ETSI TR 101 854 V1.1.1 (2000-09)

Technical Report

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

Reference
DTR/TM-04088

Keywords
Point-to-point, radio, transmission

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Association à but non lucratif enregistrée à la
Sous-Préfecture de Grasse (06) N° 7803/88

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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, in an interference limited assignment system, the assignment criteria between Digital Fixed Service systems, occupying different bandwidths and using different types of modulation is 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.

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.530-8: "Propagation data and prediction methods required for the design of terrestrial line-of-sight systems".

[2] ITU-R Recommendation P.676-4: "Attenuation by atmospheric gases".

[3] ITU-R Recommendation F.1101: "Characteristics of digital radio-relay systems below about 17 GHz".

[4] ITU-R Recommendation F.746-4: "Radio-frequency channel arrangements for radio-relay systems".

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

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
GHz	GigaHertz
Hz	Hertz
K	Boltzmanns Constant
MHz	MegaHertz
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
C/N	Carrier to Noise
CW	Continuous Wave
EIRP	Effective Isotropic Radiated Power
FEC	Forward Error Correction
FS	Fixed Service
FSPL	Free Space Path Loss
IF	Intermediate Frequency
M	Fade Margin
N/I	Noise to Interference
NFD	Net Filter Discrimination
QAM	Quadrature Amplitude Modulation
Rx	Receiver
RF	Radio Frequency
Tx	Transmitter

4 Overview

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

4.1 The Link Budget

A link budget ensures that the Effective Isotropic 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 (BERs) of 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.530-8 [1] and ITU-R Recommendation P.676-4 [2] respectively.

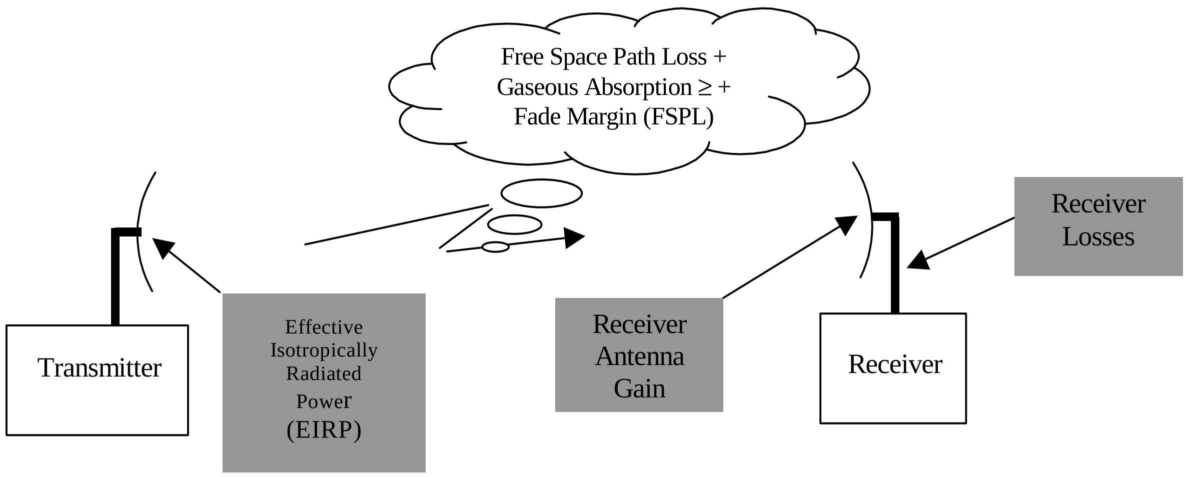

Figure 1: Fixed Link Budget

Rx Reference Sensitivity Level = Tx EIRP – FSPL – Fade Margin – Gaseous Absorption + Rx Antenna Gain - Rx Losses (Antenna to receiver I/P ports)

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 methodology shown in Table 1 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.

