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Fixed Radio Systems;
Point-to-point equipment;
Derivation of receiver interference parameters useful for planning fixed service point-to-point systems operating different equipment classes and/or capacities

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Transmission and Multiplexing (TM).

Introduction

The present document explains how the assignment criteria between Digital Fixed Service systems, occupying different bandwidths and using different types of modulation are determined.

The primary aim of spectrum management is to use limited spectrum in the most efficient and effective manner. Thus the maintenance of interference free operation, alongside the sometime conflicting desire to establish a maximum link density with guaranteed system availability, are the primary aims of any spectrum management system.

1 Scope

The present document gives, initially, a basic overview of how a fixed point-to-point system is allocated an EIRP guaranteeing predetermined link availability. It then reviews the methodology for deriving the parameters necessary for the sharing of FS systems in an environment with different equipment classes and capacity. The methodology is based on the limitation of noise and is not exclusive. In addition a method for calculation of RSL based on normalized values is presented.

The present document highlights the primary parameters from European standards, which are vital to the development of an assignment system. These parameters are:

- Transmitter radiation patterns.
- Receiver sensitivity.
- Receiver adjacent channel rejection.
- Receiver co-channel rejection.

In addition to these parameters the antenna radiation profile and, if fitted, the ATPC operating characteristics will have a major effect on link density.

2 References

For the purposes of this Technical Report (TR), the following references apply:

[1] ITU-R Recommendation P.530: "Propagation data and prediction methods required for the design of terrestrial line-of-sight systems".

[2] ITU-R Recommendation P.676: "Attenuation by atmospheric gases".

[3] ITU-R Recommendation F.746: "Radio-frequency arrangements for fixed service systems".

[4] ETSI EN 301 390: "Fixed Radio Systems; Point-to-point and Multipoint Systems; Spurious emissions and receiver immunity limits at equipment/antenna port of Digital Fixed Radio Systems".

[5] ITU-R Recommendation SM.328-10: "Spectra and bandwidth of emissions".

[6] ETSI EN 300 630: "Fixed Radio Systems; Point-to-point equipment; Low capacity point-to-point digital radio systems operating in the 1,4 GHz frequency band".

[7] ETSI EN 301 216: "Fixed Radio Systems; Point-to-point equipment; Plesiochronous Digital Hierarchy (PDH); Low and medium capacity and STM-0 digital radio system operating in the frequency bands in the range 3 GHz to 11 GHz".

[8] ETSI EN 300 234: "Fixed Radio Systems; Point-to-point equipment; High capacity digital radio systems carrying 1 x STM-1 signals and operating in frequency bands with about 30 MHz channel spacing and alternated arrangements".

[9] ETSI EN 301 461: "Fixed Radio Systems; Point-to-point equipment; High capacity fixed radio systems carrying SDH signals (2 x STM-1) in frequency bands with 40 MHz channel spacing and using Co-Channel Dual Polarized (CCDP) operation".

[10] ETSI EN 301 127: "Fixed Radio Systems; Point-to-point equipment; High capacity digital radio systems carrying SDH signals (up to 2 x STM-1) in frequency bands with about 30 MHz channel spacing and using co-polar arrangements or Co-Channel Dual Polarized (CCDP) operation".

[11] ETSI EN 301 669: "Fixed Radio Systems; Point-to-point equipment; High capacity digital radio systems carrying STM-4 in two 40 MHz channels or 2 x STM-1 in a 40 MHz channel with alternate channel arrangement".

[12] ETSI EN 301 277: "Fixed Radio Systems; Point-to-point equipment; High capacity digital radio systems transmitting STM-4 or 4 x STM-1 in a 40 MHz radio frequency channel using Co-Channel Dual Polarized (CCDP) operation".

[13] ETSI EN 301 128: "Fixed Radio Systems; Point-to-point equipment; Plesiochronous Digital Hierarchy (PDH); Low and medium capacity digital radio systems operating in the 13 GHz, 15 GHz and 18 GHz frequency bands".

[14] ETSI EN 300 786: "Fixed Radio Systems; Point-to-point equipment; Sub-STM-1 digital radio systems operating in the 13 GHz, 15 GHz and 18 GHz frequency bands with about 14 MHz co-polar channel spacing".

[15] ETSI EN 300 639: "Fixed Radio Systems; Point-to-point equipment; Sub-STM-1 digital radio systems operating in the 13 GHz, 15 GHz and 18 GHz frequency bands with about 28 MHz co-polar and 14 MHz cross-polar channel spacing".

[16] ETSI EN 302 062: "Fixed Radio Systems; Point-to-point equipment; High capacity digital radio relay systems carrying STM-4, 4 x STM-1 or 2 x STM-1 signals in bands with 55/56 MHz channel spacing".

[17] ETSI EN 301 787: "Fixed Radio Systems; Point-to-Point equipment; Parameters for radio systems for the transmission of Sub-STM-0 digital signals operating in the 18 GHz frequency band".

[18] ETSI EN 300 430: "Fixed Radio Systems; Point-to-point equipment; Parameters for radio systems for the transmission of STM-1 digital signals operating in the 18 GHz frequency band with channel spacing of 55 MHz and 27,5 MHz".

[19] ETSI EN 300 198: "Fixed Radio Systems; Point-to-point equipment; Parameters for radio systems for the transmission of digital signals operating at 23 GHz".

[20] ETSI EN 301 785: "Fixed Radio Systems; Point-to-point packet data equipment; Parameters for radio systems with packet data interfaces for transmission of digital signals operating in the frequency range 7, 8, 13, 15, 18, 23, 26, 28, 32, 38, 52 to 55 GHz".

[21] ETSI EN 300 431: "Fixed Radio Systems; Point-to-point equipment; Parameters for radio system for the transmission of digital signals operating in the frequency range 24,50 GHz to 29,50 GHz".

[22] ETSI EN 300 197: "Fixed Radio Systems; Point-to-point equipment; Parameters for radio systems for the transmission of digital signals operating at 32 GHz and 38 GHz".

[23] ETSI EN 301 387: "Fixed Radio Systems; Point-to-point equipment; Plesiochronous Digital Hierarchy (PDH); Low and medium capacity digital radio systems operating in the frequency band 48,5 GHz to 50,2 GHz".

[24] ETSI EN 301 786: "Fixed Radio Systems; Point-to-point equipment; Parameters for digital radio systems for the transmission of digital signals operating at 52 GHz".

[25] ETSI EN 300 407: "Fixed Radio Systems; Point-to-point equipment; Parameters for digital radio systems for the transmission of digital signals operating at 55 GHz".

3 Symbols and abbreviations

3.1 Symbols

For the purposes of the present document, the following symbols apply:

dB deciBel
dBW deciBel relative to one Watt
dBW/Hz deciBel relative to one Watt per Hertz
f_n Nyquist frequency
GHz GigaHertz

Hz	Hertz
k	boltzmann's constant
MHz	MegaHertz
Mbit/s	Megabit per second
N	Modulation scheme
r_{of}	Cosine roll-off factor
T	Temperature in degrees Kelvin

3.2 Abbreviations

For the purposes of the present document, the following abbreviations apply:

ATPC	Automatic Transmit Power Control
BER	Bit Error Rate
C/I	Carrier to Interference
CPM	Continuous Phase Modulation
CS	Channel Spacing
CW	Continuous Wave
EIRP	Equivalent Isotropically Radiated Power
FEC	Forward Error Correction
FS	Fixed Service
FSPL	Free Space Path Loss
GBR	Gross Bit-Rate
IF	Intermediate Frequency
M	fade Margin
N/I	Noise to Interference
NF	Noise Figure
NFD	Net Filter Discrimination
QAM	Quadrature Amplitude Modulation
RF	Radio Frequency
RSL	Receive Signal Level
Rx	Receiver
S/N	Signal to Noise
Tx	Transmitter
W/U	Wanted to Unwanted
XPD	Cross-Polar Discrimination

4 Overview

This clause deals with the fundamental approach to noise limited assignments.

4.1 The Link Budget

A link budget ensures that the Equivalent Isotropically Radiated Power (EIRP) allocated to the transmitter maintains a pre-determined level of service defined by error performance and availability. For example, a Bit Error Rate (BER) better than 10^{-6} and availability of at least 99,99 % of time are commonly used as service levels. Figure 1 illustrates the major elements of propagation loss that are taken into consideration when assigning transmitter EIRPs to Fixed Service (FS) systems. All elements of propagation loss are frequency and path length dependent. Fade margin and gaseous absorption characteristics are addressed in ITU-R Recommendation P.530 [1] and ITU-R Recommendation P.676 [2] respectively.

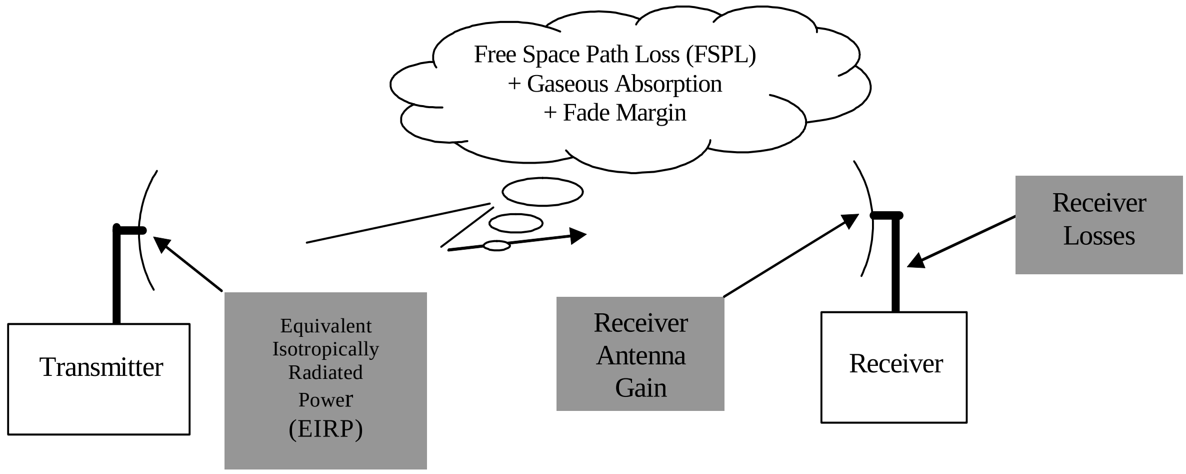


Figure 1: Fixed Link Budget

Rx Reference Sensitivity Level = Tx EIRP - FSPL - Fade Margin - Gaseous Absorption + Rx Antenna Gain - Rx Losses.

Tx EIRP = Rx Reference Sensitivity Level - Rx Antenna Gain + Rx Losses + Gaseous Absorption + FSPL + Fade Margin.

4.1.1 Receiver input level

The reference sensitivity calculated using the methodologies shown in tables 1 and 2 may be used as a theoretical guide figure. The level of reference sensitivity in most practical cases will be within a few dB of this theoretical level. When best practice noise figure and fixed losses are used in the calculation most, if not all, practical receiver reference sensitivities will be at or above the theoretical level but below that quoted in the relevant European standard.

