Electronic Communications Committee (ECC)
within the European Conference of Postal and Telecommunications Administrations (CEPT)

COMPATIBILITY OF EARTH STATIONS ON BOARD VESSELS TRANSMITTING WITHIN THE GAPS IN THE CEPT FIXED SERVICE CHANNEL PLAN FOR THE LOWER 6 GHz BAND (5 925-6 425 MHz)

Lübeck, September 2006

EXECUTIVE SUMMARY

This ECC Report addresses the issue of examining the feasibility of Earth Stations on-board Vessels (ESV) operation in the Fixed Service (FS) channel plan gaps in the lower 6 GHz frequency band (alias L6) from 5 925 MHz to 6 425 MHz.

The guidance in this report is intended for Administrations wishing to develop regulations to facilitate ESV operation closer than the 300 km regulatory exclusion limit from their coastlines, for the L6 band.

Realistic sharing scenarios were identified; however it was not possible to consider all configurations of the FS receiver (FSR) and ESV characteristics and locations. Nevertheless with some restrictions on the ESV operational conditions, minimum distances of the ESV from coast and minimum distances from the FSRs were determined for a large range of ESV and FSR characteristics and locations (See Table 16 and **Table 17** in § 6, and § 7 Conclusions).

The present report describes the methodology used and provides the results for range of input parameters, from which an administration may select the most appropriate of described cases to derive the distance limits, or apply the given methodology to deal with other specific cases.

It should be also noted that the approach proposed in this report in general complies with the terms of ITU Resolution 902 (WRC-2003) in that it constitutes a basis for ‘prior agreement’, but only for those administrations that accept the terms of the report (see Clause 4, Annex 1, Res. 902). However administrations are under no obligation to accept the terms of this report and may continue to require compliance with the more restrictive limitations given in the resolution. It was made known during approval of this report that some CEPT administrations do not intend accepting the proposed measures and will continue using the original provisions of Resolution 902 (WRC-2003).

In particular, when considering the protection of primary Fixed Service systems in the lower 6 GHz band (5925-6425 MHz), administrations, if they so wish, have the sovereign right to retain the limits on ESV operation given in ’Resolution 902 (WRC-03), as expressed in the following extract from its Annex 1, item 10:

“When ESVs operating beyond the territorial sea but within the minimum distance (300 km from the coastline) fail to comply with the terms required by the concerned administration pursuant to items 2 and 4, then that administration may:

- request the ESV to comply with such terms or cease operation immediately; or
- request the licensing administration to require such compliance or immediate cessation of the operation.”

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1 INTRODUCTION

WRC-03 adopted Resolution 902 [1] which prohibits Earth Stations aboard Vessels (ESV) transmissions within 300 km from the low water mark as officially recognised by the administration of the coastal state, in the lower 6 GHz band (alias L6 band) from 5 925 MHz to 6 425 MHz, unless prior agreement is obtained from the concerned administration. These restrictions are necessary to protect the Fixed Service (FS) in the same band from co-channel interference from the ESVs.

ECC decision (05)09 [2] and ECC decision (05)10 [3] were adopted to facilitate the free circulation and use of ESVs operating respectively within the 6/4 GHz frequency bands and within the 14/12 GHz frequency bands.

ECC adopted Report 069 [4] recommends formats for submission of information from administrations to the Office on their requirements for operation of ESVs within the separation distances identified in ITU-R Resolution 902 (WRC-03) [1].

Unlike the Ku band where the 14 – 14.25 GHz frequency band is not used by FS in Europe, the L6 band is extensively used by FS in Europe for long haul high capacity links which can not be accommodated in the higher frequency bands.

Due to:

- the global coverage of the satellites in the L6 band used by long distance ESVs;
- the continued growth of capacity needs for ESV networks;
- the requirement for bandwidth with "always on" capability;
- an increased desire to operate closer to the coastlines than 300 km in this band.

it is necessary to explore parts of the L6 band that are not used by FS in Europe. Such radio spectrum was identified to be the gaps in the L6 CEPT FS channel plan.

The ERC Recommendation 14-01 [5] gives the channel plan for the L6 band which provides for 8 x 29.65 MHz channels between 5 930.375 MHz and 6 167.575 MHz and a further 8 x 29.65 MHz channels between 6 182.415 MHz and 6 419.615 MHz, as shown in Figure 1 below.

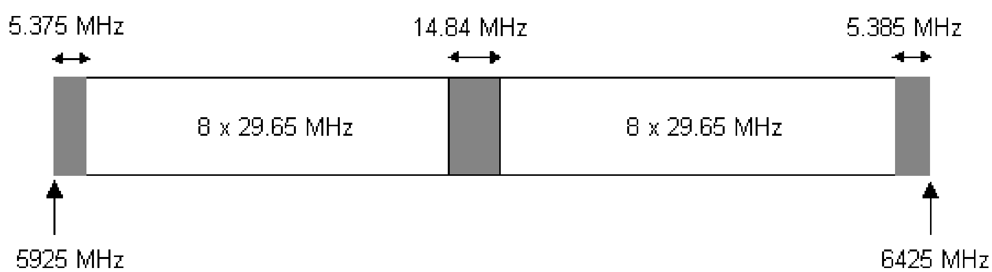


Figure 1: ERC Recommendation 14-01 channel plan

This leaves the following spectrum potentially available for use by ESVs:

Lower gap: 5 925.000 to 5 930.375MHz (5.375 MHz bandwidth)

Centre gap: 6 167.575 to 6 182.415 MHz (14.84 MHz bandwidth)

Upper gap: 6 419.615 to 6 425.000 MHz[1] (5.385 MHz bandwidth).

The ESVs are moving and create a different interference scenario than fixed earth stations, making impractical the usual coordination on a case by case basis between ESVs and FS.

Therefore this report examines the feasibility of ESV operation in the channel plan gaps within the 300 km regulatory exclusion zone without the need for detailed coordination, while maintaining the FS protection requirements.

[1] In the UK, the upper gap is used by an old FS channel plan.

In the remainder of this report, the details of representative ESV and FS system characteristics employed in the interference modelling are outlined. This is followed by a description of the interference analysis methodology and sharing scenarios. The results of the analysis are then provided. Finally, the key conclusions of the work are presented.

The guidance in this report is intended for Administrations wishing to develop regulations facilitating ESVs' operation closer than the 300 km regulatory exclusion limit from their coastlines, for the L6 band.

2 REFERENCES

The present document makes reference to the following documents:

[1] Resolution 902 (WRC-03): "Provisions relating to earth stations located on board vessels which operate in fixed-satellite service networks in the uplink bands 5 925 - 6 425 MHz and 14 - 14.5 GHz"

[2] ECC/DEC/(05)09: "ECC Decision of 24 June 2005 on the free circulation and use of Earth Stations on board Vessels operating in Fixed Satellite service networks in the frequency bands 5 925-6 425 MHz (Earth-to-space) and 3 700-4 200 MHz (space-to-Earth)"

[3] ECC/DEC/(05)10: "ECC Decision of 24 June 2005 on the free circulation and use of Earth Stations on board Vessels operating in fixed satellite service networks in the frequency bands 14-14.5 GHz (Earth-to-space), 10.7-11.7 GHz (space-to-Earth) and 12.5-12.75 GHz (space-to-Earth)"

[4] ECC Report 069: "Formats for submission of information from administrations to the Office on conditions for operation of Earth stations aboard vessels within the separation distances identified in ITU-R Resolution 902"

[5] ERC Recommendation 14-01(ERC/REC 14-01): "Radio-frequency channel arrangements for high capacity analogue and digital radio-relay systems operating in the band 5 925 MHz - 6 425 MHz"

[6] ITU-R Recommendation SF.1650: "The minimum distance from the baseline beyond which in-motion earth stations located on board vessels would not cause unacceptable interference to the terrestrial service in the bands 5 925-6 425 MHz and 14-14.5 GHz"

[7] ITU-R Recommendation P.452-7: "Prediction procedure for the evaluation of microwave interference between stations on the surface of the earth at frequencies above about 0.7 GHz"

[8] ITU-R Recommendation F.1245: "Mathematical model of average radiation patterns for line-of-sight point-to-point radio-relay system antennas for use in certain coordination studies and interference assessment in the frequency range from 1 to about 40 GHz"

[9] IESS 308: "Intelsat Earth Station Standards (IESS); Performance characteristics for intermediate data rate digital carriers using convolutional encoding/Viterbi encoding and QPSK modulation (QPSK/IDR)"

[10] IESS 309: "Intelsat Earth Station Standards (IESS); Performance characteristics for Intelsat business services (IBS) (Standard A, B, C, E, F, H and K Earth Stations)"

[11] EN 301 447: "ETSI Candidate Harmonized European Standard (Telecommunications series); Satellite Earth Stations and Systems (SES); Harmonized EN for satellite Earth Stations on board Vessels (ESVs) operating in the 4/6 GHz frequency bands allocated to the Fixed Satellite Service (FSS) covering essential requirements under article 3.2 of the R&TTE directive"

[12] EN 302 217-2-2: " ETSI Candidate Harmonized European Standard (Telecommunications series); Fixed Radio Systems; Characteristics and requirements for point to point equipment and antennas; Part 2-2: Harmonized EN covering essential requirements of Article 3.2 of R&TTE Directive for digital systems operating in frequency bands where frequency co ordination is applied"

[13] TR 101 854: "ETSI 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"

[14] ERC Recommendation 14-02 (ERC/REC 14-02): "Radio-frequency channel arrangements for medium and high capacity analogue or high capacity digital radio-relay systems operating in the band 6 425 MHz - 7 125 MHz"

[15] EESS 500: "Eutelsat Satellite Multiservice System (SMS) earth station standard (Standard S)"

[16] IESS 601: "Intelsat Earth Station Standards (IESS); Standard G performance characteristics for earth stations accessing the Intelsat space segment for international and domestic services not covered by other earth station standards (6/4, 14/11 and 14/12 GHz).

3 DEFINITIONS

For the purpose of the present document the following definitions apply:

altitude: altitude is defined above the mean sea level

height: height is defined above the ground level

4 ABBREVIATIONS AND ACRONYMS

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

Â	angle between the moving ESV direction and the FSR antenna main beam axis
BER	Bit Error Ratio
BPSK	Binary Phase Shift Keying
CCDP	Co Channel Dual Polarized
CEPT	Conference Européenne des Postes et Télécommunications
CS	Channel Spacing
CW	Carrier Wave
d_c	minimum distance of the ESV to the coast
drc	distance of the receiver (i.e. the FSR) to the coast
d_0	minimum distance of the ESV to the FSR
df	guard-band between the Fs channel and the ESV carrier
ECC	Electronic Communications Committee (of CEPT)
e.i.r.p.	Equivalent Isotropically Radiated Power
EESS	Eutelsat Earth Station Standard
EN	European Norm (standard)
ES	Errored Second
ESV	Earth Station on board a Vessel
ETSI	European Telecommunication Standardisation Institute
FEC	Forward Error Correction
FS	Fixed Service
FSL	Free Space Loss
FSR	Fixed Service Receiver
FSS	Fixed Satellite Service
GIBO	Global Input Back-Off
GLG	ESV Gain - Propagation Loss + FSR Gain
HPA	High Power Amplifier
HPBW	Half Power BeamWidth
IBO	Input Back-Off
IESS	Intelsat Earth Station Standards
IF	Intermediate Frequency
ITU	International Telecommunication Union
ITU-R	ITU Radiocommunications standardization sector
LNA	Low Noise Amplifier
LO	Local Oscillator
LT_{Ag}	Long Term - Aggregate criterion
LT_{SI}	Long Term criterion for a single interferer
nPSK	n states Phase Shift Keying
PhN	Phase Noise floor
p.s.d.	power spectral density
QAM	Quadrature Amplitude Modulation
QPSK	Quadratic Phase Shift Keying
modem	MOdulator/DEModulator
NFD	Net Filter Discrimination
Rx	Receive
SES	Severely Errored Second
SI	Single Interferer criterion

SLL	Side Lobes Levels
STM-1	Synchronous Transport Module Level 1 (155,520 Mbit/s)
STM-4	Synchronous Transport Module Level 4 (622,080 Mbit/s)
ST_{ES}	Short Term interference criterion for Errored Seconds
ST_{SES}	Short Term interference criterion for Severely Errored Seconds
TR	ETSI Technical Report
Tx	Transmit
WRC	World Radiocommunication Conference

5 NOTATIONS

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

Title	Green cell of a table containing a title or a label
Constant	Brown cell of a table containing a constant
Data	Yellow cell of a table containing an input data
Result	Blue cell of a table containing a computed result

$a == b + c$ means "a" is equal to "b" plus "c" by definition

$a = b + c$ means "a" is equal to "b" plus "c" by deduction

$a := a + b$ means that the new value of "a" is equal to the previous value of "a" plus "b"

$Int(x)$ function giving the value of the closest integer less than or equal to the value of the variable x

Examples: $Int(+3{,}14) = +3;$ $Int(-3{,}14) = -4$ $-Int(-3{,}14) = +4$

$Max(x_1, x_2, ..., x_n)$ function giving the maximum value of the variables $x_1, x_2, ..., x_n$

$Min(x_1, x_2, ..., x_n)$ function giving the minimum value of the variables $x_1, x_2, ..., x_n$

$\delta(x)$ Dirac function of the variable x

$\mathcal{F}(g(x), f)$ Fourier transform of the function $g(x)$:

(1) : $$\mathcal{F}(g(x), f) == \int_{x=-\infty}^{x=+\infty} g(x).e^{i.2.\pi.f.x}.dx$$

$\mathcal{F}^{-1}(G(f), x)$ inverse Fourier transform of the function $G(f)$:

(2) : $$\mathcal{F}^{-1}(G(f), x) == \int_{f=-\infty}^{f=+\infty} G(f).e^{-i.2.\pi.f.x}.df$$

$FFT(.)$ Fast Fourier Transform

$FFT^{-1}(.)$ inverse Fast Fourier Transform

6 METHODOLOGY

6.1 Interference to an FSR from an ESV

6.1.1 Maximum acceptable levels of interference (I_{max}) and interference criteria

The level of interference (I_{max}) which may not be exceeded for more than a given percentage of the time is defined with the maximum value $\left(\frac{I}{N}\right)_{\max}$ of the ratio $\left(\frac{I}{N}\right)$ where N is the equivalent noise level of the FSR receiver at the antenna flange, and I is the level of interference received by the FSR from an ESV, at the FSR antenna flange:

(3) : $$\boxed{I_{\max} = N.\left(\frac{I}{N}\right)_{\max}}$$

The value of N is given by the following equation:

(4) : $$\boxed{N = k.\left(T_{Antenna} + L_{Feeder}.\left(F_{LNA} - 1\right).T_0 + T_0.\left(L_{Feeder} - 1\right)\right).B_{FSR}}$$

and the system temperature is:

(5) : $$\boxed{T_S = T_{Antenna} + L_{Feeder}.\left(F_{LNA} - 1\right).T_0 + T_0.\left(L_{Feeder} - 1\right)}$$

where:

k is the Boltzmann's constant (k = -228.6 dBW/K/Hz),

F_{LNA} is the FSR Low Noise Amplifier (LNA) noise factor corresponding to the noise figure 10*log(F_{LNA}) in dBs,

T_0 is the reference temperature (T_0 = 290 K),

$T_{Antenna}$ is FSR antenna temperature,

B_{FSR} is the FSR receiver noise bandwidth,

L_{Feeder} is the FSR antenna feeder loss ($L_{Feeder} \geq 1$).