Table 1: Example showing the calculation of receiver reference level

Factor	Detail	Example
Channel Bandwidth		14 MHz
Payload rate		Assume 34,368 Mbit/s
Assumes Gross bit rate (including FEC and service channel)	~ 1,1 Payload rate (Systems without FEC) ~1,15 payload rate (Systems with FEC)	Assume system with FEC. ∴Overall bit rate ≈ 1,15 x 34,368 Mbit/s ≈ 39,523 Mbit/s
Assumed Modulation	16 QAM (2^n states, n = 4)	-
Thermal Noise kT (dBW/Hz)	10 log [K (Boltzmann's constant) x T (Thermal Noise in Degrees Kelvin)]	Using T = 288 ∴kT = - 204 dBW/Hz
Rx noise Bandwidth Factor B (dBHz)	10 $\log_{10}$ 1,4 x (Gross bit rate/n)	≈ 10 $\log_{10}$ (34,368 x 10^6/4) x (1 + 0,4) ≈ 70,8 dBHz
Receiver Noise kTB (dBW)	Thermal Noise (kT) + Bandwidth Factor (B)	- 133 dBW
Noise Figure (dB)	Assume 9	9
C/N for BER 10^{-6}	See ITU-R Recommendation F.1101 [3]	20,5
Fixed System Losses	Assume 4	4
FEC improvement for a BER = 10^{-6}	- FEC factor	- 3
Interference Margin (see clause 4.2.2)	Assume 1	1
Reference Sensitivity for 10^{-6} (dBW)	(see European standard)	- 101,5 dBW
Median Rx Input Level (dBW)	(≈ Reference Sensitivity plus calculated fade margin)	- 101,5 + 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.		

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 carefully considered. The correct implementation of the ATPC profile into the assignment process will significantly improve link density.

4.2.2 Wanted to Unwanted 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 signal from a number of sources.

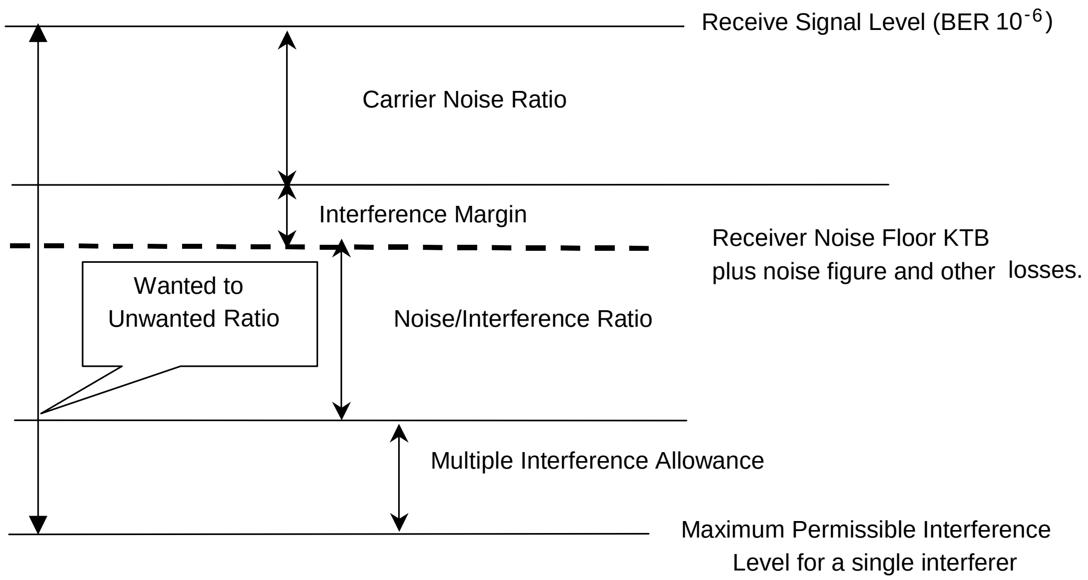

Figure 2: Derivation of Single Interferer Co-channel Interference limit

4.2.3 The 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. By analysing the generic spectrum mask, as shown in Figure 3, 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 [5] can be applied.

