	0	3	0	3
Adjusted location deviation, σ_s, (dB)	**2**	**8.8**	**6.2**	**11.3**	**6.2**	**11.3**

It is noted that the HD Radio system’s approach to signal reception considers 99% for ‘good’ indoor reception, while certain other approaches may require only 95%. This higher requirement (of 99%) results in considering a higher adjusted location deviation of 11.3 dB as opposed to an adjusted location deviation of only 7.9 dB for 95% indoor reception.

3.2.7 Adjusted reception location loss

The total reception location loss accounts for the signal path loss and the reception location signal variability. Both depend on the reception modes. The calculations are as follows:

$$L_{r1} = \sigma_s + L_h + L_f + L_b \tag{25}$$

where:

L_{rl}: total adjusted reception location loss (dB).

The results are summarized in Table 74.

TABLE 74

Adjusted location loss

Reception mode	FX	MO	PO	PI	PO-H	PI-H
Reception antenna location	Outdoor	Outdoor	Outdoor	Indoor	Outdoor	Indoor
Adjusted location deviation, σ_s, (dB)	2	8.8	6.2	11.3	6.2	11.3
Height loss factor, L_h	0	10	10	10	17	17
Feeder cable loss L_f	1.4	0.3	0	0	0	0
Building penetration loss L_b	**0**	**0**	**0**	**9**	**0**	**9**
Total reception location losses, L_{rl}, (dB)	**3.4**	**19.1**	**16.2**	**30.3**	**23.2**	**37.3**

It is noted that the HD Radio system's approach to signal reception considers 99% for 'good' indoor reception, while certain other approaches may require only 95%. This higher requirement (of 99%) results in considering higher total location losses of 3.4 dB more than the total location losses for only 95% indoor reception.

3.3 Design related correction factors

This section provides the basis for the calculations approach for correction factors that are related to receiver design methodology.

Receiver design approaches, in the specific context of best matching the received signal for minimizing the antenna related path loss, may vary across the different systems. This is typically characterized by different analysis and design methodology of the antenna system and the RF front end. A legacy distributed approach was established and largely, though not completely, addressed by reference documents. However, more recent integrated approach is also employed and needs to be accommodated.

The distributed approach separately addresses the antenna and the RF front end. For each reception mode and its applicable antenna structure, analysis and numerical references are provided by either calculations or measurements. As a result, a set of different antenna gains was provided and was further followed by different sets of matching (or otherwise mismatching) losses, and then followed by allowable man-made noise in combination with discrete (provided separately) receiver noise figure.

The integrated approach follows more recent design methodology, where an antenna, followed (optionally) by dynamically adjustable matching circuitry and then a low noise amplifier of buffer are integrated in whole or in part. Whether the antenna is actually integrated or not, it may be constantly (i.e. dynamically) matched, and therefore the entire chain may be viewed as having one gain value but different overall noise figure. The applicable calculations and specific values for this approach are used in this document for calculating the mean minimum field strength.

3.3.1 Correction factors for integrated methodology

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 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 [12].

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, may be derived from Attachment 1. Required adjustments for the physical antenna gain are further described in this section.

3.3.1.1 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 in Attachment 1. 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 [14]. 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 75.

TABLE 75

Antenna physical gain correction

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

3.3.1.2 Allowance for man-made noise

The allowance for man-made noise, P_{mmn} (dB), takes into account the effect of the man-made noise received by the antenna on the system performance.

The legacy approach to calculating certain antenna noise Fa is described in [15] and is also indicated in [13]. However, these values are based on measurements taken in 1974, under completely different RF environments and different antenna system implementation approaches, and may not be considered realistic anymore; and thus, not applicable for reliable calculation for man-made noise allowance.

The approach in [15] views an external antenna noise figure and separately a receiver noise figure (as opposed to integrated systems). Such an approach considers the antenna gain for calculating P_{mmn}. While it may be applicable to positive gains that relate the antenna radiation patterns, it may not be suitable for negative antenna gains which typically relate the matching between the antenna and the receiver (typically the LNA section). The integrated receiver system methodology mitigates that problem.

More recent studies (2001-2003) by OFCOM, as indicated in [16] and [17], and by others in [18] 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 [17] 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 [12] and employed in this Annex.