The following typical values are used

FS Receiver (FSR)	
Antenna temperature	300 K
Feeder loss	3 dB
Receiver noise figure	4.125 dB
Receiver bandwidth	22 906 kHz
FSR noise temperature	750 K
FSR system temperature	2 085 K
N	-121.81 dBW

Table 1: FSR noise level at the antenna flange

In order to limit adjacent channel interference to the FS, some offset between the edge of a gap in the FS channel plan and the nearest ESV carrier will be needed. The receiver bandwidth which will be used to determine the required frequency offset (*df*) which yields an NFD of at least 35 dB is the receiver bandwidth of FS carrier type S1 with a 40% roll-off (see in section 6.3.2.3). As can be seen in Figure 16 to Figure 24 this receiver bandwidth is applicable for frequency offset (*df*) greater than 1.4 MHz to 1.7 MHz depending on the limitations on the ESV e.i.r.p. and the e.i.r.p. spectral density.

Three sets of interference criteria have been considered within this report (criteria sets 1 to 3), as described in Table 2.

Note that the short term criteria for Errored Seconds (ESs) and Severely Errored Seconds (SESs) are taken from ITU-R Rec. SF.1650 [6]. The long term criteria for single entry and aggregate interference are based on ITU-R Recs. F.758, SF.1006.

Interference criteria	$LT_{SI'}$	$LT_{SI''}$	$LT_{Ag'}$	$LT_{Ag''}$	ST_{ESs}	ST_{SESs}
Number of interferers	1	1	All	All	All	All
Max. time percentage	20%	20%	20%	20%	$4{,}50\text{x}10^{-4}$%	$1{,}20\text{x}10^{-5}$%
$(I/N)_{max}$	-19 dB	-10 dB	-10 dB	-20 dB	+19 dB	+23 dB
I_{max}	-140,81 dBW	-131,81 dBW	-131,81 dBW	-141,81 dBW	-102,81 dBW	-98,81 dBW
Criteria set #1	X		X		X	X
Criteria set #2				X	X	X
Criteria set #3		X			X	X

LT_{SI}: Long Term - Single Entry

LT_{Ag}: Long Term - Aggregate

SI: Single Interferer

ST_{ES}: Short Term interference criterion for Errored Seconds

ST_{SES}: Short Term interference criterion for Severely Errored Seconds

Table 2: Interference criteria

6.1.2 Interference level (I) received by the FSR

The level of interference (*I*) received by the FSR at its antenna flange from the ESV is given by the following equation:

(6) :
$$\boxed{I_{[dBW]} = EIRP_{ESV}\left(\varphi_{ESV}\right)_{[dBW]} - L\left(d\right)_{[dB]} + G_{FSR}\left(\varphi_{FSR}\right)_{[dBi]} - NFD_{[dB]}}$$

where:

$EIRP_{ESV}\left(\varphi_{ESV}\right)_{[dBW]}$ is the ESV e.i.r.p. of all transmitted signals (in-band, out-of-band and spurious signals) for the off-axis angle φ_{ESV} of the direction towards the FSR,

$L\left(d\right)_{[dB]}$ is the propagation loss between the ESV and the FSR at distance d ,

$G_{FSR}\left(\varphi_{FSR}\right)_{[dBi]}$ is the FSR antenna reference gain for the off-axis angle φ_{FSR} in the direction towards the ESV,

$NFD_{[dB]}$ is the Net Filter Discrimination of the ESV signal by the FSR receiver.

6.1.3 Propagation loss between the ESV and the FSR

The propagation loss $L\left(d\right)_{[dB]}$ between the ESV and the FSR is computed according to ITU-R Recommendation P.452-7 [7]:

(7) :
$$L\left(d\right)_{[dB]} = L_{P.452}\left(f_{[GHz]}, N_0, \Delta N, \beta_e, Profile, h_{r[m]}, h_{t[m]}, G_{r[dBi]}, G_{t[dBi]}, d_{[km]}, p_{[\%]}\right)_{[dB]}$$

where:

$f_{[GHz]}$ is the frequency,

N_0 is the annual mean surface refractivity in N-units (See Rec. P.452 [7]),

ΔN is the annual delta-N value (See Rec. P.452 [7]),

β_e is the effective value of beta, i.e., beta-r with latitude and longitude correction (See Rec. P.452 [7]),

Profile is a table giving for each point of the path between the ESV and the FSR (See example in Fig. 50):

- the distance to the FSR,
- the ground altitude above the sea level,
- the climate: land, coastal or sea,

$h_{r\,[m]}$ is the FSR antenna height above ground level. The FSR ground altitude is one of the data in *Profile*,

$h_{t\,[m]}$ is the ESV antenna height above sea level,

$G_{r[dBi]}$ the FSR antenna gain in the direction of the ESV

$G_{t\,[dBi]}$ the ESV antenna gain in the direction of the FSR,

$d_{[km]}$ is the distance of the ESV from the FSR,

$p_{[\%]}$ is the time percentage over one year for which loss is not exceeded.

Error! Reference source not found. gives the values of the parameters used for propagation loss computation.

N_0	330
ΔN	50,0
β_e	1,35
$G_{r[dBi]}$	0 dBi
$G_{t\,[dBi]}$	0 dBi
Coastal width	50 km

Table 3: Parameters used for propagation loss computation

The free space loss between the ESV and the FSR when they are within line-of-sight of each other is given by:

(8) : $$\boxed{L(d)_{[dB]} = 20.\log\left(\frac{4.\pi.d_{[m]}}{\lambda_{[m]}}\right)}$$

where:

$\lambda_{[m]}$ is the wave length,

$d_{[m]}$ is the distance between the FSR and the ESV.

6.2 ESV characteristics

6.2.1 ESV density

According to industry estimates, there are about 800 ships equipped with C-band ESVs operating on a world-wide basis. Due to the size of these systems (2.4 m or larger and over 700 kg) and the cost of the C-band space segment, all of these systems are on very large cruise ships with large operational areas or ships that support specialized applications, such as seismic mapping, where broadband connections are required far from the coast.

Cruising in European waters is very popular during the summer months (April through September). Many of these cruise ships 'migrate' from other areas of the world for the European cruise season and, therefore, if they have ESVs, these are likely to be C-band ESVs. The actual number of C-band ESVs operating in European waters is not known as there are no official records for them currently. However, if we base the estimate on the statistics for the worldwide distribution of cruise ships, it would be reasonable to assume that there would be less than 150 ships equipped with C-band ESVs operating in European waters during the Summer months and these ships would be spread across all parts of the Atlantic seaboard from the North Cape of Norway to the Straits of Gibraltar and throughout the Baltic and Mediterranean seas. During the winter months there are very few ships equipped with C-band ESVs operating in European waters and these will be primarily ships that are making trans-Atlantic voyages.

In order to correctly characterize the potential for interference from an ESV to an FSR and to bound the calculations within a reasonable limit, it is necessary to focus on the busiest cruise months and certain "busy" locations where many vessels will travel within a short distance, such as in the English Channel or the Straits of Gibraltar. Using a database of ship-location reports from the 2005 summer season, the busiest locations have been identified that are susceptible to receive the highest amount of interference (i.e. where a south-pointing ESV is within a commonly traversed waterway and the coast is directly south of this location). Nevertheless, only one occasion was identified where three C-band ESVs passed the same point within a 24-hour period and that location is in the English channel near the tip of the Cherbourg peninsula (Latitude: 49.717°/N; West longitude: 1.950°).

6.2.2 Number of ESVs per day

For 150 ESVs along the approximately 28 000 km of the European coasts, the mean distance between ESVs is about 187 km. Therefore, if the speed of these ESVs is equal to 18.3 km/h (i.e. 10 knots, the typical minimum speed identified in Recommendation ITU-R SF.1650 [6]), an ESV passes by an FSR main beam every 10 hours and 12 minutes. Thus during the summer months the mean number of ESVs per day would be 2.35.

For the purpose of the present study three values have been selected: 1 ESV/day, 1.5 ESVs/day and 3 ESVs/day.

These values are those which were used in the ITU-R Recommendation SF.1650 [6] that led to adoption of ITU-R Resolution 902 [1].

6.2.3 ESV speed

Most vessels travel at full speed when they are 10 km from the coast or beyond. For modern cruise ships, the typical speed is between 18 and 25 knots. In this speed range, vessels are required to maintain a safety distance in order to prevent collision. This mandatory separation of vessels underway plays a significant role in the probability distribution of ESV transmissions. The usual safety distance for ships travelling at 15 knots or more is around 5 nautical miles (≈ 9.25 km). On the other hand, the width of the half power beamwidth of the FSR at 20 km distance is only 700 m. Therefore, it is expected that while ESVs maintain a minimum separation distance of at least 9 km, the probability of two ESVs being as close as 700 m in distance is very low. Moreover, given the high density of shipping traffic in European waters and the low proportion of ships equipped with C-band ESVs to all other ships, there is a very high probability that many ships without an ESV will come between those equipped with ESVs, which lowers the probability density even further.

For the purpose of the present study the speed of the ESV was assumed to be equal to 18.3 km/h (10 knots).

This value is the typical minimum value for ESV speed, when in open waters, used in the ITU-R Recommendation SF.1650 [6] that led to adoption of ITU-R Resolution 902 [1].

6.2.4 ESV antenna height

Information from ESV operators indicates that ESV antenna heights can range from 3.5 m, as a minimum, to a maximum of about 50 m.

For the purpose of the present study the ESV antenna height was assumed to be equal to 40 m.

This value is the typical value for ESV height used in the ITU-R Recommendation SF.1650 [6] that led to adoption of ITU-R Resolution 902 [1].

6.2.5 ESV antenna

6.2.5.1 ESV antenna diameter and efficiency

ITU-R Resolution 902 [1] requires that the antenna diameters are not lower than 2.4 m for 6/4 GHz band ESVs. For the purpose of the present study, a typical ESV antenna with the following characteristics has been used:

- diameter: 2.4 m,
- efficiency: 65.8%,
- on-axis gain at 6175 GHz: 42 dBi.

Remark: An ESV transmitting the same e.i.r.p. towards the satellite but with a larger antenna will radiate off-axis emissions at a lower level.

6.2.5.2 ESV antenna gain pattern

The ESV antenna gain ($G_{ESV}(\varphi)_{[dBi]}$) within the ESV antenna main beam is obtained by application of the method specified in the ITU-R Recommendation F.1245-0 (1997) [8] for off-axis angles φ lower than φ_m, as defined within that Recommendation.

The ESV antenna off-axis gain is such that 90% of the side lobe peaks, for off-axis angles φ greater than φ_m is as specified in Table 4:

Angle off-axis φ [°]	Ideal off-axis gain [dBi]
2.5° < φ < 20°	29 – 25 log($\varphi_{[°]}$)
20° < φ < 26.3°	-3.5
26.3° < φ < 48°	32 – 25 log ($\varphi_{[°]}$)
48° < φ < 180°	–10

Table 4: Off-axis gain of an ESV antenna, for $\varphi \geq \varphi_m$

In order to take account of the side lobe peaks, for the present report the ESV antenna off-axis gain is assumed to be 3 dB above the limit specified in Table 4.

An example is given in Figure 2.

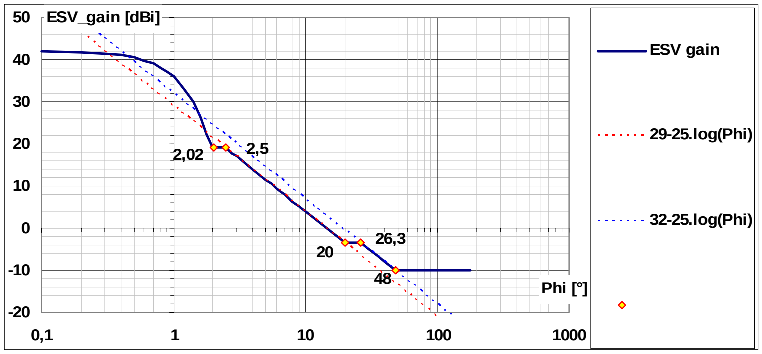


Figure 2: ESV antenna (2,4 m, 65,8% efficiency) ideal gain at 6,175 GHz

6.2.6 ESV power spectral density (p.s.d.)

A generic mask of the power spectral density (p.s.d.), relative to the unmodulated carrier power, of a modulated carrier using a roll-off shaping filter (α = 40%) at the output of the HPA of an ESV was proposed by ETSI TC SES WG MAR ESV. It is defined by the following table 5:

$\lvert f\text{-}fc \rvert$	$psd_c(f)_{[dBc/Hz]} =$
0 to 7.88 x B_n	$10.\log\left(10^{\left(\frac{psd_{c,HPA}(f)_{[dBc/Hz]}}{10}\right)}+10^{\left(\frac{psd_{c,LO}(f)_{[dBc/Hz]}}{10}\right)}\right) dB_c/Hz$
7.88 x B_n to 84 MHz	$psd_{c,LO}(f)_{[dBc/Hz]}$

Table 5: ESV power spectral density mask

where:

f is the considered frequency;

f_c is the carrier central frequency;

$psd_c(f)$ is the power spectral density of the transmitted signal at the frequency, f, at the reference point (e.g. the antenna flange);

$psd_c(f_c)$ is the power spectral density of the transmitted signal at the carrier frequency, f_c, at the reference point (e.g. the antenna flange);

B_n is the Nyquist bandwidth of the transmitted signal, B_n = x kHz including FEC and overhead for a transmission at x kbaud using one of the following modulations: BPSK, QPSK, nPSK, 2^nQAM;

$psd_{c,HPA}(f)_{[dBc/Hz]}$ is the power spectral density (p.s.d.) relative to an unmodulated carrier of a modulated carrier (QPSK, 40% roll-off) at the output of an HPA, generated by an ideal modulator. The generic HPA p.s.d. mask is defined by the following table:

|f-fc|	$psd_{c,HPA}(f)_{[dBc/Hz]}$ =		|f-fc|	$psd_{c,HPA}(f)_{[dBc/Hz]}$ =
0.00 x B_n	0.00		2.46 x B_n	-42.32
0.41 x B_n	-0.20		2.72 x B_n	-51.90
0.58 x B_n	-6.00		3.46 x B_n	-52.62
0.72 x B_n	-24.60		3.73 x B_n	-61.00
0.90 x B_n	-27.60		4.60 x B_n	-61.60
1.47 x B_n	-27.49		7.88 x B_n	-71.56
1.68 x B_n	-41.40			
Note: Within each frequency interval $psd_{c,HPA}(f)_{[dBc/Hz]}$ is linearly interpolated in dB/Hz.				