See annex D for guidance on S/N ratios and Noise Figure (NF) values.

Table 1 sets out an example calculation for RSL. This method of calculation may be used in conjunction with a noise limited assignment system.

Table 1: Example showing calculation of RSL

Factor	Notes	Example values
Channel Bandwidth (MHz)		14
Payload rate (Mbit/s)		34,368
Gross bit rate (Mbit/s) (including FEC and service channel)	~ 1,1 x Payload rate (without FEC) ~1,15 x payload rate (with FEC) = 1,15 × 34,368 Mbit/s	39,523
Modulation scheme	16 QAM (2^n states, n = 4)	
Thermal Noise kT (dBW/Hz)	10 log [k (Boltzmann's constant) × T (288 K)]	-204
Rx noise Bandwidth Factor B (dBHz)	10 log [1,4 (Gross bit rate/n)] = 10 log [1,4 (39,523 × 10^6/4)]	71,4
Receiver Noise kTB (dBW)	Thermal Noise (kT) + Bandwidth Factor (B)	-132,6
Noise Figure (dB)	See annex D	7,5
S/N for BER = 10^{-6} (dB)	See annex D	17,6
Fixed System Losses (dB)	Assume 4 dB	4
Interference Margin (dB) (see clause 4.2.2)	Assume 1 dB	1
RSL for BER = 10^{-6} (dBW)	kTB + Noise Figure + Fixed System Losses + Interference Margin + S/N	-102,5
Median Rx Input Level (dBW)	≈ RSL plus calculated fade margin	-102,5 + M
NOTE 1: Where figures are quoted they are shown as an example and do not relate to any specific frequency band, equipment type or European standard. NOTE 2: Column 3 uses as an example a 34 Mbit/s, 16 QAM system with FEC and occupying a bandwidth of 14 MHz.		

An alternative method for calculation of RSL is set out below. This approach calculates a normalized value of RSL where the bit rate is normalized to a value of 1 Mbit/s and NF = 0 dB. The normalized RSL value may be calculated using the well established equation 1, in conjunction with the example calculations set out in table 3:

$$RSL_{norm} = -114 + NoiseFigure + 10\log(SymbolRate) + \left(S/N\right) \quad (1)$$

where NF = 0 dB

The actual RSL (rated, typical value) may be calculated using equation 2:

$$RSL = RSL_{norm} + 10\log B(MHz) + NF + IM_F + IM_S \quad (2)$$

where:

$IM_F =$ Noise Figure Industrial Margin

$IM_s =$ S/N Industrial Margin

Table 2 shows typical Noise Figures (inclusive of simple duplexers) and associated Industrial Margin values (e.g. temperature extremes, production spread of FET devices and of RF circuits/filter attenuation) in the frequency range: 6 GHz to 42 GHz. These values may be used in conjunction with equation 2.

A value of 1 dB may be considered appropriate for the S/N Industrial Margin where the BER is in the range 10^{-3} to 10^{-6}.

Typical S/N ratios (normalized to a noise bandwidth equal to the symbol-rate) are presented in table 3. Coded values are valid for the referenced coding algorithm only; use of other coding algorithms would result in different S/N values and different symbol-rates.

Table 3 gives two normalized RSL values with respect to each system shown, one based on a BER = 10^{-3} and one based on a BER = 10^{-6}.

Table 2: Typical Noise Figures (NF) and associated Industrial Margins (IM_F)

Frequency band (GHz)	Typical Noise Figure (NF) (dB)	Industrial margin (IM_F) (dB)
1,3 to 5	~4	+1
6 to 8	~4	+1,5
11	~4,5	+1,5
13 to 18	~5	+1,5
23	~5,5	+2
26 to 28	~6,5	+2,5
32 to 42	~7,5	+3
48 to 55	~10	+3,5

Table 3: S/N normalized to the symbol rate and RSL normalized to NF = 0 dB and B = 1 Mbit/s

Modulation format	4CPM-2RC h = 0,25 (see note 1)		4PSK		16 QAM		32 QAM		64 QAM		128 QAM		
Coding (see note 3)	Un-coded	Coded (RS 255,243)	Un-coded	Coded (RS 255,243)	Un-coded	Coded (16TCM-4D+RS 255,243)	Un-coded	Coded (32TCM-2D+RS 255,243)	Un-coded	Coded (64TCM-4D+RS 255,243)	Un-coded	Coded (128TCM-4D+RS 249,243)	Coded (RS 255,241)
Gross Bit rate	B	B × (255/243)	B	B × (255/243)	B	B × (4/3,5) × (255/243)	B	B × (5/4,5) × (255/243)	B	B × (6/5,5) × (255/243)	B	B × (7/6,5) × (249/243)	B × (255/241)
Symbol rate factor "n"	2	2	2	2	4	4	5	5	6	6	7	7	7
Symbol rate	B/2	(B/2) × (255/243)	B/2	(B/2) × (255/243)	B/4	(B/3,5) × (255/243)	B/5	(B/4) × (255/243)	B/6	(B/5,5) × (255/243)	B/7	(B/6,5) × (249/243)	(B/7) × (255/241)
S/N (BER = 10^{-3})	13,5	12	11	9,6	18,2	13,2	21,5	15,2	24,5	19,9	27,6	24	27,2
S/N (BER = 10^{-6})	17,5	14	14,2	10,5	21,3	13,7	25	16,4	28	20,5	31,4	25	28,5
Normalized(2) RSL at BER = 10^{-3} (see note 2)	-103,510	-104,801	-106,010	-107,201	-101,821	-106,031	-99,490	-104,611	-97,282	-101,294	-94,851	-98,623	-95,006
Normalized(2) RSL at BER = 10^{-6}(see note 2)	-99,510	-102,801	-102,810	-106,301	-98,721	-105,531	-95,990	-103,411	-93,782	-100,694	-91,051	-97,723	-93,806
B = Payload Bit-rate													
NOTE 1: Technical background for Continuous Phase Modulation (CPM) formats may be found in ITU-R Recommendation SM.328-10 [5]. NOTE 2: Normalized to NF = 0 dB and B = 1 Mbit/s. NOTE 3: Uncoded values = theoretically achievable values Coded values = typically measured in a mass production environment by one manufacturer (these are not the limits for testing, nor the guaranteed values provided to customers).													

4.1.2 Fade margins

The two main factors considered that cause the wanted signal to fade are multipath clear air fading and rain fade. Multipath clear air fading is considered dominant below about 10 GHz and rain fade is dominant above about 15 GHz. Consequently, depending on the frequency band under consideration, the multipath, rain, or a combination of the two fade margins, are calculated to ensure that system performance requirements are met. Fade margins are dependent on frequency, path length and level of service availability required.

4.2 Interference assessment

4.2.1 General

The radio link to be assigned needs to be co-ordinated with all existing links within a defined co-ordination zone. Interference levels into/from the new link need to be assessed and compared against defined limits. The co-ordination distance is dependent on propagation conditions and therefore, in general, decreases as FS bands increase in frequency.

Interference levels to and from the proposed link are assessed taking into account such factors as receiver sensitivity, path profile, antenna gain, antenna radiation pattern and antenna cross-polar response. When fitted, the operating profile of ATPC also needs to be taken into consideration. The correct implementation of the ATPC profile into the assignment process will significantly improve link density.

4.2.2 Wanted to Unwanted (W/U) ratios

Wanted to Unwanted (W/U) ratios are determined for each single interferer combination of wanted and unwanted signal types. In a noise limited assignment system the correct inclusion of these figures, into the assignment link budget calculation, will limit the increase in noise floor, caused by interference between FS systems sharing the same frequency band, below a predetermined level. The principle behind noise limited assignments is illustrated in figure 2. It shows the elements involved in determining W/U for a single co-channel interferer. For interference scenarios where the wanted and unwanted channels are not co-channel and have a degree of NFD (see clause 4.2.4) the W/U ratio is modified to take into account the additional protection given by the NFD. The derivation of single interferer W/U ratios is covered in clause 4.2.5. Note the inclusion of a multiple interferer allowance. This additional protection takes into account the fact that the victim receiver is very likely to experience interference signals from a number of sources.

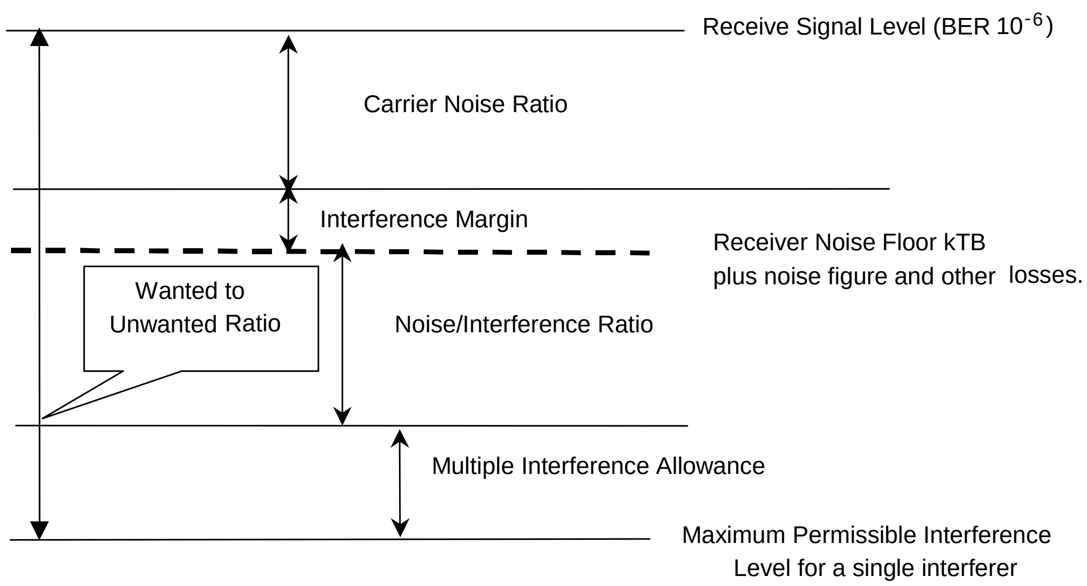


Figure 2: Derivation of single interferer co-channel interference limit

4.2.3 Receiver selectivity evaluation

An overall receiver selectivity mask for a given system type, obtained by a combination of RF, IF and base band filtering, can, in theory, be derived from the corresponding transmitter spectrum mask. It is common practice for digitally modulated systems to have Tx and Rx channel shaping such that, as far as possible, the ideal transfer function for pulses with even attenuation characteristics is equally split between the Tx and Rx.

In the absence of specific equipment data the following two methods may be used to support link assignment:

- a conservative approach of the above method is shown in annex E;
- a more realistic approach of the above method is shown in annex F.

NOTE: These approaches should not imply supplementary requirements on the equipment.

