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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Access, Terminals, Transmission and Multiplexing (ATTM).

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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

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

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

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

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

[i.4] Recommendation ITU-R SM.328-11: "Spectra and bandwidth of emissions".

[i.5] ETSI EN 302 217-2: "Fixed Radio Systems; Characteristics and requirements for point-to-point equipment and antennas; Part 2: Digital systems operating in frequency bands from 1 GHz to 86 GHz;Harmonised Standard for access to radio spectrum of article 3.2 of Directive 2014/53/EU".

[i.6] ETSI TR 103 053 (V1.1.1) (2014-09): "Fixed Radio Systems; Parameters affecting the Signal-to-Noise Ratio (SNR)and the Receiver Signal Level (RSL) threshold in point-to-point receivers; Theory and practice".

[i.7] ETSI EN 302 217-1: "Fixed Radio Systems; Characteristics and requirements for point-to-point equipment and antennas; Part 1: Overview, common characteristics and system-independent requirements".

[i.8] ETSI TR 103 103: "Fixed Radio Systems; Point-to-point systems; ATPC, RTPC, Adaptive Modulation (mixed-mode) and Bandwidth Adaptive functionalities; Technical background and impact on deployment, link design and coordination".

[i.9] ETSI GR mWT 015: "Frequency Bands and Carrier Aggregation Systems; Band and Carrier Aggregation".

[i.10] ECC/REC(01)05: "List of parameters of digital point-to-point fixed radio links used for national planning".

[i.11] Recommendation ITU-R F.758: "System parameters and considerations in the development of criteria for sharing or compatibility between digital fixed wireless systems in the fixed service and systems in other services and other sources of interference".

3 Definition of terms, symbols and abbreviations

3.1 Terms

Void.

3.2 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

3.3 Abbreviations

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

ACM	Adaptive Code and Modulation
ATPC	Automatic Transmit Power Control
BB	BroadBand
BCA	Bands and Carriers Aggregation
BER	Bit Error Rate
BW(U)	BandWidth Unwanted
BW(W)	BandWidth Wanted
C/I	Carrier to Interference
CCDP	Co-Channel Dual Polarization
CPM	Continuous Phase Modulation
CS	Channel Spacing
CW	Continuous Wave
EIRP	Equivalent Isotropically Radiated Power
FEC	Forward Error Correction
FET	Field-Effect Transistor
FM	Fade Margin
FS	Fixed Service
FSPL	Free Space Path Loss
GBR	Gross Bit-Rate
GR	Group Report

IF	Intermediate Frequency
IM_F	Industrial Margin
ITU-R	International Telecommunication Union - Radio sector (formerly CCIR)
N/I	Noise to Interference
NF	Noise Figure
NFD	Net Filter Discrimination
PDH	Plesiochronous Digital Hierarchy
QAM	Quadrature Amplitude Modulation
RE	Radio Equipment
RF	Radio Frequency
RIC	Radio Interface Capacity
RS	Reed–Solomon
RSL	Receive Signal Level
Rx	Receiver
S/N	Signal to Noise
SDH	Synchronous Digital Hierarchy
STM	Synchronous Transport Module
Tx	Transmitter
W/U	Wanted to Unwanted
XPD	Cross-Polar Discrimination

4 Overview of fundamental approach to noise limited assignments

4.1 The Link Budget

4.1.1 Introduction

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 desired availability (usually at least 99,99 % of time are commonly used as service levels, see note 1). 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 Recommendation ITU-R P.530 [i.1] and Recommendation ITU-R P.676 [i.2] respectively.

NOTE 1: In modern digital systems implementing Adaptive Code and Modulation (ACM, "mixed-mode" systems defined in ETSI EN 302 217-1 [i.7] and better described in ETSI TR 103 103 [i.8]) such availability is usually applied for the "reference mode" used for planning purpose. In some cases, a lower availability might also be acceptable, e.g. in Bands and Carriers Aggregation (BCA systems described in ETSI GR mWT 015 [i.9]) systems where high availability is guaranteed by the carrier(s) in the lower band, while the carrier(s) in the higher band might not physically exhibit sufficient fade margin for that; therefore, lower availability (best effort) is still acceptable for their "supplementary" payload.