$psd_{c,LO}(f)_{[dBc/Hz]}$ is the noise power spectral density relative to the unmodulated carrier power of the modem and up-converter local oscillators (LOs). It is a function of the frequency f. A typical pattern is defined by the following table 6:

|f-fc|	$psd_{c,LO}(f)_{[dBc/Hz]}$ =
0 to 32 MHz	$psd_{c,LO}(f_c + 1\ MHz)_{[dBc/Hz]}$
32 MHz to 84 MHz	$psd_{c,LO}(f_c + 1\ MHz)_{[dBc/Hz]} - 24.\left(\frac{\lvert f - f_c\rvert_{[MHz]} - 32}{84 - 32}\right) dB$

Table 6: ESV LOs power spectral density mask

$psd_{c,LO}(f_c + 1\ MHz)_{[dBc/Hz]}$ is the value of $psd_{c,LO}(f)_{[dBc/Hz]}$ for a frequency offset of about 1 MHz, where the p.s.d. becomes constant.

For the generic ESV spectrum mask the following typical value is used:

(9) : $$psd_{c,LO}(f_c + 1\ MHz)_{[dBc/Hz]} = -120\ \ dB_c / Hz$$

Within the Intelsat Earth Station Specifications (IESS) 308 [9] and 309 [10] the maximum permitted value of the phase noise floor is -90 dBc/Hz. The values of the modems are between this maximum value and -130 dBc/Hz. The purpose of this IESS maximum value is not for the protection of the spectrum, but for an acceptable Eb/N_0 ratio at the demodulator input, when taking account the remaining noise from the carrier recovery system.

Within the ETSI EN 301 447 [11] applicable to ESVs, there is no requirement on the value of this parameter but some other specifications may indirectly limit the value of this parameter.

For a wanted signal transmitted with a given e.i.r.p. ($EIRP_{[dBW]}$) within a given Nyquist bandwidth (B_n), then:

- the in-band p.s.d. is equal to:

(10) : $$psd(f_c)_{[dBW/Hz]} = EIRP_{[dBW]} - 10.\log(B_{n,Hz})\ dBW / Hz$$

- the out-of-band noise floor p.s.d. is equal to:

(11) : $$psd(f_c + 10\ MHz)_{[dBW/Hz]} = EIRP_{[dBW]} + psd_{c,LO}(f_c + 1\ MHz)_{[dBc/Hz]}$$

- the ratio of the in-band p.s.d. to the out-of-band noise floor p.s.d. is equal to:

$$(12): \quad \left(\frac{psd\left(f_c\right)}{psd\left(f_c + 10\ MHz\right)} \right)_{[dB]} = -psd_{c,LO}\left(f_c + 1\ MHz\right)_{[dBc/Hz]} - 10.\log\left(B_{n,Hz}\right)$$

The larger is the Nyquist bandwidth (B_n), the lower is the above ratio, as shown within the following table 7 for a phase noise floor of -120 dBc/Hz.

Bit rate [kbit/s]	64	128	256	512	1024	2048
FEC	3/4	3/4	3/4	3/4	3/4	3/4
Modulation	QPSK	QPSK	QPSK	QPSK	QPSK	QPSK
B_n [kHz]	42.7	85.3	170.7	341.3	682.7	1 365.3
Ratio [dB]	74	71	68	65	62	59

Table 7: In-band p.s.d. to out-of-band noise floor p.s.d. ratio for various bit rates

An example spectrum mask is represented on **Error! Reference source not found.** for a carrier with the parameters values given in Table 8:

Information Rate	2 048 kbit/s
FEC ratio	3/4
Data rate including overhead	2 048 kbit/s
Transmitted bit rate	2 730.667 kbit/s
Modulation rate	2 bit/Hz
Nyquist bandwidth (B_n)	1 365.333 kHz
On-axis e.i.r.p.	58.00 dBW
Phase noise floor level	-120.0 dBc/Hz
$psd_{c,LO}\left(f_c + 1\ MHz\right)_{[dBc/Hz]}$	58.65 dB

Table 8: ESV transmitted carrier spectrum mask parameters

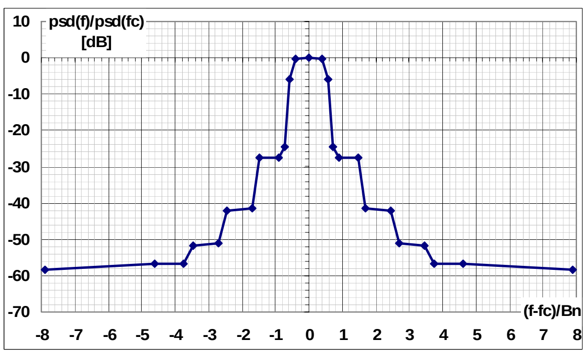


Figure 3: Example of ESV transmitted carrier spectrum mask over 16 x B_n

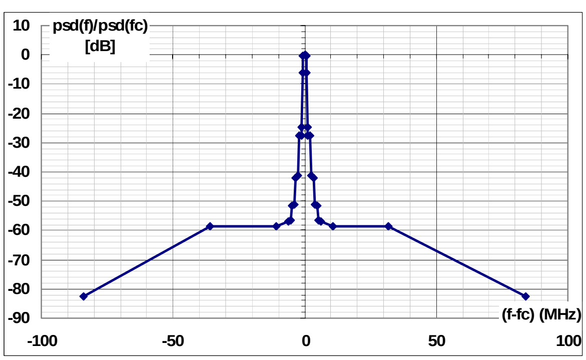


Figure 4: Example of ESV transmitted carrier spectrum mask over ± 84 MHz

Remark: No information was available on the noise floor mask of modulators and up-converters using the L band as Intermediate Frequency (IF).

For the continuous phase noise, only the noise floor has been taken into account. Other contributions to the phase noise are considered to be negligible.

Discrete phase noise components are assumed to have negligible impact on the potential for interference to an FS carrier.

6.2.7 ESV off-axis e.i.r.p. of the wanted signal

The ESV e.i.r.p. of the wanted signal for the off-axis angle φ_{ESV} of the direction towards the FSR is given by:

(13) : $$\boxed{EIRP_{ESV}\left(\varphi_{ESV}\right)_{[dBW]} = EIRP_{ESV}\left(0°\right)_{[dBW]} - G_{ESV}\left(0°\right)_{[dBi]} + G_{ESV}\left(\varphi_{ESV}\right)_{[dBi]}}$$

where:

$EIRP_{ESV}\left(0°\right)_{[dBW]}$ is the ESV on-axis e.i.r.p. of the wanted signal,

$G_{ESV}\left(0°\right)_{[dBi]}$ is the ESV on-axis antenna gain,

$G_{ESV}\left(\varphi_{ESV}\right)_{[dBi]}$ is the ESV off-axis antenna gain for the angle φ_{ESV} of the direction towards the FSR.

6.2.8 ESV on-axis e.i.r.p. of the wanted signal

Typical values of ESV parameters were proposed by ETSI TC SES WG MAR ESV. They are given within the following table:

Data rate [kbit/s]	FEC ratio	Modulation	Tx rate [kbaud] Nyquist Bandwidth [kHz]	Estimated Peak On-axis e.i.r.p. [dBW]	Estimated peak on-axis e.i.r.p. density [dBW/(kbit/s)]	Estimated peak on-axis e.i.r.p. spectral density [dBW/kHz]
64	1/2	QPSK	64	43	24.94	24.94
128	1/2	QPSK	128	46	24.93	24.93
256	1/2	QPSK	256	49	24.92	24.92
512	1/2	QPSK	512	52	24.91	24.91
1024	1/2	QPSK	1024	55	24.90	24.90
2048	1/2	QPSK	2048	58	24.89	24.89
64	3/4	QPSK	43	43	24.94	26.67
128	3/4	QPSK	85	46	24.93	26.71
256	3/4	QPSK	171	49	24.92	26.67
512	3/4	QPSK	341	52	24.91	26.67
1024	3/4	QPSK	683	55	24.90	26.66
2048	3/4	QPSK	1365	58	24.89	26.65

From these data the following two approximations may be used:

(14) : $$\boxed{EIRP_{ESV}\left(0°\right)_{[dBW]} = 24,9 + 10.\log\left(R_{[kbit/s]}\right)\ dBW}$$

(15) : $$\boxed{EIRP_{ESV}\left(0°\right)_{[dBW]} = 26,7 + 10.\log\left(B_{ESV[kHz]}\right)\ dBW}$$

where:

$R_{[kbit/s]}$	is the ESV data rate,
$B_{ESV[kHz]}$	is the Nyquist bandwidth of the ESV transmitted signal.

6.2.9 ESV limitations

6.2.9.1 Limits of ITU-R Resolution 902

6.2.9.1.1 ESV e.i.r.p. towards the horizon

The ESV e.i.r.p. of the wanted signal towards the horizon is limited by ITU-R Resolution 902 [1] to 20.8 dBW in the frequency band from 5 925 MHz to 6 425 MHz.

(16) : $$\boxed{EIRP_{ESV}\left(El_{[\circ]}\right)_{[dBW]} \leq 20,8\ \ dBW}$$

The ESV e.i.r.p. towards the horizon is given by:

(17) : $$\boxed{EIRP_{ESV}\left(El_{[\circ]}\right)_{[dBW]} = EIRP_{ESV}\left(0°\right)_{[dBW]} - G_{ESV}\left(0°\right)_{[dBi]} + G_{ESV}\left(El_{[\circ]}\right)_{[dBi]}}$$

where:

$El_{[\circ]}$	is the ESV main beam axis elevation.

6.2.9.1.2 ESV e.i.r.p. spectral density towards the horizon

The ESV e.i.r.p. spectral density of the wanted signal towards the horizon is limited by ITU-R Resolution 902 [1] to 17 dB(W/MHz) in the frequency band from 5 925 MHz to 6 425 MHz.

(18) : $$\boxed{EIRPsd_{ESV}\left(El_{[\circ]}\right)_{[dBW]} \leq 17\ \ dB\left(W/MHz\right)}$$

The ESV e.i.r.p. spectral density towards the horizon is given by:

(19) : $$\boxed{EIRPsd_{ESV}\left(El_{[\circ]}\right)_{[dBW/MHz]} = EIRPsd_{ESV}\left(0°\right)_{[dBW/MHz]} - G_{ESV}\left(0°\right)_{[dBi]} + G_{ESV}\left(El_{[\circ]}\right)_{[dBi]}}$$

with:

(20) : $$\boxed{EIRPsd_{ESV}\left(0°\right)_{[dBW/MHz]} = EIRP_{ESV}\left(0°\right)_{[dBW]} - 10.\log\left(\frac{\max\left(B_{ESV[Hz]}, 1\ MHz\right)}{1\ MHz}\right)}$$

where:

$EIRPsd_{ESV}\left(0°\right)_{[dBW/MHz]}$	is the ESV on-axis e.i.r.p. maximum spectral density measured in any 1 MHz bandwidth,
$El_{[\circ]}$	is the ESV main beam axis elevation,
$B_{ESV[kHz]}$	is the Nyquist bandwidth of the ESV transmitted signal.

6.2.9.2 Limits of EN 301 447

The ETSI EN 301 447 [11] contains other specifications which mainly limit the off-axis out-of-band emissions.

6.3 FSR characteristics

6.3.1 FSR antenna

6.3.1.1 FSR antenna diameter

Three values for the FSR antenna diameter are used 1.20 m, 1.80 m and 3.00 m corresponding to on-axis gains equal to 36 dBi, 40 dBi and 44 dBi, at 6.2 GHz.

6.3.1.2 FSR antenna gain pattern

The FSR antenna gain pattern used is the one recommended in ITU-R Rec. F.1245-0 (Mathematical model of average radiation patterns for line-of-sight point-to-point radio-relay system antennas for use in certain coordination studies and interference assessment in the frequency range from 1 GHz to about 40 GHz) [8].

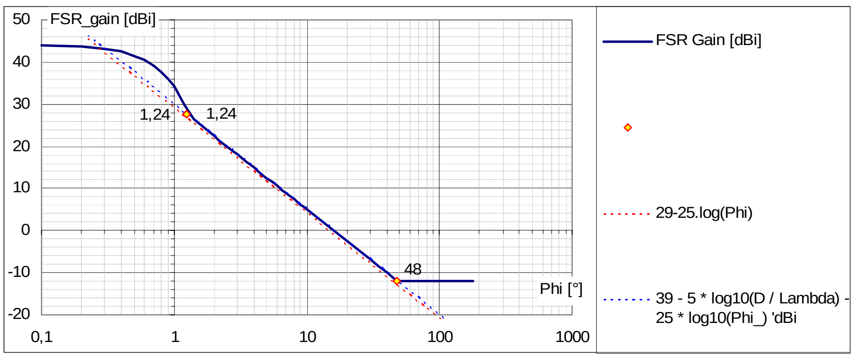


Figure 5: FSR antenna (3 m, 64.6% efficiency) gain pattern

Three types of FSR antenna were considered, each complying with ITU-R Recommendation F.1245 [8]:

Antenna diameter	Antenna efficiency	Frequency	FSR on-axis gain	FSR half beamwidth
m		MHz	dBi	°
1.20	64.0%	5925	35.50	1.462
		6175	35.86	1.402
		6425	36.20	1.348
1.80	71.5%	5925	39.50	0.974
		6175	39.86	0.935
		6425	40.21	0.899
3.00	64.6%	5925	43.50	0.585
		6175	43.86	0.561
		6425	44.20	0.539

Table 9: FSR antenna characteristics

6.3.2 FS receiver filters and NFD

6.3.2.1 Selected typical FS systems

The following types of FS system considered have been taken from ETSI EN 302 217-2-2 [12] Part 2 Annexes B and C, within the U6 and L6 band:

- in L6 band listed in Table B-4 in Annex B of ETSI EN 302 217-2-2 [12]:
  - B.1-2 - 34 Mbit/s - 28/29 MHz,
  - B.1-2 - 34 Mbit/s - 29.65/30 MHz,
  - B.2-5A (type 1) - STM-1 - 28/29 MHz,
  - B.2-5A (type 1) - STM-1 – 29.65/30 MHz,

- in U6 band listed in Table C-4 in Annex C of of ETSI EN 302 217-2-2 [12]:
  - C.1,
  - C.2.