4.2.4 Net Filter Discrimination (NFD)

It is common practice in co-existence studies between transmitters and receivers of different symbol rate and modulation formats to use the concept of Net Filter Discrimination (NFD).

$$NFD = 10 \log (Pc/Pa) \quad (3)$$

Where:

- Pc is the total power received after co-channel RF, IF and base band filtering.
- Pa is the total power received after offset RF, IF and base band filtering.

NOTE 1: In the definition of NFD the following assumptions are made:

- adjacent channels XPD, if any, is not been taken into account.
- a single sideband interfering channel only is considered; for double side like-modulated interferences a NFD 3 dB lower should be taken into account.

As pointed out in ITU-R Recommendation F.746 [3], this value is produced purely by the Tx spectrum and by the overall Rx filtering. It does not include any other decoupling (e.g. antenna discrimination, XPD or the actual interfering power level).

An estimation of NFD can be made using the following series of calculations. (Reference to the diagrams in annex C will help the reader to understand the procedure).

With Tx and Rx masks aligned in the co-channel configuration (see left hand side of diagram in annex C).

1) Sample the transmitter spectrum mask and receiver filter mask. Step size is likely to be dependent on the bandwidth of the narrowest system.
2) Add corresponding Rx and Tx samples. (Obviously in practice the transmitted signal will experience a degree of attenuation throughout its bandwidth, however minor, when processed through the filter. This step is purely a scaling exercise.).
3) Convert decibel sum calculated in 2) to absolute.
4) Sum the absolute values calculated in 3).
5) Offset the Tx mask as necessary and repeat action 1) to 4).
6) Divide the co-channel summation by the offset summation.
7) Convert the value found in 6) to a decibel value.

The actions above can be summarized in the following formula:

$$NFD = 10 \times \log \left[\sum_{i=0}^{i=n-1} 10^{\frac{(Tci + Rci)/10}{}} \right] / \left[\sum_{i=0}^{i=n-1} 10^{\frac{(Toi + Rci)/10}{}} \right] \quad (4)$$

Where: n = number of samples

- Tci = Transmission mask sampled at a defined step frequency - co-channel (dB);
- Rci = Receiver mask sample at a defined step frequency - co-channel (dB);
- Toi = Transmission mask sampled at a defined step frequency - offset (dB).

Since:

$$Pa = \sum_{i=0}^{i=n-1} 10^{\frac{(Toi + Rci)/10}{}} \qquad Pc = \sum_{i=0}^{i=n-1} 10^{\frac{(Tci + Rci)/10}{}} \quad (5)$$

NOTE 2: Equation (4) is equivalent to equation (3).

4.2.5 The Carrier to Interference (C/I) ratio in mixed payload environment

Figure 3 shows NFD values plotted against frequency separation. Values for mixed systems can be calculated and are shown on the same graph. Where the transmission bandwidth exceeds receiver bandwidth i.e. not all the transmitted power falls within the receiver bandwidth, a factor equal to 10 x log (bandwidth of interferer/bandwidth of victim) needs to be applied when calculating the necessary wanted to unwanted ratio. Scenarios illustrating the change in NFD for three systems using the same modulation order but transferring different traffic rates are shown.

1) When the traffic rate for an interferer is four times that of the victim the transmitted bandwidth will be four times the receiver bandwidth. A bandwidth factor of 6 dB (10 x log 4) is added to the NFD.

2) When the interferer and the victim's rates are equal there is no bandwidth factor.

3) When the victim's bandwidth exceeds that of the interferer, the NFD out to approximately three times the mean sum of both bandwidths will be below the value for "like with like" systems. This is because within this range of frequencies the transmitted power lies within the receiver bandwidth over a greater number of channel offsets.

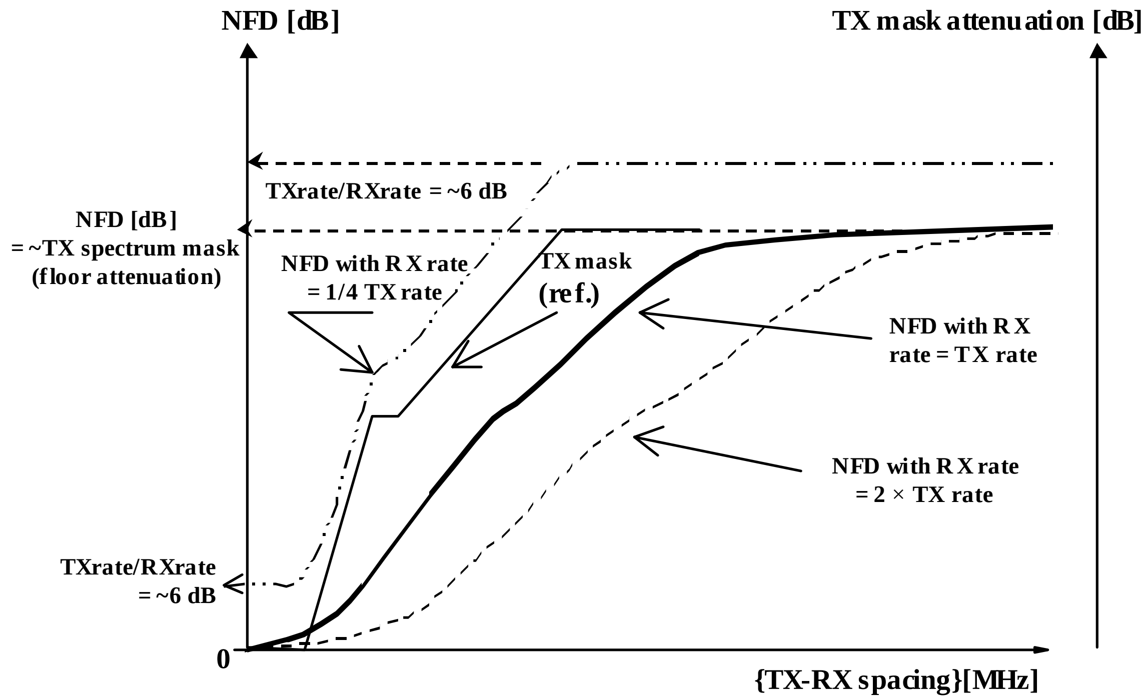


Figure 3: Qualitative examples of mixed NFD among different rate systems of the same class

Where a managing authority allocates channels and EIRPs that authority will ensure that the established network and the new system will co-exist without degradation in system performance. This is achieved by keeping interference levels below defined limits whilst ensuring that transmission EIRPs (see clause 4.1) are sufficient to maintain the required level of system performance. The necessary protection is achieved by ensuring that the level of interference from individual transmissions is kept below defined limits. These protection levels, the ratio between required signal and interferer, are referred to as wanted to unwanted ratios. The evaluation of W/U is covered in clause 4.2.6.

4.2.6 Evaluation of the Wanted to Unwanted (W/U) ratios

NFD is evaluated at all possible frequency offsets and for all possible Tx and Rx system combinations. Once calculated the values are subtracted from the co-channel or in mixed systems, the near co-channel, W/U (see clause 4.2.2). Tables of typical W/U ratios for two sets of systems combinations are given in annex B.

W/U = Co-channel/near co-channel W/U - NFD

5 Interference limited assignments

The noise limited approach described earlier makes two assumptions regarding the number of multiple interferers and in addition it also sets a pre-determined level of noise floor degradation. Both of these elements can impose limitations and can, in some cases, be overcome by the adoption of an interference limited approach. An explanation of this is given in annex A.

6 Summary

The present document has concentrated on equipment performance and not considered the major contribution to spectrum engineering made by the antenna. Obviously parameters such as off axis and cross-polar performance of antennas in a mixed FS environment significantly affect the level of interference experienced by a victim receiver.
A generic approach has been taken although a modern computer based assignment system will provide facilities which enhance link density by utilizing guaranteed performance when the guaranteed level exceeds the generic limit.

Annex A: Interference limited assignments

The assumption that a specified number of multiple interferers are present when planning the interference margin in a noise limited assignment system makes it necessary to add an additional protection margin to the N/I ratio.
For example, assume that the noise limited assignment system for co-channel operation is based on degradation in noise floor of 1 dB (equivalent to a N/I of 6 dB) and that the multiple co-channel allowance assumes that the number of multiple interferers is between 2 and 3. Thus the total N/I for a single co-channel interferer consists of 6 dB plus a multiple element of 4 dB (10 $\log_{10}$ 2,5). In practice such a system will ensure that all co-channel interferers are limited to 10 dB below noise floor. However, as the examples below demonstrates there will be occasions when single interferers can breach the 10 dB threshold without a detrimental effect on link availability:

EXAMPLE 1: Assume two co-channel interferers: N/I of Int_1 = 7 dB;
N/I of Int_2 = 13 dB.

Cumulative increase in interference = $10^{-0,7} + 10^{-1,3}$ in relative terms = 0,249.

Degradation in noise = 10 $\log_{10}$ (1 + 0,249) = 0,967 dB.

EXAMPLE 2: When the number of multiple interferers exceeds the number assumed the level of interference experienced is likely to exceed the theoretical level used for assignment purposes.

The interference limited approach can overcome the problems illustrated above. Interference limited assignment systems calculate and record the cumulative interference level into each receiver. There are two possibilities which will ensure the rejection of a new assignment. The first occurs when the establishment of an additional transmitter causes the cumulative interference level into an established link receiver to exceed the assignment limit. Secondly the new assignment may fail because one, or both, end/s of the link may be subjected to cumulative interference from the established network, which exceeds the assignment limit.

Obviously a decrease in assignment N/I, resulting in an increase in interference margin, will resolve certain problems. The resulting increase in Tx EIRPs and receiver C/I may improve link density. Two scenarios exist. The first covers the situation where an increase in a single or very limited number of links EIRPs overcomes a specific problem. The second, the global approach, requires a general increase in system EIRP throughout the network. Obviously the first scenario will address local problems and have a limited effect on link density. The global approach can give significant increases in the level of link density but is extremely difficult in practice to implement. A study within the UK Radio communications Agency suggests that a one off EIRP increase to the order of 10 dB is necessary to obtain useful benefits within a well-established network designed to operate with a 6 dB N/I ratio. Increases in EIRP of this order are rarely feasible in practice.

A balance between power, path length and link availability is necessary. Simulations which estimate link density and include elements for N/I ratio, transmitter output, receiver performance, antenna gain and profile, target path lengths, link availability, system distribution, system losses, propagation losses and fade margins will help those involved with spectrum engineering to define a practical level of N/I and thus noise degradation. Once the assignment criteria and the network are established the scope for changes to criteria are very limited for the reasons mentioned previously.

In practice there is only a subtle difference between noise limited and interference limited assignments. An assignment system which is truly interference limited will give some degree of flexibility to address local spectrum congestion but will require a greater degree of sophistication. On a medium to large scale the additional sophistication will be incorporated into the assignment system software. On a smaller scale, when manual assignments are undertaken, the penalty will be time related. Different problems require different solutions. Spectrum engineers should assess the problems in their area of responsibility and base their solution on the unique set of problems that they face.