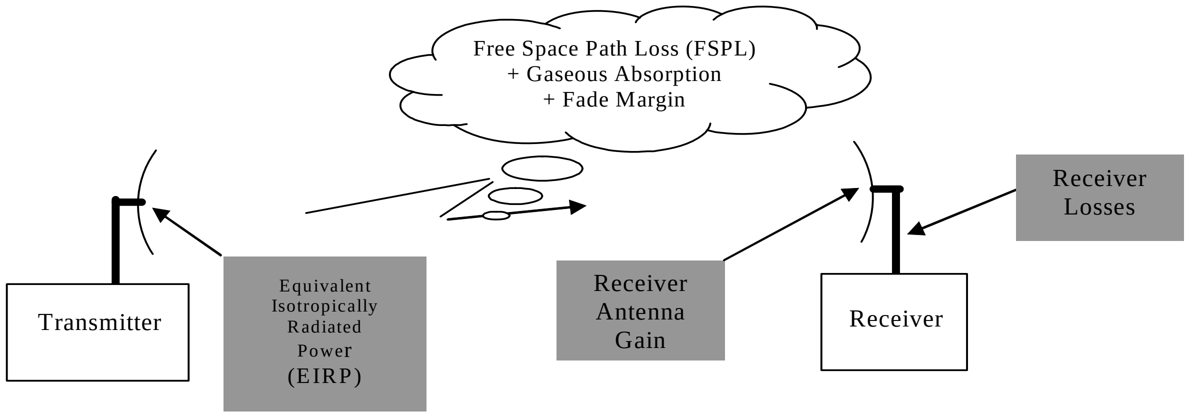

Figure 1: Fixed Link Budget

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.

NOTE 2: Rx Losses are typically due to feeder losses connecting antenna port to indoor Rx equipment; when outdoor equipment front ends are concerned, no Rx losses are usually present.

4.1.2 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
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
Median Rx Input Level (dBW)	≈ RSL plus calculated fade margin	-102 + FM

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:

$$RSL_{norm}(dBm/MHz) = -114 + Noise\ Figure + 10 * log_{10}(Symbol\ Rate) + \left(\frac{S}{N}\right) \quad (1)$$

where Noise Figure NF = 0 dB

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

$$RSL\ (dBm) = RSL_{norm} + 10 * log_{10}(B_{MHz}) + NF + IM_F + IM_S \quad (2)$$

where:

$IM_F =$ Noise Figure Industrial Margin in dB

$IM_s =$ S/N Industrial Margin in dB

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 of the system coding examples shown, one based on a BER = 10^{-3} and one based on a BER = 10^{-6} (derived from ETSI TR 103 053 [i.6], from table contained in archive tr_103053v010101p0).

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 3	~4	+3
3 to 5	~5	+3
6 to 15	~5	+3
18 to 23	~6	+3
26 to 28	~7	+3
32	~7	+3
38 to 42	~8	+3
48 to 50	~9	+3
52 to 55	~10	+3
71 to 76 / 81 to 86	~13	+4

Table 3: Examples of 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
RSL at BER = 10^{-3} (see note 2)	-103,5	-104,8	-106,0	-107,2	-101,8	-106,0	-99,5	-104,6	-97,3	-101,3	-94,9	-98,0	-95,0
RSL at BER = 10^{-6} (see note 2)	-99,5	-102,8	-102,8	-106,3	-98,7	-105,5	-96,0	-103,4	-93,8	-100,7	-91,1	-97,0	-93,7

B = Payload Bit-rate

NOTE 1: Technical background for Continuous Phase Modulation (CPM) formats may be found in ITU-R Recommendation SM.328-11 [i.4].
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).

4.1.3 Fade margin (FM)

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 margin is dependent on frequency, path length and level of service availability required (see clause 4.1).

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, ERC/REC(01)05 [i.10] gives common guidelines on limits for use in typical link planning. 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.

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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.

When link is first planned in absence of any significant interference ($W/U \rightarrow \infty$), the inclusion of a multiple interferer allowance may be appropriate. This additional protection takes into account the fact that the victim receiver is very likely, in future, to experience new interference signals from a number of sources, in particular from multiple FS links in the same co-ordination zone (e.g. interference margin up to 3 dB as provided by ECC/REC(01)05 [i.10]), but also from emissions from other services sharing the same band; the latter contribution, if any, is defined by specific sharing studies, based on Recommendation ITU-R F.758 [i.11], which, in most cases, are based on a globally permitted $I/N \leq -10$ dB, that would imply an additional protection of 0,5 dB.