Figure 6 and Figure 6: L6 band FS transmitter masks

show FS transmitter masks for various system types. The receiver selectivity masks were derived from the transmit spectrum masks in accordance with TR 101 854 [13].

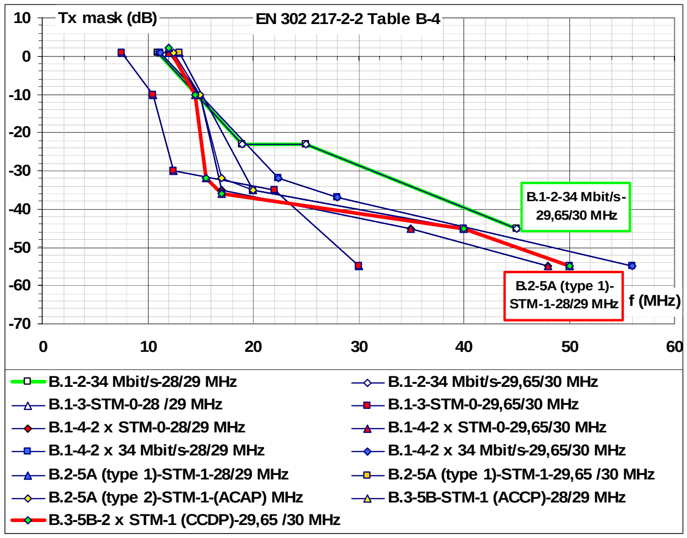


Figure 6: L6 band FS transmitter masks

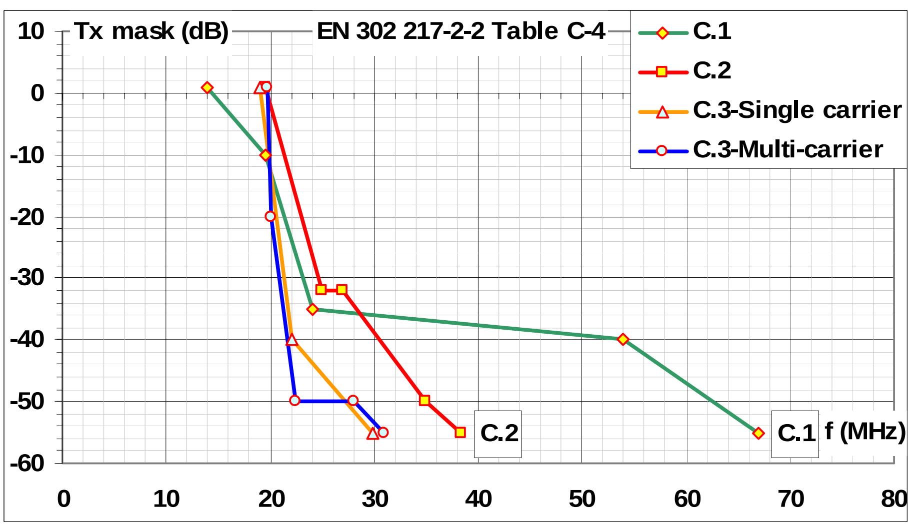


Figure 7: U6 band FS transmitter masks

6.3.2.2 FS transmitter spectrum mask

The main parameters of the selected FS system types are given in **Error! Reference source not found.**.

FS system # in this report		S1	S2	S3	S4
FS system reference in EN 302 217		B.1	B.2	C.1	C.2
Spectrum efficiency class		2	5A (Type 1)	5B (ACCP/CCDP & Type 1)	6A (ACAP)
Nominal payload bit rate	Mbit/s	34	STM-1	up to 2 × STM-1	STM-4 or 2 × STM-1
Payload bit rate	Mbit/s	34	155.52	311.04	2 x 311.04
Channel spacing	MHz	29.65	29.65	40	2 x 40
Tx spectrum mask					
f(1)	MHz	11	13	14	19.5
f(2)	MHz	19	20	19.5	25
f(3)	MHz	25	40	24	27
f(4)	MHz	45	50	54	35
f(5)	MHz			67	38.4
Gain (1)	dB	1	1	1	1
Gain (2)	dB	-23	-35	-10	-32
Gain (3)	dB	-23	-45	-35	-32
Gain (4)	dB	-45	-55	-40	-50
Gain (5)	dB			-55	-55
Co-channel external interference sensitivity					
C/I values for 1 dB degradation of the 10-6 BER limit	dB	23	34	37	43
C/I values for 3 dB degradation of the 10-6 BER limit	dB	19	31	33	39.5
CW interference I/C					
2.5xCS < f < 5xCS	dB	30	30	30	30

Table 10: Selected FS system types main parameters

6.3.2.3 Selected FS system types' receive filter parameters

The receive filter parameters of the selected FS system types are given in Table 11. They have been obtained by application of the method described in Annex F of the ETSI TR 101 854 [13] for roll-off values of 20%, 30% and 40%.

FS system #		S1		S2		S3		S4	
FS system EN 302 217		B.1		B.2		C.1		C.2	
Spectrum efficiency class		2		5A (type 1)		5B (ACCP/CCDP) & Type 1		6A (ACCP)	
Nominal payload bit rate	Mbit/s	34		STM-1		up to 2 × STM-1		STM-4 or 2 × STM-1	
Payload bit rate	Mbit/s	34		155.52		311.04		622.08	
Channel spacing	MHz	29.65		29.65		40		40	
FSR_Rx_filter_table for 20% roll-off		f [kHz]	Gain [dB]	f [kHz]	Gain [dB]	f [kHz]	Gain [dB]	f [kHz]	Gain [dB]
Point (0)		0	0.00	0	0.00	0	0.00	0	0.00
Point (1)		9 601	0.00	10 617	0.00	12 397	0.00	15 140	0.00
Point (2)		12 001	-3.00	13 272	-3.00	15 496	-3.00	18 925	-3.00
Point (3)		14 347	-35.00	15 909	-46.00	18 575	-46.00	22 681	-44.50
Point (4)		28 667	-53.00	25 444	-64.00	32 611	-67.00	36 091	-73.00
Point (5) (See Note 1)		74 125	-53.00	74 125	-64.00	100 000	-67.00	100 000	-73.00
FSR Nyquist frequency (See Note 2)	kHz	12 001.241		13 271.715		15 495.796		18 924.909	
FSR roll_off		20%		20%		20%		20%	
FSR_Rx_filter_table for 30% roll-off		f [kHz]	Gain [dB]	f [kHz]	Gain [dB]	f [kHz]	Gain [dB]	f [kHz]	Gain [dB]
Point (0)		0	0.00	0	0.00	0	0.00	0	0.00
Point (1)		8 270	0.00	8 886	0.00	10 769	0.00	12 493	0.00
Point (2)		11 814	-3.00	12 695	-3.00	15 384	-3.00	17 847	-3.00
Point (3)		15 278	-35.00	16 479	-46.00	19 970	-46.00	23 161	-44.50
Point (4)		28 667	-53.00	25 444	-64.00	32 611	-67.00	36 091	-73.00
Point (5) (See Note 1)		74 125	-53.00	74 125	-64.00	100 000	-67.00	100 000	-73.00
FSR Nyquist frequency (See Note 2)	kHz	11 814.004		12 694.758		15 384.342		17 847.325	
FSR roll_off		30%		30%		30%		30%	
FSR_Rx_filter_table for 40% roll-off		f [kHz]	Gain [dB]	f [kHz]	Gain [dB]	f [kHz]	Gain [dB]	f [kHz]	Gain [dB]
Point (0)		0	0.00	0	0.00	0	0.00	0	0.00
Point (1)		6 872	0.00	7 239	0.00	9 005	0.00	10 083	0.00
Point (2)		11 453	-3.00	12 065	-3.00	15 009	-3.00	16 805	-3.00
Point (3)		15 931	-35.00	16 860	-46.00	20 974	-46.00	23 476	-44.50
Point (4)		28 667	-53.00	25 444	-64.00	32 611	-67.00	36 091	-73.00
Point (5) (See Note 1)		74 125	-53.00	74 125	-64.00	100 000	-67.00	100 000	-73.00
FSR Nyquist frequency	kHz	11 453.067		12 064.963		15 008.714		16 804.983	
FSR roll_off		40%		40%		40%		40%	
Note 1: The value of the frequency of the point 5 is equal to 2.5 times the channel spacing. The value given within the row corresponds to one of the channel spacing values. Note 2: For definition of “Nyquist frequency” see Table 12.									

Table 11: Selected FS system types' receive filter parameters

The receive filter gain patterns for 40% roll-off are represented in the following Figures 8-11.

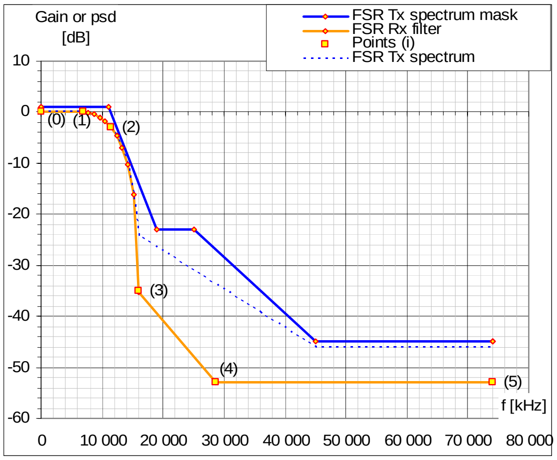


Figure 8: FS system S1 Tx spectrum mask and Rx filter

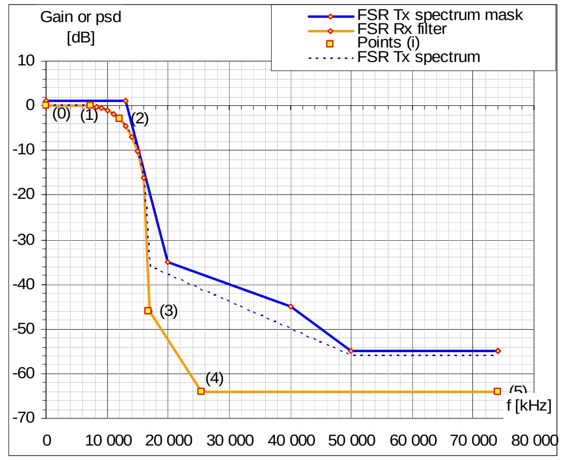


Figure 9: FS system S2 Tx spectrum mask and Rx filter

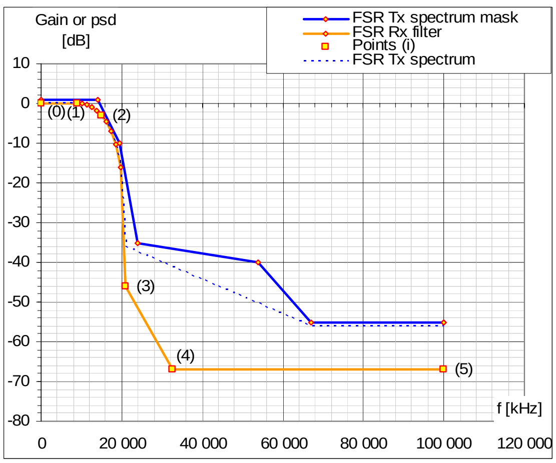


Figure 10: FS system S3 Tx spectrum mask and Rx filter

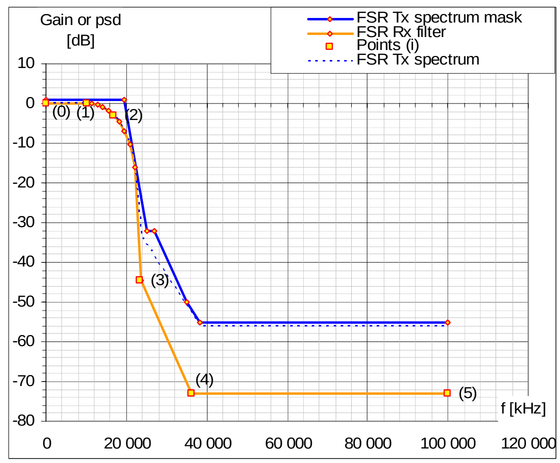


Figure 11: FS system S4 Tx spectrum mask and Rx filter

6.3.2.4 FS receiver filter gain pattern

The gain ($G_{FSR[dB]}(f)$) of the FS receiver filter is defined by the following table:

Frequency (f)	**Gain ($G_{FSR[dB]}(f)$)**
$\lvert f-f_c \rvert \le f_1$	$G_{FSR[dB]}(f)=0\ dB$
$f_1 \le \lvert f-f_c \rvert \le f_3$	$G_{FSR[dB]}(f)=10.\log\left(\frac{1}{2}.\left(1-Sin\left(\frac{\pi}{2}.\frac{1}{\alpha}.\left(\frac{f-f_c}{f_n}-1\right)\right)\right)\right)dB$
$f_3 \le \lvert f-f_c \rvert \le f_4$	$G_{FSR[dB]}(f)=G_{3[dB]}+\frac{G_{4[dB]}-G_{3[dB]}}{f_4-f_3}.(\lvert f-f_c \rvert - f_3)\ dB$
$\lvert f-f_c \rvert \ge f_4$	$G_{FSR[dB]}(f)=G_{4[dB]}\ dB$

Table 12: FS receiver filter amplitude response (gain)

where:

f is the considered frequency;

f_c is the FS receive filter central frequency;

f_k is the frequency of the k[th] point of the FS receive filter given within the "FSR_Rx_filter_table" in Table 11;

$G_{k\,[dB]}$ is the gain of the k[th] point of the FS receive filter given within the "FSR_Rx_filter_table" in Table 11;

f_n is the Nyquist frequency of the FS receive filter; it is equal to half of the Nyquist bandwidth of both the transmit and receive filters; f_n is equal to the second value (f_2) of the "FSR_Rx_filter_table" in Table 11;.