Annex B: Wanted to Unwanted (W/U) ratios

Tables B.1 and B.2, shown as examples, give the wanted to unwanted ratios for two system types. All possible interference sources are shown and protection ratios out to at least three times the wanted channel spacing are shown.

When the wanted and unwanted channels of digital systems are not equal, Step 1 in the Wanted to Unwanted tables is equal to 1/2 the narrowest bandwidth. Thereafter the step sizes are equivalent to the narrowest bandwidth. When the wanted and unwanted channels are the same, all step sizes are equal to the bandwidth of these systems. Shaded Steps indicate a Wanted to Unwanted Ratio of -40 dB.

Step sizes where the interferer is analogue are calculated using an assumed bandwidth of 7 MHz for systems with a base band of < 3,5 MHz and 14 MHz for systems whose base band is < 10 MHz.

Table B.1: Wanted System 8 Mbit/s in 3,5 MHz

Class	Unwanted System (Mbit/s in MHz)	Wanted/Unwanted Ratio (dB) versus Step Size (see annex B)																					
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	2 in 7	-	26	4	-12	-27	-40	-40															
1	2 x 2 in 7	-	26	4	-12	-27	-40	-40															
1	8 in 14	-	24	21	1	-10	-19	-27	-35	-40													
2	2 in 3,5	31	7	-26	-40	-40																	
2	2 x 2 in 3,5	31	7	-17	-40	-40																	
2	8 in 7	-	26	4	-12	-27	-40	-40															
2	8 x 2 in 14	-	24	21	1	-10	-19	-27	-35	-40													
2	34 in 28	-	22	21	15	6	-2	-7	-13	-18	-23	-28	-32	-36	-40								
4	8 in 3,5	31	5	-20	-37	-40																	
4	8 x 2 in 7	-	28	10	-9	-18	-40																
4	34 in 14	-	25	21	1	-10	-21	-31	-36	-40													
4	51 in 14	-	25	25	13	-6	-10	-15	-20	-40													
4	51 in 28	-	22	21	15	6	-2	-7	-13	-18	-23	-28	-32	-36	-40								
4	140/155 in 56	-	19	19	19	17	15	9	4	-1	-5	-8	-12	-15	-18	-21	-23	-26	-28	-33	-35	-37	-40
5b	140/155 in 28	-	22	22	22	21	2	-14	-18	-21	-23	-25	-27	-28	-30	-40							
< 3,5 (s)	Analogue in 21	-	29	22	8	-16	-36	-40															
< 10 (s)	Analogue in 42	-	26	26	23	23	5	5	-17	-17	36	-36	-40										
NOTE: All Wanted/Unwanted ratios in the shaded area are equal to -40 dB.																							

Table B.2: Wanted system 51 Mbit/s in 14 MHz

Class	Unwanted System (Mbit/s in MHz)	Wanted/Unwanted Ratio (dB) versus Step Size (see annex B)														
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	2 in 7	-	32	13	-6	-26	-40									
1	2 x 2 in 7	-	32	13	-6	-26	-40									
1	8 in 14	34	10	-14	-40											
2	2 in 3,5	-	33	24	11	2	-7	-17	-32	-40						
2	2 x 2 in 3,5	-	33	24	11	2	-7	-15	-29	-40						
2	8 in 7	-	32	13	-6	-26	-40									
2	8 x 2 in 14	34	10	-14	-40											
2	34 in 28	-	31	10	-7	-21	-40									
4	8 in 3,5	-	33	26	11	9	1	-14	-33	-40						
4	8 x 2 in 7	-	32	11	-2	-33	-40									
4	34 in 14	34	10	-26	-40											
4	51 in 14	34	5	-17	-40											
4	51 in 28	-	31	7	-15	-28	-40									
4	140/155 in 56	-	28	21	4	-5	-13	-21	-29	-40						
5b	140/155 in 28	-	31	7	-17	-24	-40									
< 3,5 (s)	Analogue in 21	-	34	31	13	13	-10	-40								
< 10 (s)	Analogue in 42	32	29	11	-11	-33	-40									

NOTE: All Wanted to Unwanted Ratios in the shaded area are equal to -40 dB.

Annex C:
Diagram showing the NFD procedure

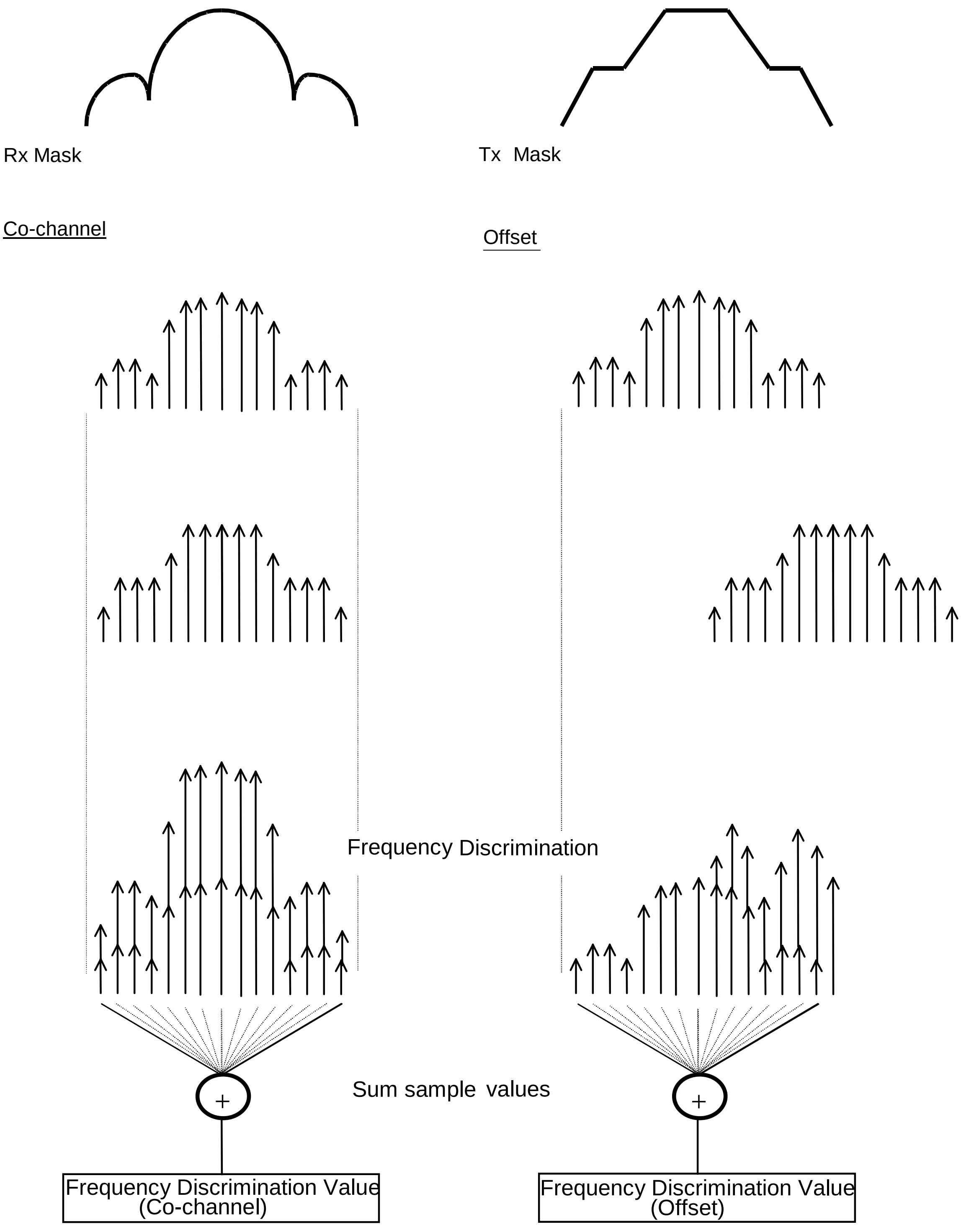


Figure C.1

Annex D: Table of typical values for noise figure and signal/noise at BER = 10^{-6}

The table of Noise Figure and Signal/Noise values shown below is based on contributions from manufacturers (towards the end of 2002). The Noise Figure values shown may be considered typical for equipment operating the modulation schemes indicated. The S/N ratios for a BER = 10^{-6} are shown as a range of values. The actual S/N value will depend on whether forward error correction and coded modulation schemes are employed and on the actual improvement on the un-coded performance. It has been assumed that error correction is used with systems operating 16 QAM modulation and higher and that an improvement of 2 dB with respect to un-coded values is (currently) achieved.

Frequency band	**1,350 GHZ to 1,517 GHz**					**3,6 GHz to 4,2 GHz**				
System Option Capacity (Mbit/s) in Bandwidth (MHz) unless stated otherwise (Modulation scheme)	64 kbit/s in 75 kHz (4 State)	192 kbit/s in 250 kHz (4 State)	704 kbit/s in 500 kHz (4 State)	704 kbit/s in 1 (2 State)	2 in 1 (16 QAM)	2 in 1,75 (4 State)	2 × 2 in 1,75 (16 QAM)	2 × 2 in 3,5 (4 State)	8 in 3,5 (16 QAM)	8 in 7 (4 State)
Reference Standard	EN 300 630 [6]	EN 300 630 [6]	EN 300 630 [6]	EN 300 630 [6]	EN 300 630 [6]	EN 301 216 [7]	EN 301 216 [7]	EN 301 216 [7]	EN 301 216 [7]	EN 301 216 [7]
NF (dB)	4	4	4	4	4	4	4	4	4	4
S/N (dB)	10,5 to 14,2	10,5 to 14,2	10,5 to 14,2	10,5	13,7 to 19,3	10,5 to 14,2	13,7 to 19,3	10,5 to 14,2	13,7 to 19,3	10,5 to 14,2

Frequency band	**3,6 GHz to 4,2 GHz**										
System Option Capacity (Mbit/s) in Bandwidth (MHz) (Modulation scheme)	2 × 8 in 7 (16 QAM)	2 × 8 in 14/15 (4 State)	34 in 14/15 (16 QAM)	2 × 34 in 14/15 (64 QAM)	51 in 14/15 (32 QAM)	51 in 20 (16 QAM)	34 in 29/30 (4 State)	2 × 34 in 29/30 (16 QAM)	51 in 29/30 (16 QAM)	140/STM-1 in 29/30 (128 QAM)	2 × STM-1 in 40 (CCDP) (64/128 QAM)
Reference Standard	EN 301 216 [7]	EN 301 216 [7]	EN 301 216 [7]	EN 301 216 [7]	EN 301 216 [7]	EN 301 216 [7]	EN 301 216 [7]	EN 301 216 [7]	EN 301 216 [7]	EN 300 234 [8]	EN 301 461 [9]
NF (dB)	4	4	4	4	4	4	4	4	4	4	4
S/N (dB)	13,7 to 19,3	10,5 to 14,2	13,7 to 19,3	20,5 to 26	16,4 to 23	13,7 to 19,3	10,5 to 14,2	13,7 to 19,3	13,7 to 19,3	23,6 to 29,4	20,5 to 26/ 23,6 to 29,4

Frequency band	**5,925 GHz to 6,425 GHz**					**6,425 GHz to 7,125 GHz**		
System Option Capacity (Mbit/s) in Bandwidth (MHz) (Modulation scheme)	34 in 29,65 (4 State)	2 × 34 in 29,65 (16 QAM)	51 in 29,65 (16 QAM)	140/STM-1 in 29,65 (128 QAM)	2 × STM-1 in 29,65 (CCDP) (128 QAM)	51 in 20 (16 QAM)	2 × STM-1 in 40 (CCDP) (64/128 QAM)	2 × STM-1 in 40 (512 QAM)
Reference Standard	EN 301 216 [7]	EN 301 216 [7]	EN 301 216 [7]	EN 300 234 [8]	EN 301 127 [10]	EN 301 216 [7]	EN 301 461 [9]	EN 301 669 [11] (see note)
NF (dB)	4	4	4	4	4	4	4	4
S/N (dB)	10,5 to 14,2	13,7 to 19,3	13,7 to 19,3	23,6 to 29,4	23,6 to 29,4	13,7 to 19,3	20,5 to 26/ 23,6 to 29,4	31,1 to 33,5
NOTE: EN 301 669 [11] allows for STM-4 using 2 × STM-1 carriers.								