Applying the methodology in [12] to an antenna with a gain higher than –2.2 dBd results in a P_{mmn} of 14.1 dB. This is considered applicable to the cases where the receiver system structure is reasonably physically controlled, such as in a fixed installation, automotive, and larger portable devices.

Respectively, applying an adjusted methodology in [12] to handheld devices that employ an antenna system with significantly lower gain or equivalently high NF (as applicable to integrated systems methodology) does not produce realistically considerable P_{mmn}.

The applied P_{mmn} is listed in Table 76.

TABLE 76

Allowance for man-made noise for integrated design

	FX, MO. PO, PI	**PO-H, PI-H**
Man-made noise allowance, P_{mmn}, (dB)	14.1	0

3.4 Channel models and fading margins

The specific EIA-approved channel (fading) models used in this analysis are provided in Attachment 2. 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 C/N 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 (referred to by their symbols in Attachment 2) are provided in Table 77.

TABLE 77

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

4 Field strength requirements analysis

4.1 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 [12] 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 Cd/N_0 (digital power to noise density ratio) as analysed for planning purposes are provided in Table 78.

TABLE 78

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

4.2 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 79. 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 Attachment 1 and in [19].

In portable devices, power constraints are assumed to result in LNA noise figures that may be slightly higher (approximately 1 dB) than LNA noise figures 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 [12].

TABLE 79

HD radio overall receiver system noise figure

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).

4.2.1 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.

4.3 Minimum wanted field strength used for planning

The minimum median required field strength calculations are according to the integrated approach, as described in Attachment 1.

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 80 to 84.

It is noted that while the calculations follow the ITU guidelines as indicated in the respective sections in this Annex, 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 80

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 81

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 82

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 83

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 84

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 nedian field strength (dBµV/m)	20.9	43.4	45.6	53.2	57.5	65.1

Attachment 1
to Annex 4

Calculation of minimum median field strength level – integrated method

For the systems that employ the integrated method for calculating the minimum median field strength, this Attachment provides the background for the reference calculations, followed by the required steps/expressions.

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:

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

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:

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

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:

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

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:

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

or equivalently:

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

The carrier to noise density ratio at the output of the LNA is given by:

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

This is expressed in dB as:

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

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 C/N:

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

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 C/N and the applicable NF, where NF is the receiver system integrated noise figure in dB and C/N_0 is the carrier to noise density ratio in dB-Hz.

The following relationship may be used for convenience:

$$C/No = 10 \cdot \log\left(\frac{C}{No}\right) = SNR + 10 \cdot \log(BWn) \quad (38)$$

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:

$$E_r\,(dBu) = C/No - 58.5 + NF \quad (39)$$

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:

$$\Delta_{AG}\,[\mathrm{dB}] = \mathrm{Ag}\,[\mathrm{dB}] + 0.4 \quad (40)$$

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:

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

or otherwise:

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

where:

L_{rl} : reception location loss (dB)

L_{im} : implementation loss (dB)

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

Attachment 2
to Annex 4

Channel models

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

TABLE 85

Fixed reception under white Gaussian noise (FXWGN) channel model

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

TABLE 86

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 87

Urban fast rayleigh multipath (UFRM) channel model

Ray	Delay (μsec)	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 88

Rural Fast Rayleigh Multipath (RFRM) channel model

Ray	Delay (µsec)	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 89

Terrain Obstructed Fast Rayleigh Multipath (TORM) channel model

Ray	Delay (µsec)	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	

TABLE 89 (*end*)

Ray	Delay (µsec)	Attenuation (dB)	Doppler frequency (Hz)
6	8.0	5.0	
7	12.0	2.0	
8	14.0	8.0	
9	16.0	5.0	

Attachment 3
to Annex 4

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,

$$SNR_{dB} = (Cd/N)_{dB} = Cd_{dB} - N_{dB}$$

$$N_{dB} = No_{dB} + 10 \cdot \log(70\text{ kHz}) = No_{dB} + 48.45\text{ dB}$$

Then:

$$SNR_{dB} = (Cd/N_0)_{dB} - 48.45\text{ dB}$$

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