α is the roll-off ratio of the FS receive filter; it is equal to:

(21) : $$\alpha = 1 - \frac{f_3}{f_2}$$

6.3.2.5 Justification for limiting the study to the L6 band

According to the ERC Recommendation 14-02 [14], within the U6 frequency band the lowest channel edge frequency is at 5 MHz from the U6 lower bound (i.e. 6425 MHz) for 20 MHz channel spacing and at 15 MHz from the U6 lower bound (i.e. 6425 MHz) for 40 MHz channel spacing. The selected systems within U6 use 40 MHz channel spacing.

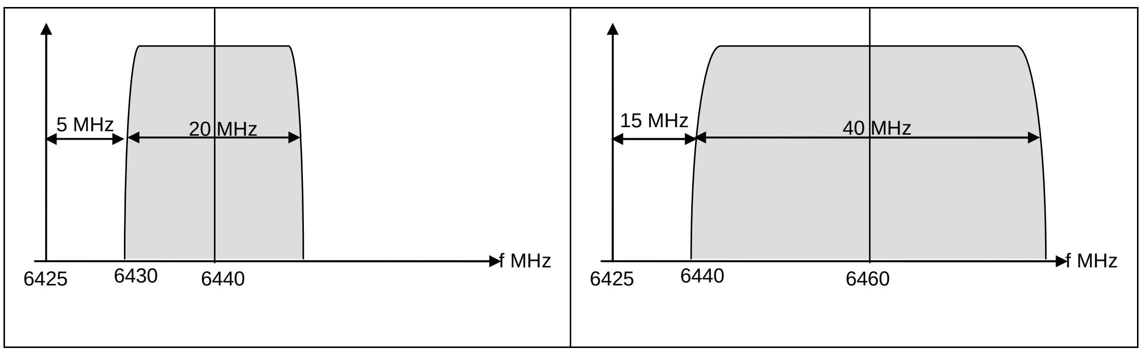


Figure 12: First channels within the U6 frequency band according to ERC/REC 14-02

As shown on Figure 13, systems S3 and S4, operating within U6 frequency band, will be substantially less affected by adjacent channel interference from ESV carriers operating below 6 425 MHz than systems S1 and S2, operating within L6 frequency band. Thus only system types S1 and S2 were taken into account.

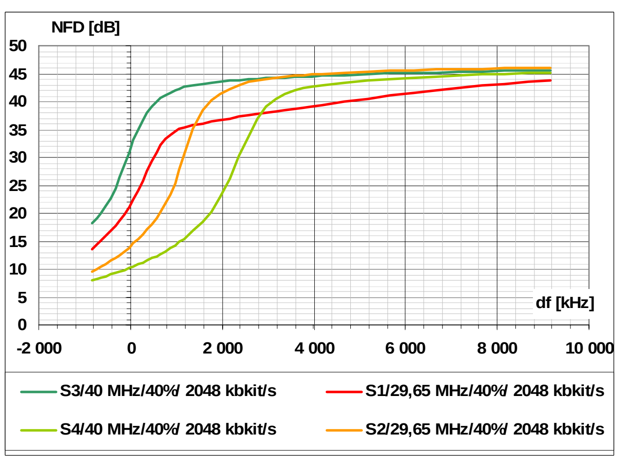


Figure 13: NFD of the S1 to S4 receiver filters for a 2,048 Mbit/s ESV carrier

In each case *df* is the frequency difference between the edge of the FSR channel and the edge of the ESV carrier (see also § 6.3.2.6.2). Note that for FS systems S1/S2 and S3/S4 operated in U6 band and ESV operated below 6425 MHz, *df* will be always greater than 5 MHz or 15 MHz respectively, as may be shown by comparing Fig. 12 with Fig. 14 below.

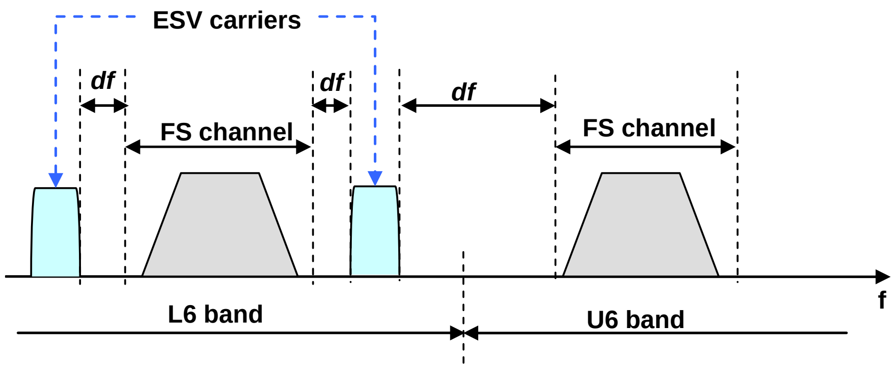


Figure 14: FS channels, ESV carriers and guard bands *df*

6.3.2.6 Net Filter Discrimination (NFD)

6.3.2.6.1 General

The Net Filter Discrimination (NFD) of the FS receiver filter is defined as the ratio of the power (P_{in}) of the interferer measured at the input of the filter to the power (P_{out}) measured at the output of the filter.

(22) : $$NFD_{[dB]} = 10.\log\left(\frac{P_{in}}{P_{out}}\right) = P_{in\,[dBW]} - P_{out\,[dBW]}$$

In order to avoid confusion between the guard-band (*df*) with the variation of the frequency (*f*) within integrals, within this section the frequency (*f*) is represented by another symbol (ν).

The p.s.d. ($psd_{in}(\nu)_{[dBW/Hz]}$) of the interferer at the input of the filter is equal to:

(23) : $$psd_{in}(\nu)_{[dBW/Hz]} = P_{in\,[dBW]} + psd_c(\nu)_{[dBc/Hz]}$$

$psd_c(\nu)_{[dBc/Hz]}$ is the ESV power spectral density relative to the unmodulated carrier power of the transmitted modulated carrier at the frequency ν at the reference point (e.g. the antenna flange) (See § 6.2.6);

The p.s.d. ($psd_{out}(\nu)_{[dBW/Hz]}$) of the interferer at the output of the filter is equal to:

(24) : $$psd_{out}(\nu)_{[dBW/Hz]} = \begin{cases} = psd_{in}(\nu)_{[dBW/Hz]} + G_{FSR\,[dB]}(\nu) \\ = P_{in\,[dBW]} + psd_c(\nu)_{[dBc/Hz]} + G_{FSR\,[dB]}(\nu) \end{cases}$$

Note: in this section G_{FSR} is used to denote gain of FSR filter, dB, as defined in 6.3.2.4 (Table 12).

The power ($P_{out[dBW]}$) of the interferer at the output of the filter is equal to:

(25) : $$P_{out[W]} = \int_{\nu=0}^{\nu=\infty} psd_{out}(\nu)_{[W/Hz]}.d\nu$$

Then:

(26) : $$\boxed{NFD = -10.\log\left(\int_{\nu=0}^{\nu=\infty} 10^{\left(psd_c(\nu)_{[dBc/Hz]} + G_{FSR\,[dB]}(\nu)\right)/10}.d\nu\right)}$$

For an un-calibrated ESV spectrum mask $S_{ESV}(\nu)$:

(27) : $$S_{ESV}(\nu)_{[dB/Hz]} = S_0 + psd_c(\nu)_{[dBc/Hz]}$$

where S_0 is an arbitrary scale factor of P_{in} and P_{out} which disappears in the final expression of the NFD.

(28) : $$\boxed{NFD = -10.\log\left(\frac{\int_{\nu=0}^{\nu=\infty} 10^{\left(S_{ESV}(\nu)_{[dB/Hz]}+G_{FSR\,[dB]}(\nu)\right)/10}.d\nu}{\int_{\nu=0}^{\nu=\infty} 10^{\left(S_{ESV}(\nu)_{[dB/Hz]}\right)/10}.d\nu}\right)}$$

The NFD is a function of:

$f_{c,ESV}$ the ESV carrier centre frequency,

$f_{c,FSR}$ the FSR carrier centre frequency,

$B_{Ch,FSR}$ the FSR channel bandwidth,

$B_{-10\,dB,ESV}$ the ESV carrier bandwidth, measured 10 dB below the maximum power spectral density,

df the guard-band between the ESV carrier edge and the FS channel edge.

The relationship between these parameters is the following:

(29) : $$\boxed{df = \left|f_{c,ESV} - f_{c,FSR}\right| - \frac{B_{Ch,FSR}}{2} - \frac{B_{-10\,dB,ESV}}{2}}$$

Within the following sections, the NFD will be considered as a function of the guard-band (*df*), denoted as $NFD(df)$.

6.3.2.6.2 NFD range of values for selected FS system types and ESV carriers

6.3.2.6.2.1 General

For any given ESV spectrum corresponding to given bit rate, HPA back-off and phase noise the NFD may be determined:

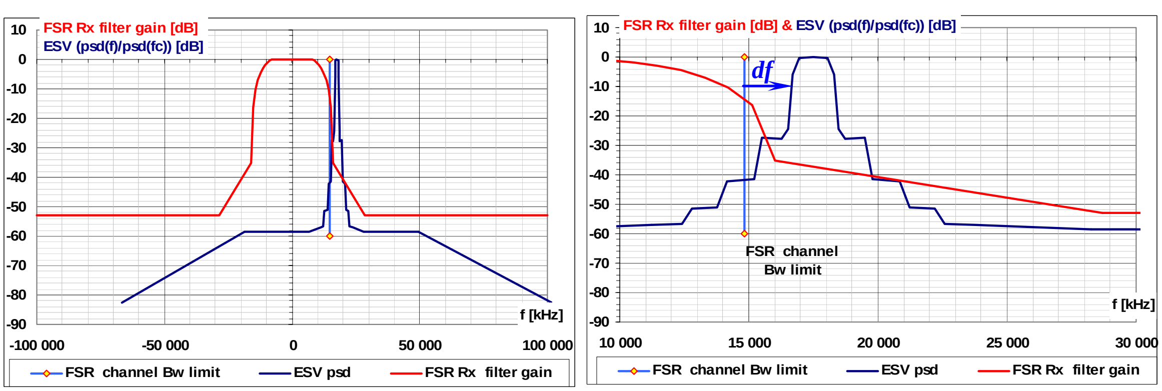


Figure 15: Example of FSR filter gain and ESV spectrum mask for a 2.048 Mbit/s carrier

The guard-band (*df*) is defined as the separation in frequency between the edge of the adjacent FS channel and the nearest edge of the ESV carrier. The edge of the ESV carrier is measured 10 dB below its maximum in-band power density.

With the selected FS system types receiver filters, and for the smallest and largest ESV carriers types, for filter roll-offs ranging from 20% to 40%, the NFD vs. frequency separation for each combination is shown on the following two figures.

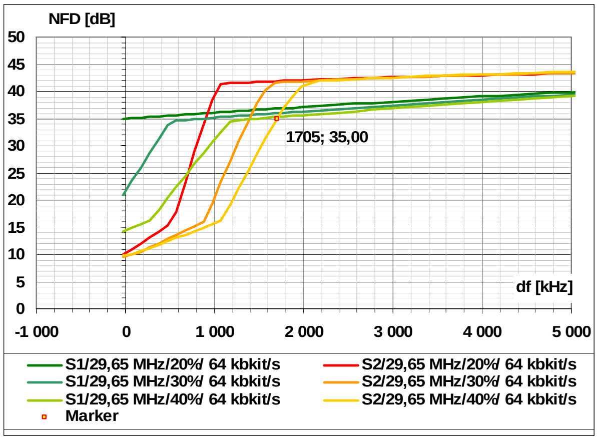


Figure 16: FS systems' Rx filter NFD for the minimum channel spacing values and an ESV carrier at 64 kbit/s

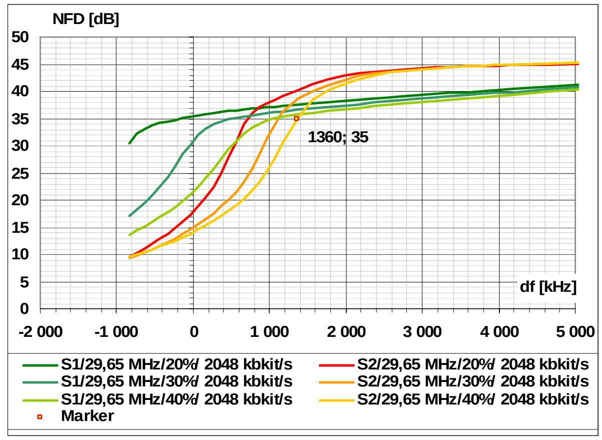


Figure 17: FS systems' Rx filter NFD for the minimum channel spacing values and an ESV carrier at 2.048 Mbit/s

The equations of the level of interference (*I*) and the FSR noise level (*N*) within the present section are introduced here in order to help in the determination of the suitable value of the NFD. These equations will be explained with more details later in the document.

The level of interference (*I*) received by the FSR at its antenna flange from the ESV is given by the following equation:

(30) : $$I_{[dBW]} = EIRP_{ESV}\left(\varphi_{ESV}\right)_{[dBW]} - L\left(d\right)_{[dB]} + G_{FSR}\left(\varphi_{FSR}\right)_{[dBi]} - NFD\left(df\right)_{[dB]}$$

where the terms are successively: the ESV off-axis e.i.r.p., the propagation loss, the FSR antenna gain in the direction of the ESV and the NFD of the FSR receiver filter for the guard-band (*df*).

The ESV off-axis e.i.r.p. in the direction of the FSR is given by the following equation:

(31) : $$EIRP_{ESV}\left(\varphi_{ESV}\right)_{[dBW]} = EIRP_{ESV}\left(0°\right)_{[dBW]} - G_{ESV}\left(0°\right)_{[dBi]} + G_{ESV}\left(\varphi_{ESV}\right)_{[dBi]}$$

where the terms are successively: the ESV on-axis e.i.r.p., the ESV antenna on-axis gain and the ESV antenna off-axis gain.

The noise level of the FSR is given by the following equation:

(32) : $$N = k.T_S.B_{FSR}$$

where the terms are successively: the Boltzmann's constant, the FSR system noise temperature at its antenna flange and the FSR noise bandwidth (approximately equal to the Nyquist bandwidth of the wanted signal).