Frequency band	7,425 GHz to 7,9 GHz									
System Option Capacity (Mbit/s) in Bandwidth (MHz) (Modulation scheme)	8 in 7 (4 State)	2 × 8 in 7 (16 QAM)	2 × 8 in 14 (4 State)	34 in 14 (16 QAM)	2 × 34 in 14 (64 QAM)	51 in 14 (32 QAM)	51 in 20 (16 QAM)	34 in 28 (4 State)	2 × 34 in 28 (16 QAM)	51 in 28 (16 QAM)
Reference Standard	EN 301 216 [7]	EN 301 216 [7]	EN 301 216 [7]	EN 301 216 [7]	EN 301 216 [7]	EN 301 216 [7]	EN 301 216 [7]	EN 301 216 [7]	EN 301 216 [7]	EN 301 216 [7]
NF (dB)	4	4	4	4	4	4	4	4	4	4
S/N (dB)	10,5 to 14,2	13,7 to 19,3	10,5 to 14,2	13,7 to 19,3	20,5 to 26	16,4 to 23	13,7 to 19,3	10,5 to 14,2	13,7 to 19,3	13,7 to 19,3

Frequency band	7,425 GHz to 7,9 GHz		10,7 GHz to 11,7 GHz			12,75 GHz to 13,25 GHz				
System Option Capacity (Mbit/s) in Bandwidth (MHz) (Modulation scheme)	STM-1 in 28 (128 QAM)	2 × STM-1 in 28 (CCDP) (128 QAM)	STM-4/ 4 × STM-1 in 40 (CCDP) (512 QAM)	2 × STM-1 in 40 (CCDP) (64/128 QAM)	2 × STM-1 in 40 (512 QAM)	2 in 1,75 (4 State)	2 × 2 in 1,75 (16 QAM)	2 × 2 in 3,5 (4 State)	8 in 3,5 (16 QAM)	8 in 7 (4 State)
Reference Standard	EN 301 127 [10], EN 300 234 [8]	EN 301 127 [10]	EN 301 277 [12]	EN 301 461 [9]	EN 301 669 [11] (see note)	EN 301 128 [13]	EN 301 128 [13]	EN 301 128 [13]	EN 301 128 [13]	EN 301 128 [13]
NF (dB)	4	4	4,5	4,5	4,5	5	5	5	5	5
S/N (dB)	23,6 to 29,4	23,6 to 29,4	31,1 to 33,5	20,5 to 26/ 23,6 to 29,4	31,1 to 33,5	10,5 to 14,2	13,7 to 19,3	10,5 to 14,2	13,7 to 19,3	10,5 to 14,2
NOTE: EN 301 669 [11] allows for STM-4 using 2 × STM-1 carriers.										

Frequency band	12,75 GHz to 13,25 GHz									
System Option Capacity (Mbit/s) in Bandwidth (MHz) (Modulation scheme)	2 × 8 in 7 (16 QAM)	2 × 8 in 14 (4 State)	34 in 14 (16 QAM)	51 in 14 (32 QAM)	51 in 28 (16 QAM)	34 in 14 (16 QAM)	34 in 28 (4 State)	2 × 34 in 28 (16 QAM)	STM-1 in 28 (128 QAM)	2 × STM-1 in 28 (CCDP) (128 QAM)
Reference Standard	EN 301 128 [13]	EN 301 128 [13]	EN 301 128 [13]	EN 300 786 [14]	EN 300 639 [15]	EN 301 128 [13]	EN 301 128 [13]	EN 301 128 [13]	EN 300 234 [8], EN 301 127 [10]	EN 301 127 [10]
NF (dB)	5	5	5	5	5	5	5	5	5	5
S/N (dB)	13,7 to 19,3	10,5 to 14,2	13,7 to 19,3	16,4 to 23	13,7 to 19,3	13,7 to 19,3	10,5 to 14,2	13,7 to 19,3	23,6 to 29,4	23,6 to 29,4

Frequency band	14,5 GHz to 15,35 GHz									
System Option Capacity (Mbit/s) in Bandwidth (MHz) (Modulation scheme)	2 in 1,75 (4 State)	2 × 2 in 1,75 (16 QAM)	2 × 2 in 3,5 (4 State)	8 in 3,5 (16 QAM)	8 in 7 (4 State)	2 × 8 in 7 (16 QAM)	2 × 8 in 14 (4 State)	34 in 14 (16 QAM)	51 in 14 (32 QAM)	51 in 28 (16 QAM)
Reference Standard	EN 301 128 [13]	EN 301 128 [13]	EN 301 128 [13]	EN 301 128 [13]	EN 301 128 [13]	EN 301 128 [13]	EN 301 128 [13]	EN 301 128 [13]	EN 300 786 [14]	EN 300 639 [15]
NF (dB)	5	5	5	5	5	5	5	5	5	5
S/N (dB)	10,5 to 14,2	13,7 to 19,3	10,5 to 14,2	13,7 to 19,3	10,5 to 14,2	13,7 to 19,3	10,5 to 14,2	13,7 to 19,3	16,4 to 23	13,7 to 19,3

Frequency band	14,5 GHz to 15,35 GHz					17,7 GHz to 19,7 GHz				
System Option Capacity (Mbit/s) in Bandwidth (MHz) (Modulation scheme)	34 in 28 (4 State)	2 × 34 in 28 (16 QAM)	STM-1 in 28 (128 QAM)	2 × STM-1 in 28 (CCDP) (128 QAM)	2 × STM-1 in 56 (128 QAM)	2 × 8 in 13,75 (4 State)	34 in 13,75 (16 QAM)	51 in 14 (32 QAM)	51 in 28 (16 QAM)	34 in 27,5 (16 QAM)
Reference Standard	EN 301 128 [13]	EN 301 128 [13]	EN 300 234 [8]	EN 301 127 [10]	EN 302 062 [16] (see note)	EN 301 128 [13]	EN 301 128 [13]	EN 300 786 [14]	EN 300 639 [15]	EN 301 128 [13]
NF (dB)	5	5	5	5	5	5	5	5	5	5
S/N (dB)	10,5 to 14,2	13,7 to 19,3	23,6 to 29,4	23,6 to 29,4	23,6 to 29,4	10,5 to 14,2	13,7 to 19,3	16,4 to 23	13,7 to 19,3	13,7 to 19,3
NOTE: EN 302 062 [16] allows for STM-4/4 × STM-1 using two 2 × STM-1 carriers.										

Frequency band	17,7 GHz to 19,7 GHz						22,0 GHz to 23,6 GHz			
System Option Capacity (Mbit/s) in Bandwidth (MHz) (Modulation scheme)	2 × 34 in 27,5 (16 QAM)	9,792 (sSTM-14) in 3,5 (16 QAM)	14,400 (sSTM-22) in 3,5 (64 QAM)	STM -1 in 27,5 (128 QAM)	STM-1 in 55 (16 QAM)	2 × STM-1 in 56 (128 QAM)	2 in 3,5 (2 State)	2 × 2 in 3,5 (4 State)	8 in 3,5 (16 QAM)	8 in 7 (4 State)
Reference Standard	EN 301 128 [13]	EN 301 787 [17]	EN 301 787 [17]	EN 300 430 [18]	EN 300 430 [18]	EN 302 062 [16] (see note)	EN 300 198 [19]	EN 300 198 [19]	EN 300 198 [19]	EN 300 198 [19]
NF (dB)	5	5	5	5	5	5	5,5	5,5	5,5	5,5
S/N (dB)	13,7 to 19,3	13,7 to 19,3	20,5 to 26	23,6 to 29,4	13,7 to 19,3	23,6 to 31,4	10,5	10,5 to 14,2	13,7 to 19,3	10,5 to 14,2
NOTE: EN 302 062 [16] allows for STM-4/4 × STM-1 using two 2 × STM-1 carriers.										

Frequency band	22,0 GHz to 23,6 GHz									
System Option Capacity (Mbit/s) in Bandwidth (MHz) (Modulation scheme)	2 × 8 in 7 (16 QAM)	2 × 8 in 14 (4 State)	34 in 14 (16 QAM)	34 in 28 (4 State)	51 in 14 (32 QAM)	51 in 28 (16 QAM)	51 in 56 (4 State)	140/STM-1 in 28 (128 QAM)	140/STM-1 in 56 (16 QAM)	2 × STM-1 in 56 (128 QAM)
Reference Standard	EN 300 198 [19]	EN 300 198 [19]	EN 300 198 [19]	EN 300 198 [19]	EN 300 198 [19]	EN 300 198 [19]	EN 300 198 [19]	EN 300 198 [19]	EN 300 198 [19]	EN 302 062 [16] (see note)
NF (dB)	5,5	5,5	5,5	5,5	5,5	5,5	5,5	5,5	5,5	5,5
S/N (dB)	13,7 to 19,3	10,5 to 14,2	13,7 to19,3	10,5 to14,2	16,4 to 23	13,7 to 19,3	10,5 to 14,2	23,6 to 29,4	13,7 to 19,3	23,6 to 29,4
NOTE: EN 302 062 [16] allows for STM-4/4 × STM-1 using two 2 × STM-1 carriers.										