This methodology derives receiver selectivity limits, shown in Figure 3, and follows the relationship:

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

The theoretical overall Rx selectivity mask in the shaded area of Figure 3 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 will are not used to define Net Frequency Discrimination.

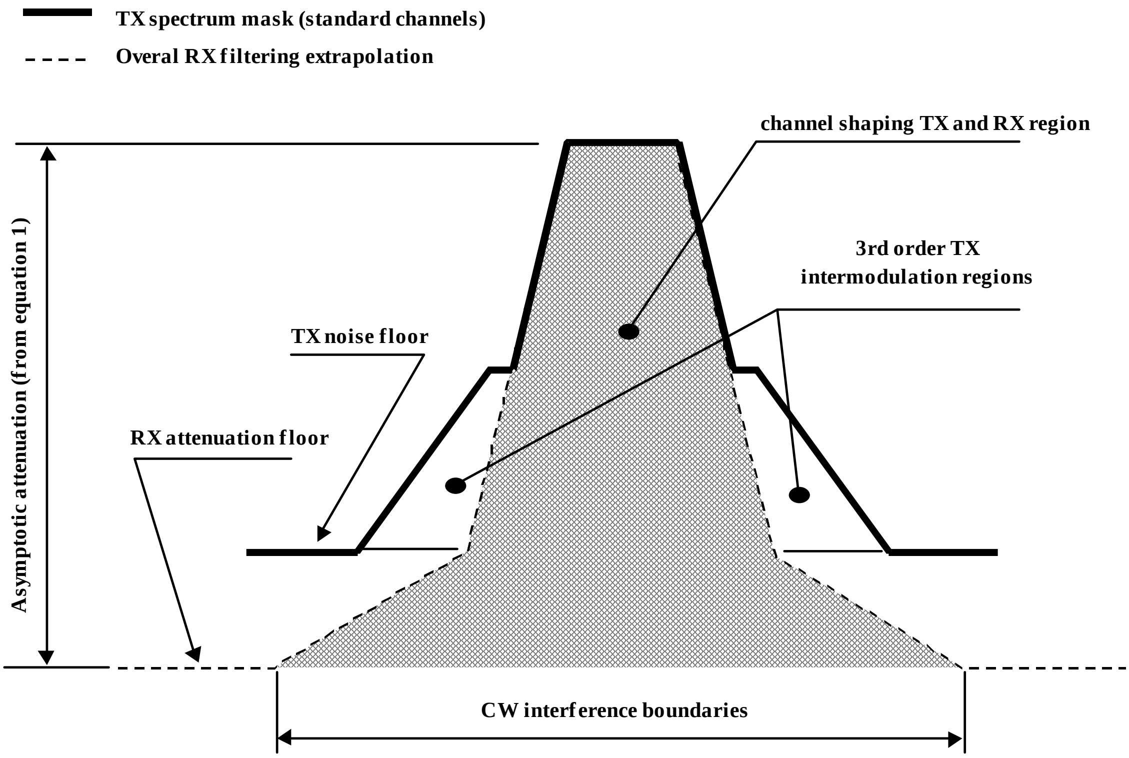

Figure 3: Deriving the Receiver Filter Selectivity from the Transmitter Spectrum Mask and CW Interference Sensitivity Requirement

4.2.4 The 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).

$$\text{NFD} = 10 \log (\text{Pc}/\text{Pa}) \quad (2)$$

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: 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 Recommendation. F 746 [4], 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:

$$NFD = 10 \times \log\left[\sum_{i=0}^{i=n-1} 10^{\frac{(Tci + Rci)/10}{}}\right] / \left[\sum_{i=0}^{i=n-1} 10^{\frac{(Toi + Rci)/10}{}}\right] \quad (3)$$

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:

$$Pa = \sum_{i=0}^{i=n-1} 10^{\frac{(Toi + Rci)/10}{}} \qquad Pc = \sum_{i=0}^{i=n-1} 10^{\frac{(Tci + Rci)/10}{}} \tag{4}$$

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

4.2.5 The Carrier to Interference Ratio (C/I) in Mixed Payload Environment

Figure 4 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.