Then the (*I/N*) ratio is given by the following equation:

(33) : $$\left(\frac{I}{N}\right)_{[dB]} = EIRP_{ESV}\left(0°\right)_{[dBW]} - \left(NFD\left(df\right)_{[dB]} + B_{FSR[dBHz]}\right) + S_0$$

with:

(34) : $$S_0 = \begin{Bmatrix} -G_{ESV}\left(0°\right)_{[dBi]} + G_{ESV}\left(\varphi_{ESV}\right)_{[dBi]} - L\left(d\right)_{[dB]} + G_{FSR}\left(\varphi_{FSR}\right)_{[dBi]} \\ -k_{[dBW/Hz/K]} - T_{S[dBK]} \end{Bmatrix}$$

When an ESV is in a given location, transmitting towards the given satellite a single carrier with a given guard band (*df*) from the FSR channel edge, the variations of the ratio (*I/N*) depends on the ESV e.i.r.p., the ESV carrier bit rate or bandwidth and also on the FSR receiver filter roll-off and noise bandwidth . Three cases are considered:

1. the case where the ESV on-axis e.i.r.p. is limited,
2. the case where the ESV on-axis e.i.r.p. and e.i.r.p. spectral density are limited and
3. the case where the ESV on-axis e.i.r.p. and e.i.r.p. spectral density are limited but with a highest e.i.r.p. spectral density.

For these 3 cases, the same worst case combination of FSR system, ESV carrier and NFD has been used.

- NFD = 35 dB
- FSR:
    - FS system #: S2
    - Roll-off: 40%
    - Noise bandwidth: 24 130 kHz
- ESV carrier:
    - Bit rate: 2.048 Mbit/s
    - FEC rate: ¾
    - Modulation: QPSK
    - Nyquist bandwidth: 1 365.33 kHz
    - Spectrum bandwidth at -10 dB: 1 666 kHz (i.e. 1.22 x Nyquist bandwidth).

This combination is used within the remaining parts of this study as the only combination to consider, since the other combinations lead to smaller separation distances.

Remark: The computations of the minimum distance have been done with a FSR noise bandwidth equal to 24 906 kHz (i.e. the FS system #1 Nyquist bandwidth). The noise level difference is equal to 0.23 dB. So the computed minimum distances are slightly higher than the minimum distance which would be obtained with a FSR noise bandwidth equal to 24 130 kHz.

As calculated below, these 3 cases lead to the following three alternatives:

Case	ESV maximum on-axis e.i.r.p.	ESV maximum e.i.r.p. spectral density	Minimum guard band (*df*)
1	58 dBW		1 700 kHz
2	58 dBW	26.65 dBW/kHz	1 400 kHz
3	58 dBW	29.65 dBW/kHz	1 500 kHz

Case 3 gives the maximum flexibility to the ESV for the use of the available bandwidth and transmitted power.

6.3.2.6.2.2 Case where the ESV on-axis e.i.r.p. is limited

In the case of constant on-axis e.i.r.p. (e.g. 58 dBW for the highest bit rate: 2.048 Mbit/s), the variation of the (*I/N*) ratio level depends on the variation of the NFD and on the FSR receiver bandwidth, i.e. on the sum S_2:

(35) : $$S_2 == \left(NFD\left(df\right)_{[dB]} + B_{FSR[dBHz]} \right)$$

The values of that sum S_2 and the corresponding values of the NFD are represented on the following figures for a 64 kbit/s carrier and a 2.048 Mbit/s carrier.

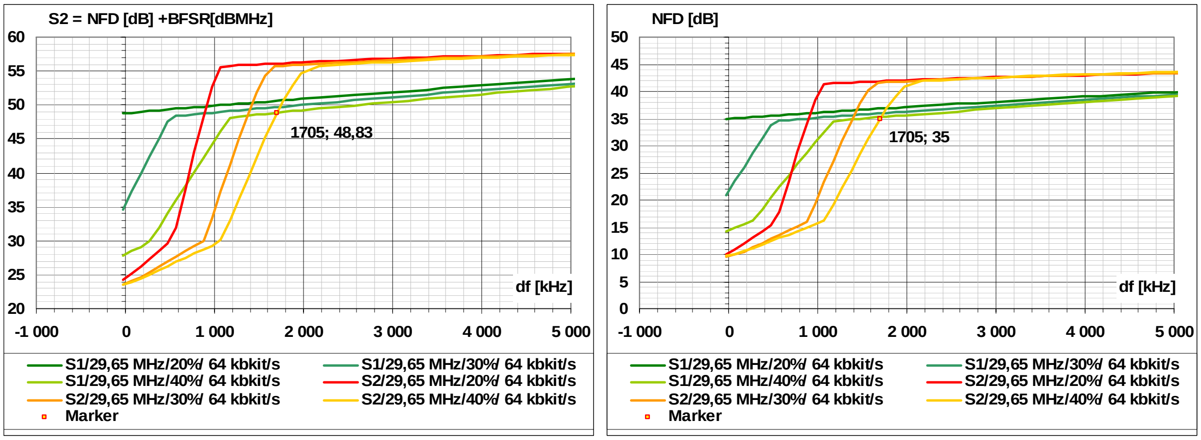


Figure 18: FS systems' Rx filter *S2* and NFD for the minimum channel spacing values and an ESV carrier at 64 kbit/s

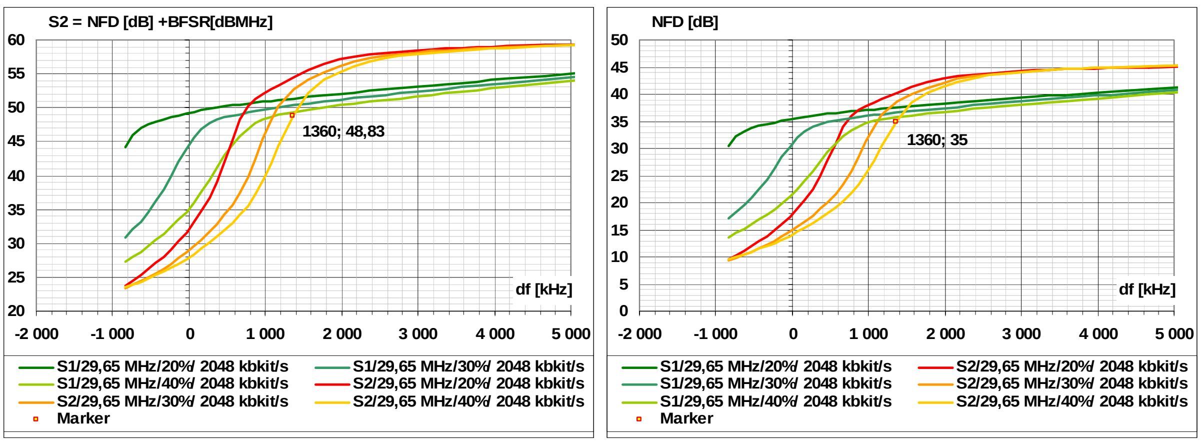


Figure 19: FS systems' Rx filter (NFD+Bw) and NFD for the minimum channel spacing values and an ESV carrier at 2.048 Mbit/s

Due to the fact that with narrow carriers the energy is less spread than with large carriers and that the parts of the ESV spectrum farther from the channel edge are more attenuated than the parts closer to the channel edge, the NFD is higher for large carriers than for narrow carriers. This can be observed in comparing the above figures.

In the case where the ESV on-axis e.i.r.p. is limited to a given value (e.g. 58 dBW for the highest bit rate (2.048 Mbit/s)) and the NFD limited to a minimum value (e.g. 35 dB for the highest bit rate) the minimum guard-band (*df*) is determined for the narrowest carrier:

> Minimum guard-band $df \geq$ 1 700 kHz for NFD = 35 dB
>
> Remark: 1 700 kHz is the round value greater than or very close to the maximum of 1 705 kHz and 1 360 kHz.

6.3.2.6.2.3 Case where the ESV on-axis e.i.r.p. and e.i.r.p. spectral density are limited

The ESV on-axis e.i.r.p. is given by the following equation:

$$(36): \quad EIRP_{ESV}\left(0°\right)_{[dBW]} = EIRP_{sd,ESV}\left(0°\right)_{[dBW/kHz]} + Bn_{ESV[dBkHz]}$$

where the terms are successively: the ESV on-axis e.i.r.p. spectral density (in band), and the Nyquist bandwidth of the ESV carrier.

In that case, the ratio (*I/N*) is given by the following equation:

$$(37): \quad \left(\frac{I}{N}\right)_{[dB]} = EIRP_{sd,ESV}\left(0°\right)_{[dBW/kHz]} - \left(NFD\left(df\right)_{[dB]} + B_{FSR[dBHz]} - Bn_{ESV[dBkHz]}\right) + S_0$$

For given on-axis e.i.r.p. spectral density, NFD and FSR receiver bandwidth, the (*I/N*) ratio for a narrow bandwidth carrier then is lower than for a large bandwidth carrier.

The ESV maximum on-axis e.i.r.p. is given by the following equation for the larger carrier bandwidth:

$$(38): \quad EIRP_{\max,ESV}\left(0°\right)_{[dBW]} = EIRP_{sd,ESV}\left(0°\right)_{[dBW/kHz]} + Bn_{\max,ESV[dBkHz]}$$

then:

$$(39): \quad \left(\frac{I}{N}\right)_{[dB]} = EIRP_{\max,ESV}\left(0°\right)_{[dBW]} - \left(NFD\left(df\right)_{[dB]} + B_{FSR[dBHz]} - \left(\frac{Bn_{ESV}}{Bn_{\max,ESV}}\right)_{[dB]}\right) + S_0$$

The variation of the (*I/N*) ratio level depends on the following sum S_3 of parameters:

$$(40): \quad S_3 == \left(NFD\left(df\right)_{[dB]} + B_{FSR[dBHz]} - \left(\frac{Bn_{ESV}}{Bn_{\max,ESV}}\right)_{[dB]}\right)$$

The values of that sum S_3 and the corresponding values of the NFD are represented on the following figures for a 64 kbit/s carrier and a 2.048 Mbit/s carrier.

In the case of a 2.048 Mbit/s carrier transmitted with a ¾ FEC and QPSK modulation the Nyquist bandwidth ($Bn_{\max,ESV}$) is equal to 1 365.333 kHz.

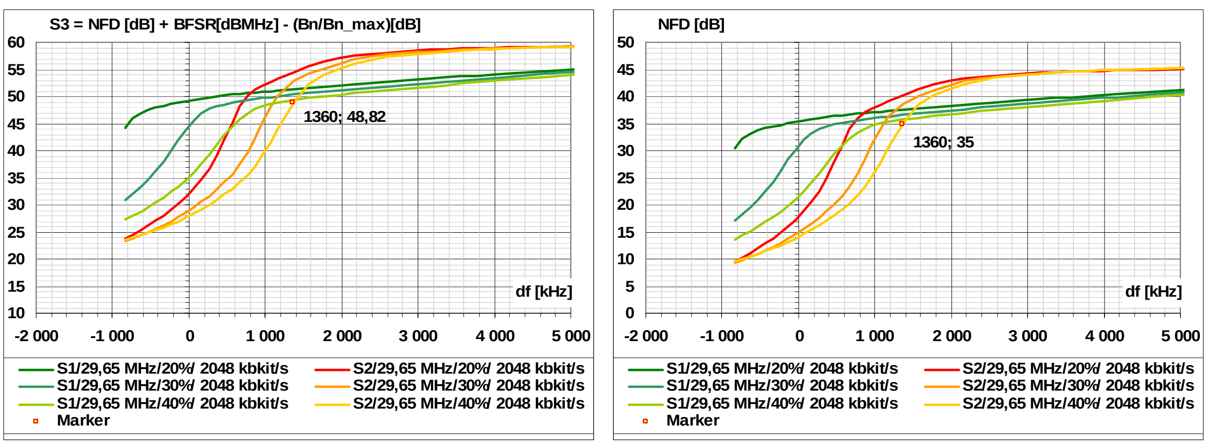


Figure 20: FS systems' Rx filter sum S_3 and NFD for the minimum channel spacing values and an ESV carrier at 2.048 Mbit/s

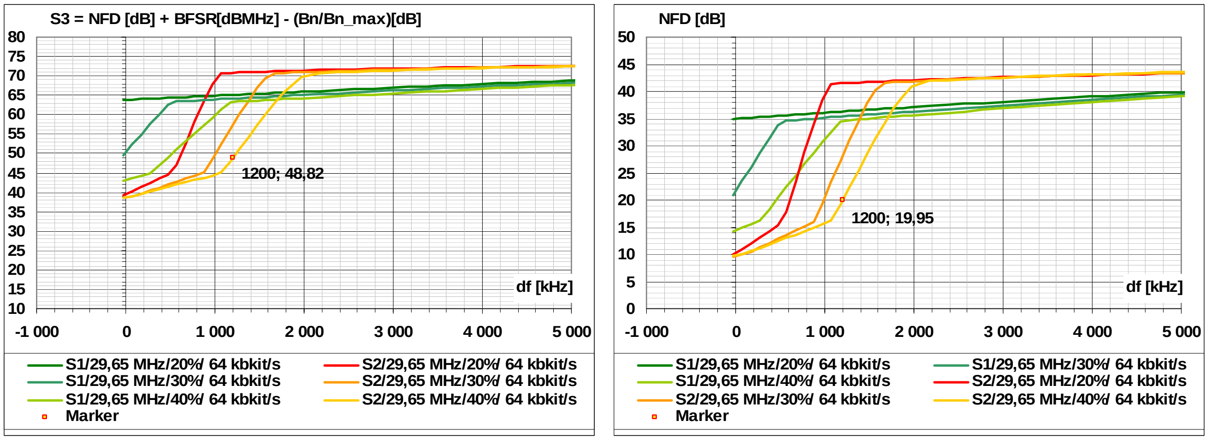


Figure 21: FS systems' Rx filter sum S_3 and NFD for the minimum channel spacing values and an ESV carrier at 64 kbit/s

In the case where the ESV on-axis e.i.r.p. spectral density is limited to a given value (e.g. 26.65 dBW/kHz corresponding to 58 dBW for the highest bit rate (2.048 Mbit/s)) and the NFD limited to a minimum value (e.g. 35 dB) the minimum guard-band (*df*) is determined for the largest carrier:

Minimum guard-band $df \geq$ 1 400 kHz for NFD = 35 dB for the highest bit rate (2.048 Mbit/s)

Remark: 1 400 kHz is the round value greater than or very closer to the maximum of 1 200 kHz and 1 360 kHz.

6.3.2.6.2.4 Case where the ESV on-axis e.i.r.p. and e.i.r.p. spectral density are limited but with a higher e.i.r.p. spectral density limit

More flexibility may be given to the low bit rate carriers, in increasing the maximum on-axis e.i.r.p. spectral density (e.g. by 3 dB) but also in limiting the on-axis e.i.r.p. (e.g. to 58 dBW).