Frequency band	22,0 GHz to 23,6 GHz					24,5 GHz to 26,5 GHz				
System Option Capacity (Mbit/s) in Bandwidth (MHz) (Modulation scheme)	10 in 3,5 (16 QAM)	10 in 7 (4 State)	100 in 28 (16 QAM)	100 in 28 (64 QAM)	100 in 56 (16 QAM)	2 in 3,5 (4 State)	2 × 2 in 3,5 (4 State)	8 in 3,5 (16 QAM)	8 in 7 (4 State)	2 × 8 in 7 (16 QAM)
Reference Standard	EN 301 785 [20]	EN 301 785 [20]	EN 301 785 [20]	EN 301 785 [20]	EN 301 785 [20]	EN 300 431 [21]	EN 300 431 [21]	EN 300 431 [21]	EN 300 431 [21]	EN 300 431 [21]
NF (dB)	5,5	5,5	5,5	5,5	5,5	6,5	6,5	6,5	6,5	6,5
S/N (dB)	13,7 to 19,3	10,5 to 14,2	13,7 to 19,3	20,5 to 26	13,7 to 19,3	10,5 to 14,2	10,5 to 14,2	13,7 to 19,3	10,5 to 14,2	13,7 to 19,3

Frequency band	**24,5 GHz to 26,5 GHz**									
System Option Capacity (Mbit/s) in Bandwidth (MHz) (Modulation scheme)	2 × 8 in 14 (4 State)	34 in 14 (16 QAM)	51 in 14 (32 QAM)	34 in 28 (4 State)	51 in 28 (16 QAM)	140/STM-1 in 28 (128 QAM)	51 in 56 (4 State)	140/STM-1 in 56 (16 QAM)	10 in 3,5 (16 QAM)	10 in 7 (4 State)
Reference Standard	EN 300 431 [21]	EN 300 431 [21]	EN 300 431 [21]	EN 300 431 [21]	EN 300 431 [21]	EN 300 431 [21]	EN 300 431 [21]	EN 300 431 [21]	EN 301 785 [20]	EN 301 785 [20]
NF (dB)	6,5	6,5	6,5	6,5	6,5	6,5	6,5	6,5	6,5	6,5
S/N (dB)	10,5 to 14,2	13,7 to 19,3	16,4 to 23	10,5 to 14,2	13,7 to 19,3	23,6 to 29,4	10,5 to14,2	13,7 to 19,3	13,7 to 19,3	10,5 to 14,2

Frequency band	**24,5 GHz to 26,5 GHz**				**27,5 GHz to 29,5 GHz**					
System Option Capacity (Mbit/s) in Bandwidth (MHz) (Modulation scheme)	100 in 28 (16 QAM)	100 in 28 (64 QAM)	100 in 56 (16 QAM)	2 × STM-1 in 56 (128 QAM)	2 in 3,5 (4 State)	2 × 2 in 3,5 (4 State)	8 in 3,5 (16 QAM)	8 in 7 (4 State)	2 × 8 in 7 (16 QAM)	2 × 8 in 14 (4 State)
Reference Standard	EN 301 785 [20]	EN 301 785 [20]	EN 301 785 [20]	EN 302 062 [16] (see note)	EN 300 431 [21]	EN 300 431 [21]	EN 300 431 [21]	EN 300 431 [21]	EN 300 431 [21]	EN 300 431 [21]
NF (dB)	6,5	6,5	6,5	6,5	6,5	6,5	6,5	6,5	6,5	6,5
S/N (dB)	13,7 to 19,3	20,5 to 26	13,7 to 19,3	23,6 to 29,4	10,5 to 14,2	10,5 to 14,2	13,7 to 19,3	10,5 to 14,2	13,7 to 19,3	10,5 to 14,2
NOTE: EN 302 062 [16] allows for STM-4/4 × STM-1 using two 2 × STM-1 carriers.										

Frequency band	**27,5 GHz to 29,5 GHz**									
System Option Capacity (Mbit/s) in Bandwidth (MHz) (Modulation scheme)	34 in 14 (16 QAM)	51 in 14 (32 QAM)	34 in 28 (4 State)	51 in 28 (16 QAM)	140/STM-1 in 28 (128 QAM)	51 in 56 (4 State)	140/STM-1 in 56 (16 QAM)	10 in 3,5 (16 QAM)	10 in 7 (4 State)	100 in 28 (16 QAM)
Reference Standard	EN 300 431 [21]	EN 300 431 [21]	EN 300 431 [21]	EN 300 431 [21]	EN 300 431 [21]	EN 300 431 [21]	EN 300 431 [21]	EN 301 785 [20]	EN 301 785 [20]	EN 301 785 [20]
NF (dB)	6,5	6,5	6,5	6,5	6,5	6,5	6,5	6,5	6,5	6,5
S/N (dB)	13,7 to 19,3	16,4 to 23	10,5 to 14,2	13,7 to 19,3	23,6 to 29,4	10,5 to 14,2	13,7 to 19,3	13,7 to 19,3	10,5 to 14,2	13,7 to 19,3

Frequency band	**27,5 GHz to 29,5 GHz**		**31,8 GHz to 33,4 GHz**							
System Option Capacity (Mbit/s) in Bandwidth (MHz) (Modulation scheme)	100 in 28 (64 QAM)	100 in 56 (16 QAM)	2 in 3,5 (4 State)	2 × 2 in 3,5 (4 State)	8 in 3,5 (16 QAM)	8 in 7 (4 State)	2 × 8 in 7 (16 QAM)	2 × 8 in 14 (4 State)	34 in 14 (16 QAM)	51 in 14 (32 QAM)
Reference Standard	EN 301 785 [20]	EN 301 785 [20]	EN 300 197 [22]	EN 300 197 [22]	EN 300 197 [22]	EN 300 197 [22]	EN 300 197 [22]	EN 300 197 [22]	EN 300 197 [22]	EN 300 197 [22]
NF (dB)	6,5	6,5	7,5	7,5	7,5	7,5	7,5	7,5	7,5	7,5
S/N (dB)	20,5 to 26	13,7 to 19,3	10,5 to 14,2	10,5 to 14,2	13,7 to 19,3	10,5 to 14,2	13,7 to 19,3	10,5 to 14,2	13,7 to 19,3	16,4 to 23

Frequency band	31,8 GHz to 33,4 GHz						37,0 GHz to 39,5 GHz			
System Option Capacity (Mbit/s) in Bandwidth (MHz) (Modulation scheme)	34 in 28 (4 State)	51 in 28 (16 QAM)	140/STM-1 in 28 (128 QAM)	51 in 56 (4 State)	140/STM-1 in 56 (16 QAM)	2 × STM-1 in 56 (128 QAM)	2 in 3,5 (4 State)	2 × 2 in 3,5 (4 State)	8 in 3,5 (16 QAM)	8 in 7 (4 State)
Reference Standard	EN 300 197 [22]	EN 300 197 [22]	EN 300 197 [22]	EN 300 197 [22]	EN 300 197 [22]	EN 302 062 [16] (see note)	EN 300 197 [22]	EN 300 197 [22]	EN 300 197 [22]	EN 300 197 [22]
NF (dB)	7,5	7,5	7,5	7,5	7,5	7,5	7,5	7,5	7,5	7,5
S/N (dB)	10,5 to 14,2	13,7 to 19,3	23,6 to 29,4	10,5 to 14,2	13,7 to 19,3	23,6 to 29,4	10,5 to 14,2	10,5 to 14,2	13,7 to19,3	10,5 to 14,2

NOTE: EN 302 062 [16] allows for STM-4/4 × STM-1 using two 2 × STM-1 carriers.

Frequency band	37,0 GHz to 39,5 GHz									
System Option Capacity (Mbit/s) in Bandwidth (MHz) (Modulation scheme)	2 × 8 in 7 (16 QAM)	2 × 8 in 14 (4 State)	34 in 14 (16 QAM)	51 in 14 (32 QAM)	34 in 28 (4 State)	51 in 28 (16 QAM)	140/STM-1 in 28 (128 QAM)	51 in 56 (4 State)	140/STM-1 in 56 (16 QAM)	2 × STM-1 in 56 (128 QAM)
Reference Standard	EN 300 197 [22]	EN 300 197 [22]	EN 300 197 [22]	EN 300 197 [22]	EN 300 197 [22]	EN 300 197 [22]	EN 300 197 [22]	EN 300 197 [22]	EN 300 197 [22]	EN 302 062 [16] (see note)
NF (dB)	7,5	7,5	7,5	7,5	7,5	7,5	7,5	7,5	7,5	7,5
S/N (dB)	13,7 to 19,3	10,5 to 14,2	13,7 to 19,3	16,4 to 23	10,5 to 14,2	13,7 to 19,3	23,6 to 29,4	10,5 to 14,2	13,7 to 19,3	23,6 to 29,4

NOTE: EN 302 062 [16] allows for STM-4/4 × STM-1 using two 2 × STM-1 carriers.

Frequency band	48,5 GHz to 50,2 GHz								51,4 GHz to 52,6 GHz	
System Option Capacity (Mbit/s) in Bandwidth (MHz) (Modulation scheme)	2 in 3,5 (4 States)	2 × 2 in 3,5 (4 States)	2 in 7 (2 States)	8 in 7 (4 States)	2 × 2 in 14 (2 States)	2 × 8 in 14 (4 States)	8 in 28 (2 States)	34 in 28 (4 States)	2 in 3,5 (4 States)	2 × 2 in 3,5 (4 States)
Reference Standard	EN 301 387 [23]	EN 301 387 [23]	EN 301 387 [23]	EN 301 387 [23]	EN 301 387 [23]	EN 301 387 [23]	EN 301 387 [23]	EN 301 387 [23]	EN 301 786 [24]	EN 301 786 [24]
NF (dB)	10	10	10	10	10	10	10	10	10	10
S/N (dB)	10,5 to 14,2	10,5 to 14,2	10,5	10,5 to 14,2	10,5	10,5 to 14,2	10,5	10,5 to 14,2	10,5 to 14,2	10,5 to 14,2

Frequency band	51,4 GHz to 52,6 GHz									
System Option Capacity (Mbit/s) in Bandwidth (MHz) (Modulation scheme)	8 in 3,5 (16 QAM)	2 in 7 (2 State)	2 × 2 in 7 (2 State)	8 in 7 (4 State)	2 × 8 in 7 (16 QAM)	8 in 14 (2 State)	2 × 8 in 14 (4 State)	34 in 14 (16 QAM)	51 in 14 (32 QAM)	2 × 8 in 28 (2 State)
Reference Standard	EN 301 786 [24]	EN 301 786 [24]	EN 301 786 [24]	EN 301 786 [24]	EN 301 786 [24]	EN 301 786 [24]	EN 301 786 [24]	EN 301 786 [24]	EN 301 786 [24]	EN 301 786 [24]
NF (dB)	10	10	10	10	10	10	10	10	10	10
S/N (dB)	13,7 to 19,3	10,5	10,5	10,5 to 14,2	13,7 to 19,3	10,5	10,5 to 14,2	13,7 to 19,3	16,4 to 23	10,5

Frequency band	51,4 GHz to 52,6 GHz					55,78 GHz to 57,0 GHz				
System Option Capacity (Mbit/s) in Bandwidth (MHz) (Modulation scheme)	34 in 28 (4 State)	51 in 28 (16 QAM)	34 in 56 (2 State)	51 in 56 (4 State)	140/STM-1 in 56 (16 QAM)	2 in 3,5 (4 State)	2 × 2 in 3,5 (4 State)	8 in 3,5 (16 QAM)	2 in 7 (2 State)	2 × 2 in 7 (2 State)
Reference Standard	EN 301 786 [24]	EN 301 786 [24]	EN 301 786 [24]	EN 301 786 [24]	EN 301 786 [24]	EN 300 407 [25]	EN 300 407 [25]	EN 300 407 [25]	EN 300 407 [25]	EN 300 407 [25]
NF (dB)	10	10	10	10	10	10	10	10	10	10
S/N (dB)	10,5 to 14,2	13,7 to 19,3	10,5	10,5 to 14,2	13,7 to 19,3	10,5 to 14,2	10,5 to 14,2	13,7 to 19,3	10,5	10,5