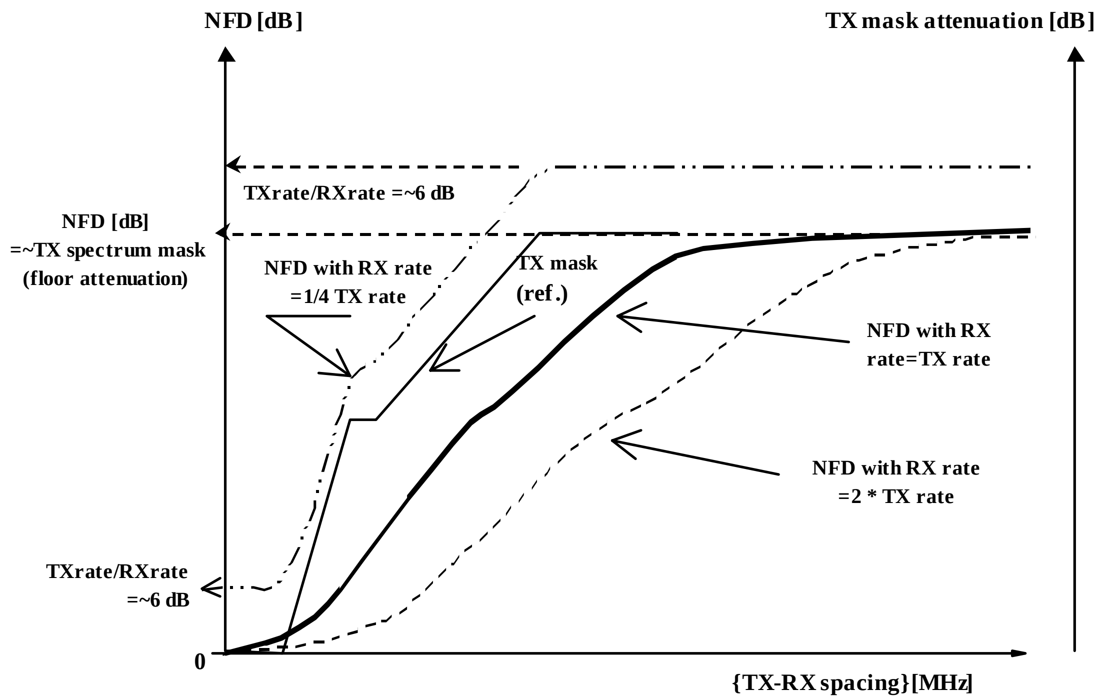

Figure 4: Qualitative examples of mixed NFD among different rate systems of the same class

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 the following clause.

4.2.6 Evaluation of the Wanted to Unwanted 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 effect 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 exceed 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 creates the rejection of a new assignment. The first occurs when the establishment of an additional transmitter causes the accumulative interference level into an established link receiver to exceed the assignment limit. Secondly the new assignment may fail because one, or both ends of the link, is 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 increases in 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 they face.

Annex B: Wanted to Unwanted Ratios

Tables B.1 and B.2, shown as examples, give the wanted to unwanted ratios for two systems 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 ½ 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 BW)	Wanted/Unwanted Ratio (dB) V's Step Size* (See Page 21)																					
		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										

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 BW)	Wanted/Unwanted Ratio (dB) V's Step Size (See Page 21)														
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	2 in 7	-	32	13	- 6	- 26	- 40	All Wanted to Unwanted Ratios in the shaded area are equal to – 40 dB								
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									