In that case, when $\Delta EIRP_{sd\max,ESV_{[dB]}}$ is the permitted increase of the maximum on-axis e.i.r.p. spectral density (e.g. equal to 3 dB), the level of interference received by the FSR is given by the following equation:

$$(41): \quad \left(\frac{I}{N}\right)_{[dB]} = EIRP_{\max,ESV}\left(0°\right)_{[dBW]} - \left(\begin{array}{l} NFD\left(df\right)_{[dB]} + B_{FSR[dBHz]} \\ -\max\left(0,\ \ \Delta EIRP_{sd\max,ESV_{[dB]}} + \left(\dfrac{Bn_{ESV}}{Bn_{\max,ESV}}\right)_{[dB]}\right)\end{array}\right) + S_0$$

or:

$$(42): \quad \left(\frac{I}{N}\right)_{[dB]} = EIRP_{\max,ESV}\left(0°\right)_{[dBW]} - \min\left(S_2,\ S_3 - \Delta EIRP_{sd\max,ESV_{[dB]}}\right) + S_0$$

with:

$$(43): \quad S_2 == \left(NFD\left(df\right)_{[dB]} + B_{FSR[dBHz]}\right)$$

$$(44): \quad S_3 == \left(NFD\left(df\right)_{[dB]} + B_{FSR[dBHz]} - \left(\frac{Bn_{ESV}}{Bn_{\max,ESV}}\right)_{[dB]}\right)$$

$$(45): \quad \boxed{\min\left(S_2, S_3 - \Delta EIRP_{sd\max,ESV_{[dB]}}\right) = \begin{cases} S_2 & when \quad Bn_{ESV} \geq Bn_{1,ESV} \\ S_3 - \Delta EIRP_{sd\max,ESV_{[dB]}} & when \quad Bn_{ESV} \leq Bn_{1,ESV}\end{cases}}$$

with:

(46) : $$\boxed{Bn_{1,ESV} == Bn_{\max,ESV}.10^{-\left(\Delta EIRP_{sd\,\max,ESV[dB]}/10\right)}}$$

In the case where the ESV on-axis e.i.r.p. and e.i.r.p. spectral density are limited to given values (e.g. 58 dBW and. 29.65 dBW/kHz, instead of 26.65 dBW/kHz) and the NFD is limited to a minimum value (e.g. 35 dB) the minimum guard-band (*df*) is determined for the carrier such that:

(47) : $$Bn_{ESV} = Bn_{1,ESV}$$

For $\Delta EIRP_{sd\,\max,ESV[dB]} = 3\ dB$ and $Bn_{\max,ESV} = 1365{,}333$ kHz (for a 2.048 Mbit/s carrier), then $Bn_{1,ESV} = 682{,}666$ kHz (for a 1.024 Mbit/s carrier).

For a 2.048 Mbit/s carrier and NFD = 35 dB: *df* = 1 360 kHz and S_2 = 48.83 dB

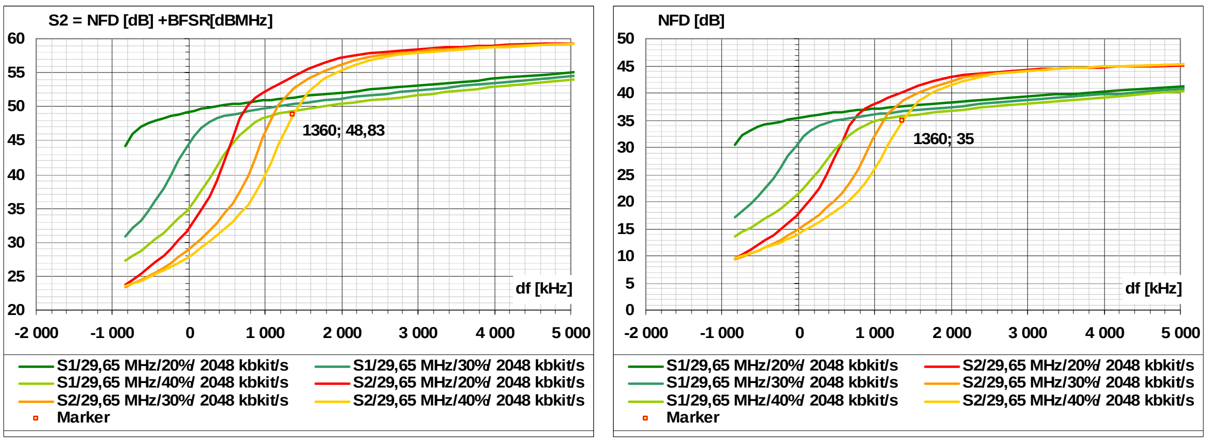


Figure 22: FS systems' Rx filter sum S_3 and NFD for the minimum channel spacing values and an ESV carrier at 2.048 Mbit/s

For a 1.024 Mbit/s carrier S_2 = 48.83 dB for NFD = 35 dB and *df* = 1 456 kHz, S_3 = 51.83 dB

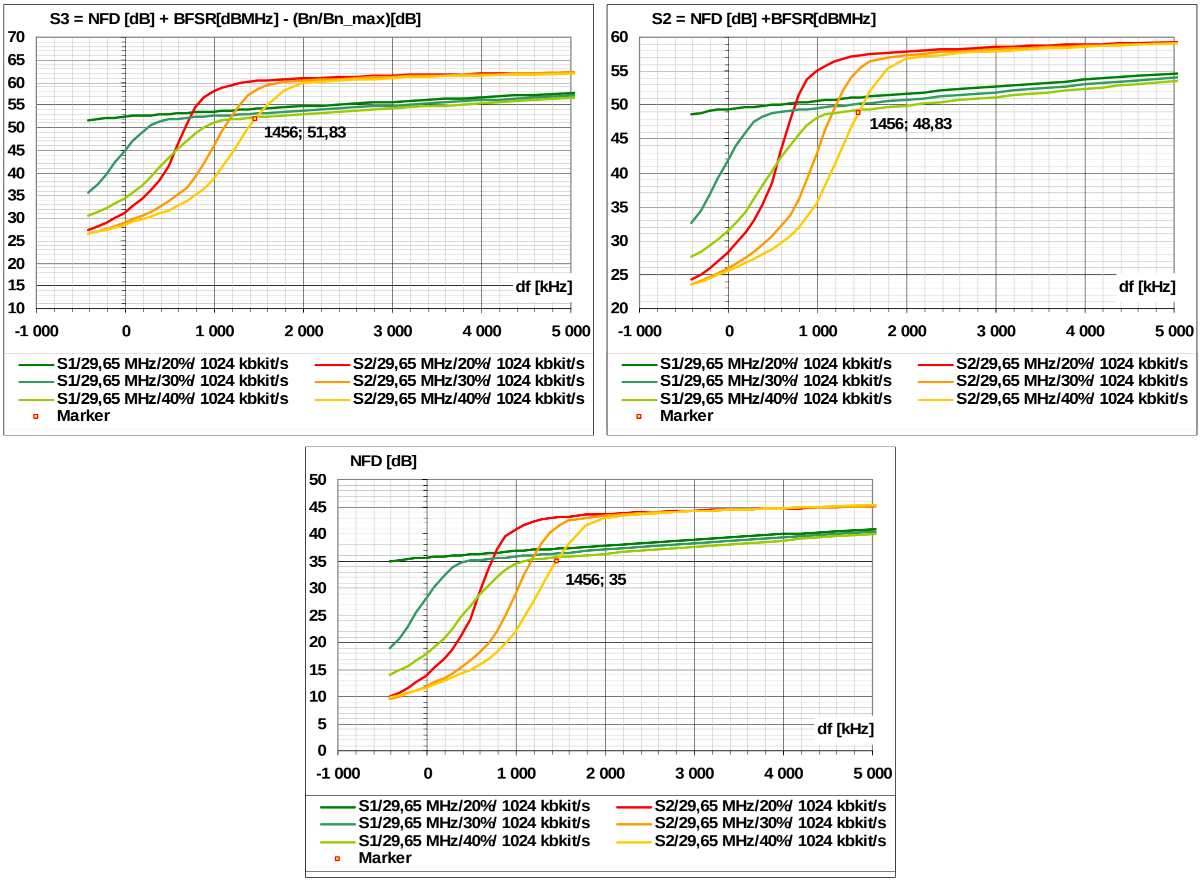


Figure 23: FS systems' Rx filter sums S_3 , S_2 and NFD for the minimum channel spacing values and an ESV carrier at 1.024 Mbit/s

For a 64 kbit/s carrier S_3 = 51.83 dB for NFD = 22.95 dB and *df* = 1 297 kHz.

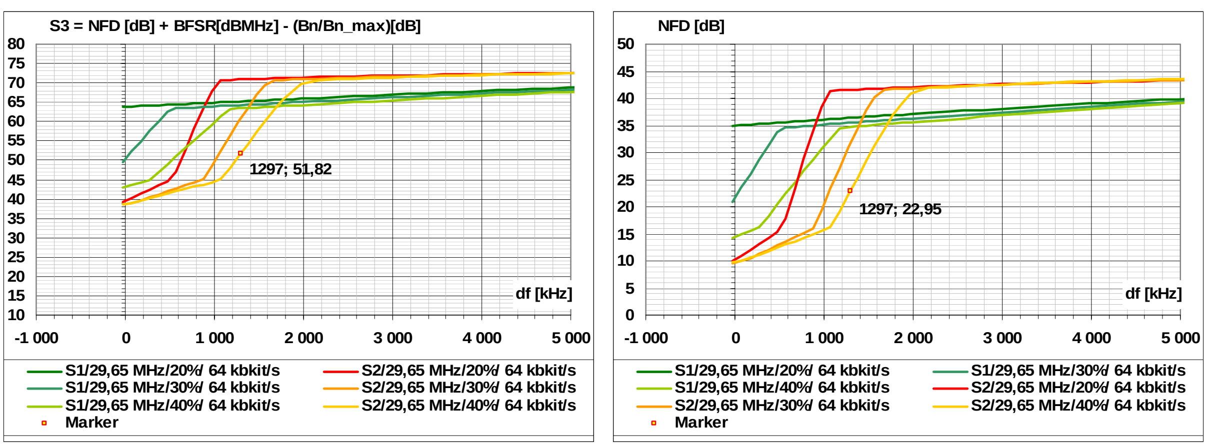


Figure 24: FS systems' Rx filter sum S_3 and NFD for the minimum channel spacing values and an ESV carrier at 64 kbit/s

In the case where the ESV on-axis e.i.r.p. and e.i.r.p. spectral density are limited to given values (e.g. 58 dBW and 29.65 dBW/kHz instead of 26.65 dBW/kHz) and the NFD limited to a minimum value (e.g. 35 dB) for the highest bit rate the minimum guard-band (*df*) is determined for the smallest carrier with the maximum e.i.r.p.:

Minimum guard-band *df* ≥ 1 500 kHz for NFD = 35 dB for the highest bit rate (2.048 Mbit/s)

Remark: 1 500 kHz is the round value greater than to the maximum of 1 360 kHz, 1 456 kHz and 1 297 kHz.

In the above figures, it can be seen that the deciding factor in determining a minimum frequency separation between an FSR channel and an ESV carrier is the noise floor of the ESV carrier, which gives a NFD of 35 dB for ESVs whose phase noise floor does not exceed -120 dBc/Hz. For a NFD not less than 35 dB for the highest bit rate, the minimum guard-band (*df*) is equal to 1.5 MHz for any combination of the selected FS systems and ESV carrier bit rates up to 2.048 Mbit/s.

6.3.3 Variations of the NFD value with ESVs

The NFD value varies with an ESVs characteristics and with its operational conditions over a large range of dBs.

Within the IESS 308 [9], the IESS 309 [10] and the EESS 500 [15] the requirement for the maximum phase noise floor is -90 dBc/Hz.

Figure 25 represents the NFD for:

- the FS systems S2 receive filter,
- an ESV carrier at 2.048 Mbit/s, and
- various values of the phase noise floors (PhN) of the ESV modulator and up-converters from -90 dBc/Hz to -130 dBc/Hz

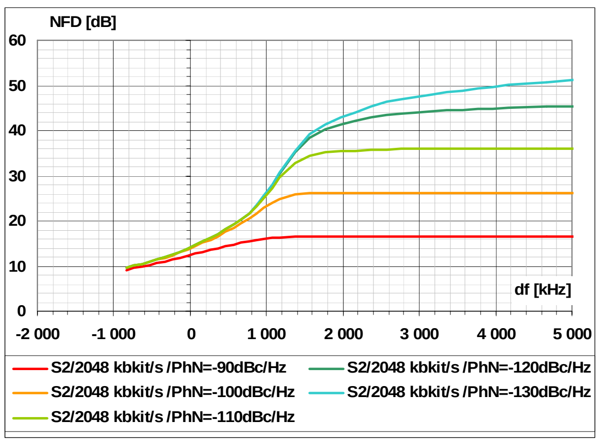


Figure 25: Rx filter NFD with FS system S2 for various values of the phase noise floors (PhN) of the ESV modulators and up-converters and an ESV carrier at 2.048 Mbit/s

The present report limits the study to the case where the ESV phase noise floor does not exceed -120 dBc/Hz.

This phase noise floor value is the typical value proposed by ETSI and is suitable to obtain an NFD of at least 35 dB for a frequency offset (*df*) between 1.4 MHz and 1,7 MHz depending on the limitations on the ESV e.i.r.p. and the e.i.r.p. spectral density.

Figure 26 represents the NFD for:

- the FS systems S2 receive filter,
- an ESV carrier at 2.048 Mbit/s, and
- various values of the 1st side lobes levels (SLLs) of the ESV spectrum mask, i.e. for various HPA back-offs.

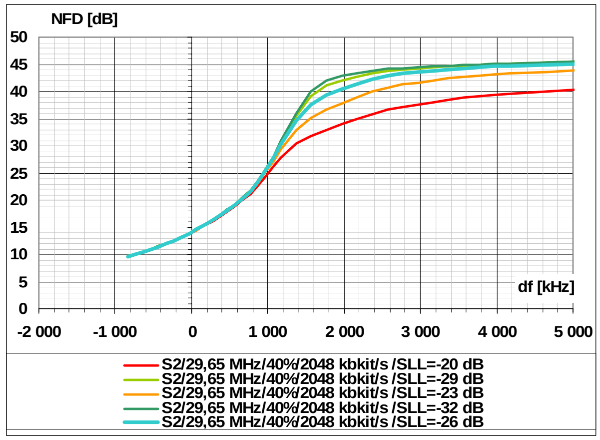


Figure 26: Rx filter NFD with FS systems S2 for various values the 1st side lobes levels (SLLs) of the ESV spectrum mask and an ESV carrier at 2.048 Mbit/s

The present report limits the study to the case where the p.s.d. of the 1st spectrum side lobe of the ESV carrier is at least 27 dB below the in-band p.s.d.