Frequency band	55,78 GHz to 57,0 GHz									
System Option Capacity (Mbit/s) in Bandwidth (MHz) (Modulation scheme)	8 in 7 (4 State)	2 × 8 in 7 (16 QAM)	8 in 14 (2 State)	2 × 8 in 14 (4 State)	34 in 14 (16 QAM)	51 in 14 (32 QAM)	2 × 8 in 28 (2 State)	34 in 28 (4 State)	51 in 28 (16 QAM)	34 in 56 (2 State)
Reference Standard	EN 300 407 [25]	EN 300 407 [25]	EN 300 407 [25]	EN 300 407 [25]	EN 300 407 [25]	EN 300 407 [25]	EN 300 407 [25]	EN 300 407 [25]	EN 300 407 [25]	EN 300 407 [25]
NF (dB)	10	10	10	10	10	10	10	10	10	10
S/N (dB)	10,5 to 14,2	13,7 to 19,3	10,5	10,5 to 14,2	13,7 to 19,3	16,4 to 23	10,5	10,5 to 14,2	13,7 to 19,3	10,5

Frequency band	55,78 GHz to 57,0 GHz	
System Option Capacity (Mbit/s) in Bandwidth (MHz) (Modulation scheme)	51 in 56 (4 State)	140/STM-1 in 56 (16 QAM)
Reference Standard	EN 300 407 [25]	EN 300 407 [25]
NF (dB)	10	10
S/N (dB)	10,5 to 14,2	13,7 to 19,3

Annex E: Receiver selectivity (conservative approach)

By analysing the generic spectrum mask, as shown in figure E.1, we can identify the portion of transmitted spectrum that is vital to the satisfactory transfer of information. The receiver needs to meet adjacent channel and "CW interference sensitivity" requirements. Therefore, it can be assumed that the overall Rx filter design is such that it meets the 1dB degradation, from the BER of 10^{-6} threshold to a 10^{-5} performance, commonly used as the EN interference criteria for FS systems.

NOTE 1: Some ETSI standards do not contain the "CW interference" requirement. For these cases the generic criteria of EN 301 390 [4] can be applied.

This methodology derives receiver selectivity limits, shown in figure E.1, and follows the relationship:

$$RXattenuation_{\text{(asymptotic)}}[dB] = C/I_{\text{(at 1 dB }10^{-6}\text{ co-channel degradation)}} - C/I_{\text{(as given by CW interference requirement)}} \quad \text{(E.1)}$$

The theoretical overall Rx selectivity mask in the shaded area of figure E.1 may be taken as a conservative value for any system. Of course the derivation of NFD levels can be calculated using the manufacturers guaranteed receiver selectivity mask.

NOTE 2: It should be remembered that some systems require separate mask profiles. For example, where a technical standard provides different criteria for innermost channels these masks are not used to define Net Frequency Discrimination.

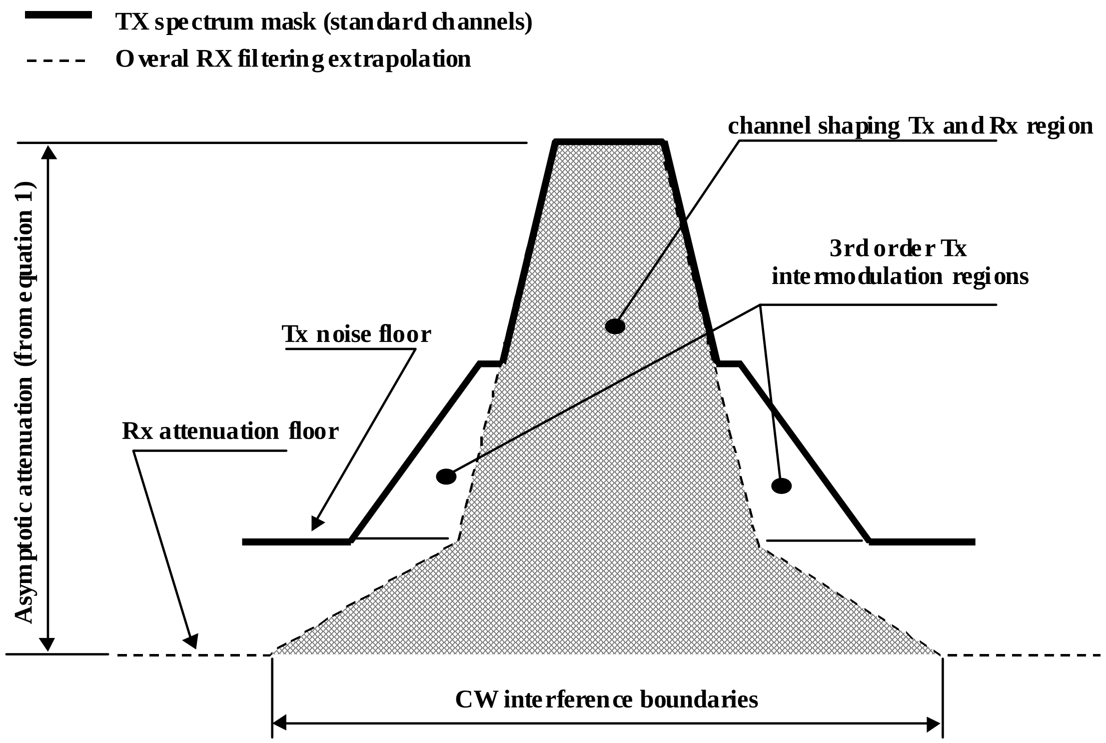


Figure E.1: Deriving the receiver filter selectivity from the transmitter spectrum mask and CW interference sensitivity requirement

NOTE 3: It should be noted that this approach is a worst case scenario. It will not fulfill the adjacent channel requirement stated in the corresponding ETSI-standard for like-systems but it can be used for worst-case calculations between unlike-systems or different equipment classes.

Annex F: Receiver selectivity (more realistic approach)

In this annex F a more realistic approach is used. The evaluation is based on Nyquist-filters in the transmit- and in the receiver path.

NOTE: It should be noted that the resulting transmitter-mask and receiver selectivity are theoretical values. Using this approach may still lead to interference between real unlike-systems or equipment classes (because of the use of typical values).

F.1 Gross bit-rate

First the gross bit-rate has do be determined. The gross bit-rate is the payload, multiplied with an overhead-factor. This overhead-factor depends on the payload (see table F.1).

This overhead-factor includes all non-payload information.

Table F.1: overhead

Payload (Mbit/s)	4	8	16	34	51	2 x 34	155
Overhead-factor (%)	10… 20	10 … 20	10 … 20	10 … 20	5 … 20	5 … 15	5 … 10

With the values given in table F.1 the total gross bit-rate is calculated as:

$$\text{Gross bit-rate GBR} = payload \times \frac{100 + overhead}{100} \qquad \text{(F.1)}$$

F.2 Derivation of transmitter spectrum mask

The second step is to derive a typical transmitter spectrum mask. To derive this mask the following parameters have to be specified:

Channel spacing CS

Gross bit-rate GBR — see clause F.1

Modulation scheme N — where N = modulation order 2^N, (e.g. 4 for 16 QAM)

Nyquist frequency f_n — where f_n = 0,5 x Symbol rate = $\frac{Grossbitrate}{2 \times N}$ (F.2)

Cosine roll-off factor r_{of} — see also clause F.4

The time signal of the pulse transmission (practical a rectangular random-data source) is transformed in the frequency domain and filtered by a root raised cosine filter. The mathematical formula for the transfer function of the magnitude of $H_{Tx}(f)$ and $H_{Rx}(f)$ for the theoretical Nyquist channel is defined by the equation:

$$H_{Total}(f)^2 = \begin{cases} 1 & f < f_n(1-r_{of}) \\ 0{,}5 \times \left(1 + \cos\left[\frac{\pi}{2 \times r_{of}}\left(\frac{f}{f_n} - 1 + r_{of}\right)\right]\right) & f_n(1-r_{of}) \le f \le f_n(1+r_{of}) \\ 0 & f > f_n(1+r_{of}) \end{cases} \qquad \text{(F.3)}$$

For the transmitter resp. receiver filtering it can be derived:

$$H_{TX}(f) = H_{RX}(f) = \sqrt{H_{Total}(f)^2} = \begin{cases} 1 & f < f_n(1-r_{of}) \\ \frac{1}{\sqrt{2}}\sqrt{1+\cos\left[\frac{\pi}{2\times r_{of}}\left(\frac{f}{f_n}-1+r_{of}\right)\right]} & f_n(1-r_{of}) \le f \le f_n(1+r_{of}) \\ 0 & f > f_n(1+r_{of}) \end{cases} \quad \text{(F.4)}$$

The course of the spectrum follows the pulse response in the frequency domain with a cosine roll-off factor selected to tangent the Tx spectrum mask until the attenuation reaches the starting level of the intermodulation region (see point T1 in figure F.1). This point may be taken from the transmitter spectrum mask of the relevant standard. From this point a straight line is drawn to the point of intersection of the spectrum mask with the mask noise floor (point T2). The mask noise floor is given in any product standard. This diagram must remain always below the spectrum mask in the relevant standard.

Figure F.1 shows a typical transmitter spectrum.