Annex C:
Diagram showing the NFD procedure

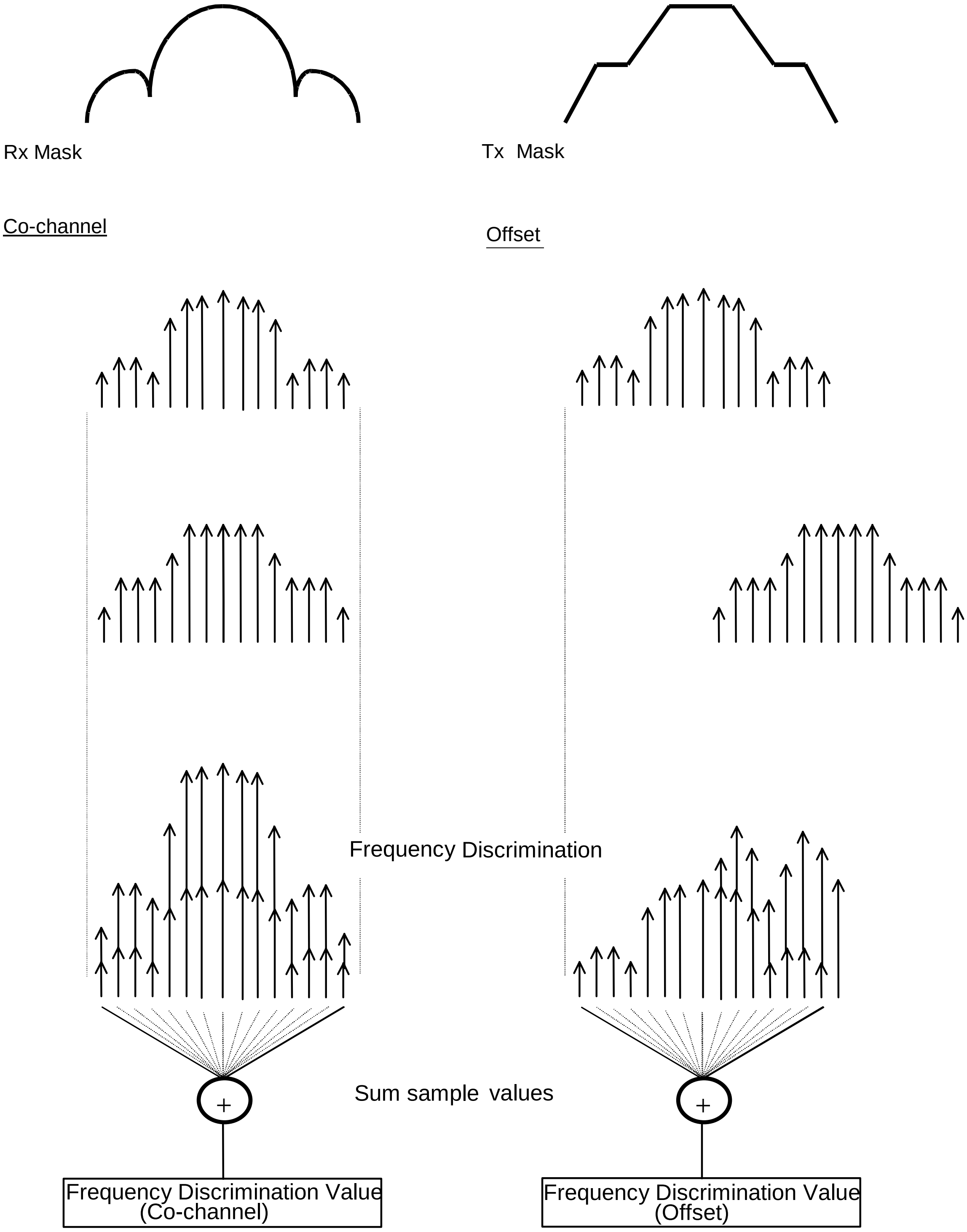

Figure C.1

History

Document history		
V1.1.1	September 2000	Publication