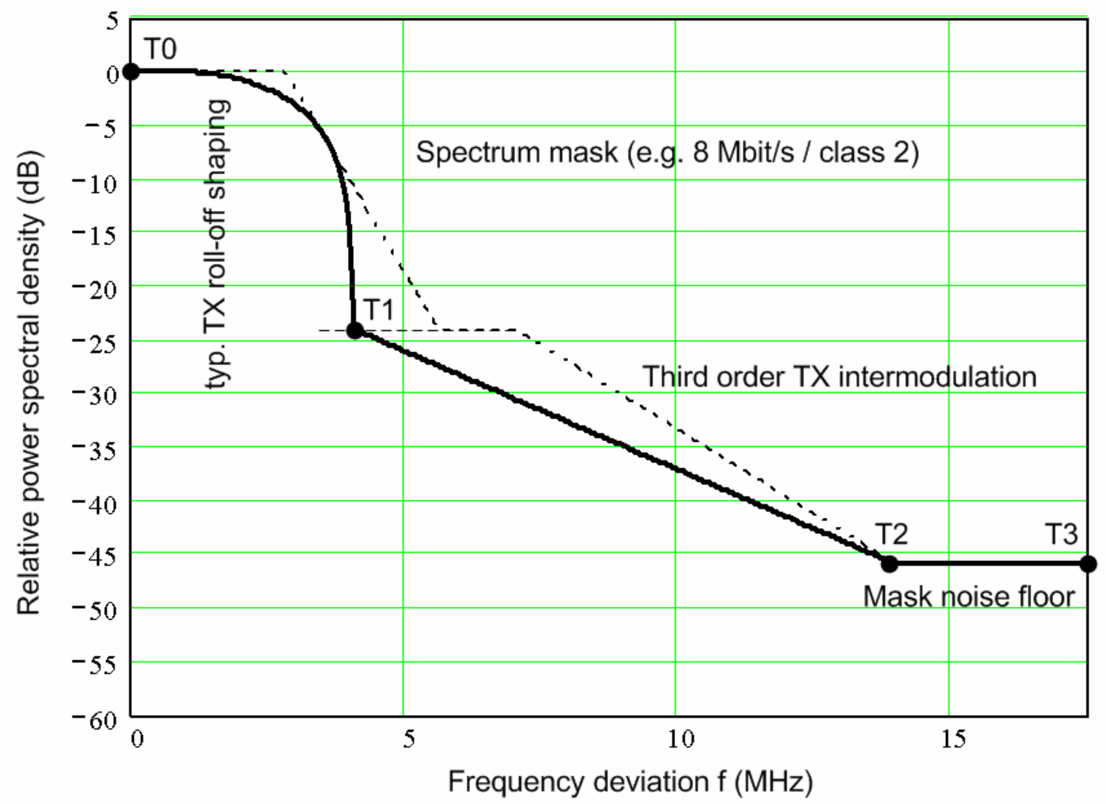


Figure F.1: Typical transmitter spectrum

Table F.2 shows the corner points of figure F.1.

Table F.2: Reference points for the typical transmitter spectrum

Reference points	Frequency deviation [f]	Relative power spectral density [dB]	Course of the spectrum
T0	0	K1 according EN	Square Root Nyquist filtering
T1	Cosine roll-off selected to tangent Tx spectrum mask	Starting level of the intermodulation region	Straight line
T2	Intersection of Tx mask with noise floor	Mask noise floor	Straight line
T3	2,5 x CS	Mask noise floor	

F.3 Derivation of receiver selectivity

For the receiver side the filter is similar. The receiver filter is a combination of a Nyquist filter and 2 straight lines until the limits of 2,5 x channel bandwidth. As figure F.2 shows the receiver selectivity follows the Nyquist filtering until the attenuation achieves halve the way between the starting level of Tx intermodulation region and Tx mask floor. From this point a straight line is drawn to the point of intersection of the extension of the first part of Tx-mask with the Rx asymptotic attenuation and from there a horizontal line up to 2,5 x CS. The value of Rx asymptotic attenuation has to be taken from the relevant standard. In the absence of the "CW-Interference" requirement this requirement may be taken from the generic standard EN 301 390 [4].

$$\text{Rx attenuation}_{(asymptotic)}\ [\text{dB}] = \text{C/I}_{\ (at\ 1\ dB\ 10^{-6}\ co\text{-}channel\ degradation)} - \text{C/I}_{\ (as\ given\ by\ CW\ interference\ requirement)} \quad (F.5)$$

For the Rx cosine roll-off factor, the same value as calculated for the transmitter mask is used.

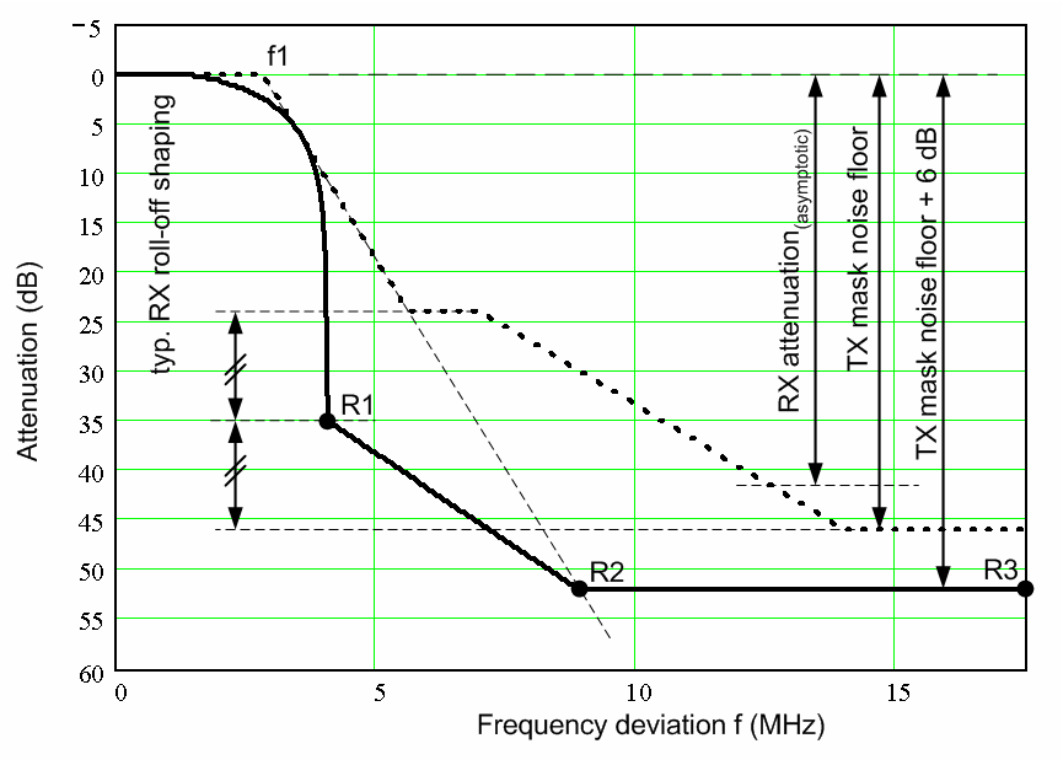


Figure F.2: Typical receiver selectivity

Table F.3 shows the corner points of figure F.2.

Table F.3: Reference points for the typical receiver selectivity

Reference points	Frequency deviation [f]	Attenuation of the receiver filter [dB]	Course of the selectivity
R0	0	K1 according EN	Square Root Nyquist filtering
R1	Cosine roll-off selected to tangent Tx spectrum mask	Half the way between starting level of intermodulation region and Tx mask noise floor	Straight line
R2	Intersection point between the line starting at corner point f1 extended to cross the corner point indicating the beginning of the intermodulation region and crossing the Rx attenuation$_{(asymptotic)}$ or Tx mask noise floor + 6 dB	Rx attenuation$_{(asymptotic)}$ or (Tx mask noise floor + 6 dB) whichever is more stringent	Straight line
R3	2,5 x CS	Rx attenuation$_{(asymptotic)}$ or (Tx mask noise floor + 6 dB) whichever is more stringent	

F.4 Derivation of cosine roll-off

The net filter discrimination (see clause 4.2.4) for the first adjacent channel, calculated with the parameters above (transmitter spectrum mask and receiver selectivity), has to comply with the requirements of the relevant standard.

If the net filter discrimination for the first adjacent channel does not comply with the requirement in the relevant standard, the cosine roll-off factor of both transmitter spectrum mask and receiver selectivity has to be changed by the same amount until the minimum requirement is met (for like-systems).

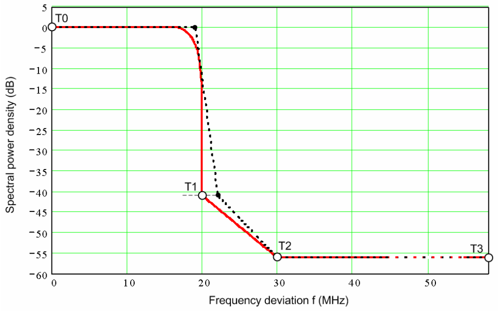
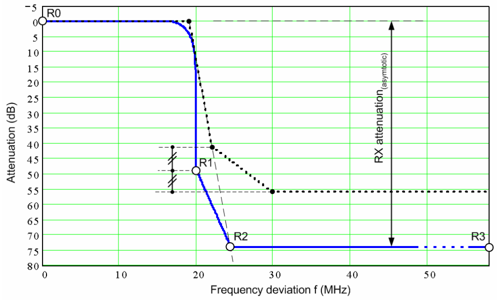
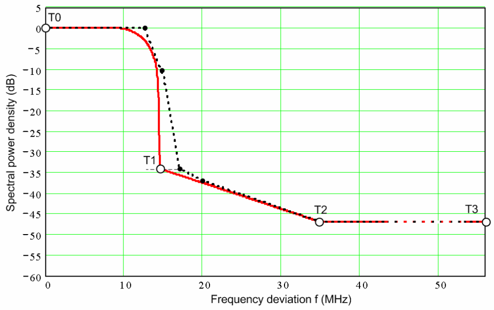
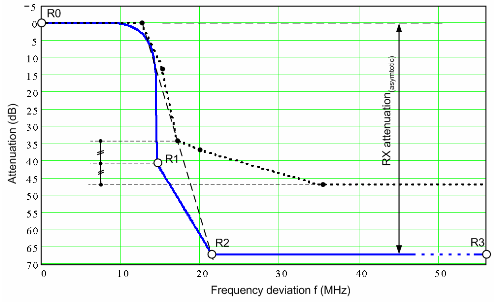
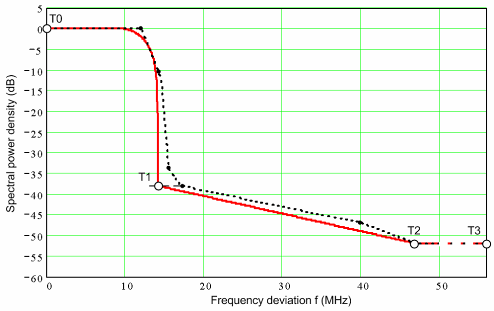
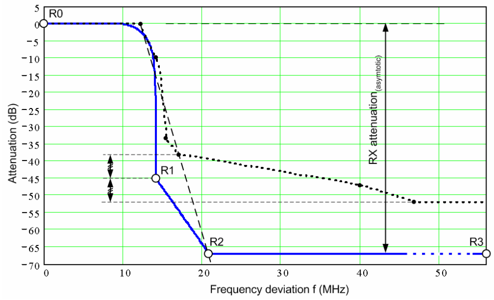
If the net filter discrimination for the first adjacent channel is already met with the parameters calculated above then the cosine roll-off factor of the receiver may be increased until the requirement for the first adjacent channel in the relevant standard is met.

The resulting transmitter spectrum mask and receiver selectivity may now be used to calculate net filter discrimination between equipment of different spectrum efficiency classes and systems (unlike-systems).

F.5 Transmitter mask and receiver selectivity of other equipment classes

The following table F.4 shows the similar approach for other system classes.

Table F.4

	Transmitter mask	Receiver selectivity
4-segment spectrum mask		
5-segment spectrum mask	See example in clauses F.2 and F.3	
6-segment spectrum mask		
7-segment spectrum mask		

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