This limit is the typical value of the ESV spectrum mask proposed by ETSI.

In case of transmission of several carriers, the NFD has to be computed with the spectrum of all carriers together.

The following figure shows the spectra of a single carrier and of 2 carriers with the same Input Back-Off (IBO). In both cases the Global Input Back-Off (GIBO) is the same.

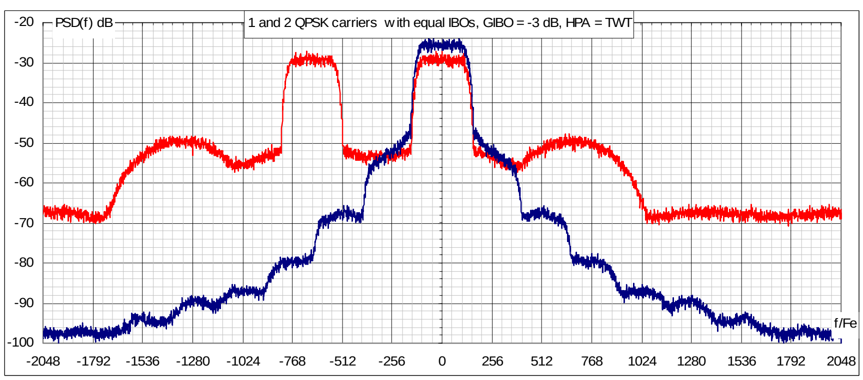


Figure 27: Examples of spectra of a single carrier and 2 carriers transmitted through an HPA

The present report limits the study to the case where the ESV transmits a single carrier per HPA.

Most of the ESVs transmit a single carrier per HPA.

6.4 Case of an ESV located below the FSR main beam axis.

6.4.1 Case of a flat Earth

The following assumptions are made:

- the Earth surface is flat,
- the FSR main beam axis is horizontal,
- the ESV is on the sea surface below the FSR main beam axis.

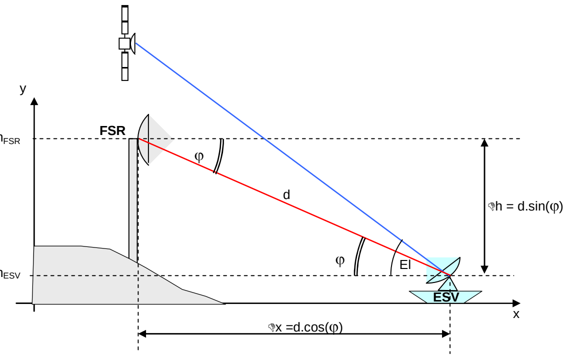


Figure 28: FSR and ESV on a flat Earth

Let:

$d_{[m]}$	the distance between the FSR and the ESV,
$\varphi_{[\circ]}$	the FSR off-axis angle of the direction towards the ESV,
$El_{[\circ]}$	the ESV main beam axis elevation,
$h_{FSR[m]}$	the FSR altitude above the sea level,
$h_{ESV[m]}$	the ESV altitude above the sea level,
$\Delta h_{[m]}$	the difference between the ESV and FSR altitudes,
$\Delta x_{[m]}$	the distance of the ESV to the FSR,

$dg_{[rad/\circ]}$ the coefficient used to convert angles in degrees into angles in radians: $dg_{[rad/\circ]} = \frac{\pi}{180}$

Then:

(48) : $$d_{[m]} = \frac{\Delta h_{[m]}}{\sin\left(\varphi_{[\circ]}.dg_{[rad/\circ]}\right)}$$

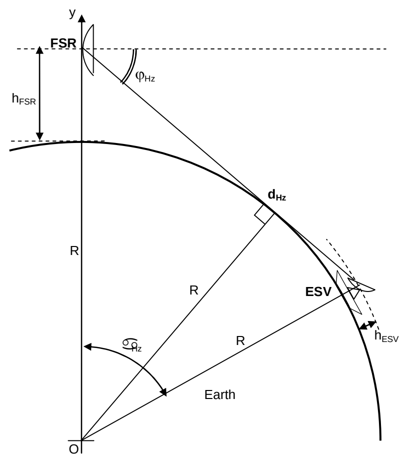
(49) : $$\Delta x_{[m]} = \frac{\Delta h_{[m]}}{\tan\left(\varphi_{[\circ]}.dg_{[rad/\circ]}\right)}$$

(50) : $$G_{FSR}\left(\varphi_{FSR}\right)_{[dBi]} = G_{FSR}\left(\varphi_{[\circ]}\right)_{[dBi]}$$

(51) : $$G_{ESV}\left(\varphi_{ESV}\right)_{[dBi]} = G_{ESV}\left(\left|El_{[\circ]} - \varphi_{[\circ]}\right|\right)_{[dBi]}$$

6.4.2 Case of a spherical Earth

6.4.2.1 FSR and ESV horizons



The following parameters are defined:

(52) : $$\alpha_{Hz} = ArcCos\left(\frac{R}{R+h_{FSR}}\right) + ArcCos\left(\frac{R}{R+h_{ESV}}\right)$$

(53) : $$d_{Hz} = \sqrt{2.R.h_{FSR} + h_{FSR}^2} + \sqrt{2.R.h_{ESV} + h_{ESV}^2}$$

The Earth radius usually used is 6 371 km. In order to take account the diffraction by the atmosphere, the equivalent Earth radius is used:

(54) : $$R = \frac{4}{3}.6371\ km$$

6.4.2.2 Case where the ESV is in line of sight of the FSR

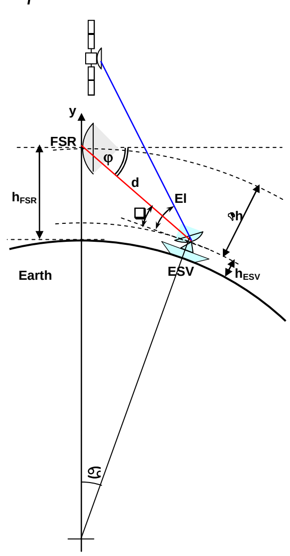


Figure 29: FSR and ESV on a spherical Earth

The angle θ is the elevation angle of the direction of the FSR at the ESV.

(55) : $$\frac{\sin(\alpha)}{d}=\frac{\cos(\varphi)}{R+h_{ESV}}=\frac{\cos(\theta)}{R+h_{FSR}}$$

(56) : $$\boxed{\varphi = ArcCos\left(\frac{R+h_{ESV}}{d}.\sin(\alpha)\right)}$$

(57) : $$d=\sqrt{(R+h_{ESV})^2+(R+h_{FSR})^2-2.(R+h_{ESV}).(R+h_{FSR}).\cos(\alpha)}$$

(58) : $$\boxed{d=\sqrt{(h_{FSR}-h_{ESV})^2+4.(R+h_{ESV}).(R+h_{FSR}).\sin\left(\frac{\alpha}{2}\right)^2}}$$

6.4.2.3 Case where the ESV is beyond the horizon of the FSR

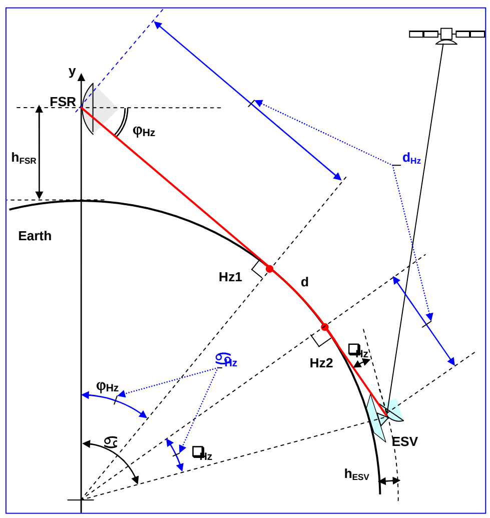


Figure 30: FSR and ESV on a spherical Earth but beyond the horizon

For the purpose of the present study, in the case where the ESV is beyond the horizon of the FSR the following approximation is done:

- The path from the FSR is in line of sight of the FSR horizon up to the point H_{z1} (See Figure 30);
- the path from the ESV is in line of sight of the ESV horizon up to the point H_{z2} (See Figure 30),
- the path is parallel to the Earth surface between the points H_{z1} and H_{z2}.

In that case:

(59) : $$d = d_{Hz}+\frac{\alpha-\alpha_{Hz}}{R}$$

where

d_{Hz} is the distance defined on Figure 30,

α_{Hz} is the angle defined on Figure 30.

with:

(60) : $$\varphi_{Hz}=ArcCos\left(\frac{R}{R+h_{FSR}}\right)$$

(61) : $$\theta_{Hz} = ArcCos\left(\frac{R}{R+h_{ESV}}\right)$$

(62) : $$\alpha_{Hz} = \varphi_{Hz} + \theta_{Hz}$$

When the ESV is below the FSR horizon, the FSR antenna off-axis angle φ_{FSR} of the direction towards the ESV is limited to the off-axis angle (φ_{Hz}) of the FSR horizon and the ESV antenna off-axis angle θ_{ESV} of the direction towards the FSR is limited to the off-axis angle (θ_{Hz}) of the ESV horizon.

6.4.3 Level of interference from an ESV located below the FSR antenna main beam axis

The level of interference received by a FSR from an ESV is given by the following equation:

(63) : $$\boxed{I_{[dBW]} = \left\{\begin{matrix} EIRP_{ESV}\left(0°\right)_{[dBW]} - G_{ESV}\left(0°\right)_{[dBi]} \\ +G_{ESV}\left(\left|El_{[°]} - \theta_{[°]}\right|\right)_{[dBi]} - L\left(d\right)_{[dB]} + G_{FSR}\left(\varphi_{[°]}\right)_{[dBi]} \\ -NFD\left(df\right)_{[dB]} \end{matrix}\right\}}$$

where:

$EIRP_{ESV}\left(0°\right)_{[dBW]}$	is the ESV on axis e.i.r.p. of all transmitted signals (in-band, out-of-band and spurious signals),
$G_{ESV}\left(0°\right)_{[dBi]}$	is the ESV antenna on axis gain,
$\varphi_{[°]}$	is the off-axis angle at the FSR of the direction towards the ESV.
$\theta_{[°]}$	is the elevation angle at the ESV of the direction towards the FSR.
	Remark: In case of a flat Earth model: $\theta_{[°]} = \varphi_{[°]}$
$G_{ESV}\left(\left\|El_{[°]} - \varphi_{[°]}\right\|\right)_{[dBi]}$	is the ESV antenna gain angle towards the FSR,
$L\left(d\right)_{[dB]}$	is the propagation loss between the ESV and the FSR,
$G_{FSR}\left(\varphi_{[°]}\right)_{[dBi]}$	is the FSR antenna gain towards the ESV,
df	is the separation in frequency between the edge of the adjacent FS channel and the nearest edge of the ESV carrier. The edge of the ESV carrier is measured 10 dB below its maximum in-band power density,
$NFD\left(df\right)_{[dB]}$	is the Net Filter Discrimination of the ESV signal by the FSR receiver filter for the frequency offset df .

For free space loss on a flat Earth:

(64) : $$L\left(d\right)_{[dB]} = 20.\log\left(\frac{4.\pi.\Delta h_{[m]}}{\lambda_{[m]}}\right) - 20.\log\left(\sin\left(\varphi_{[°]}.dg_{[rad/°]}\right)\right)$$

6.4.4 Variations of the $GLG(\varphi)_{[dB]}$ function with the ESV location

Within the present section the propagation loss is the free space loss.

Let $GLG(\varphi)_{[dB]}$ ("Gain - Loss + Gain") the sum in dBs of the FSR antenna off-axis gain, the propagation loss and the ESV antenna off-axis gain, which are the components of the formula giving the received interference level (I) which are function of the ESV location:

(65) : $$\boxed{GLG(\varphi)_{[dB]} == G_{FSR}(\varphi)_{[dBi]} - L(\varphi)_{[dB]} + G_{ESV}(|El-\theta|)_{[dBi]}}$$

For the following parameters:

FS link	
Frequency	6175 MHz
FS Receiver (FSR)	
Antenna altitude	90 m
Antenna diameter	3.00 m
Antenna efficiency	65.8%
Interfering ESV	
Antenna height	40 m
Antenna diameter	2.40 m
Antenna efficiency	65.8%
Elevation	20°
Intermediate results	
FSR altitude- ESV height	50 m
FSR on-axis gain	43.86 dBi
FSR half beamwidth	0.561°
ESV on-axis gain	42.00 dBi
ESV half beamwidth	0.701°

the following results were obtained by computation for free space losses with a flat Earth and a round Earth of radius equal to 4/3 x 6 371 km in order to take account the atmosphere diffraction:

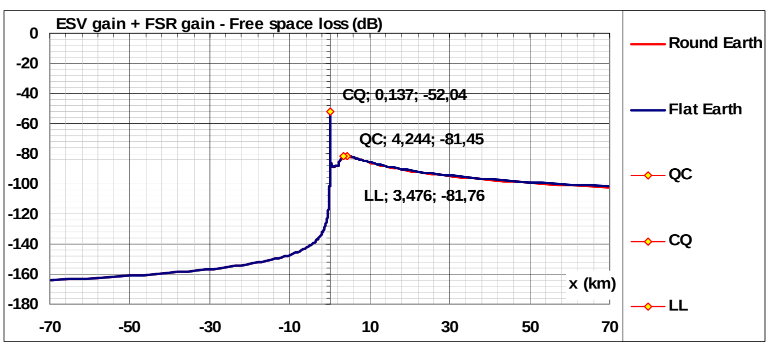


Figure 31: Function $GLG(\varphi)_{[dB]}$ vs. ESV distance (*x*) from the FSR for an ESV elevation equal to 20°

At point QC:

(66) : $$G_{FSR}(\varphi) = G_{FSR}(0°) - 3.\left(\frac{\varphi}{\varphi_{FSR,-3dB}}\right)^2 \text{ dBi for } 0° \le \varphi < \varphi_m$$

(67) : $$G_{ESV}(|El-\theta|) = G_{ESV}(48°) \text{ dBi}$$

The $GLG(\varphi)_{[dB]}$ function is maximum for:

(68) : $$\boxed{\varphi_{QC} \cong \frac{\varphi_{FSR,-3dB}}{\sqrt{0,3.Ln(10)}} = 1,203.\varphi_{FSR,-3dB}}$$ and: $$\boxed{\Delta x_{[m]} = \frac{\Delta h_{[m]}}{\tan\left(\varphi_{QC[°]}.dg_{[rad/°]}\right)}}$$

Antenna height differences [m]	**FSR antenna diameter [m]**			
	1.20	1.80	2.40	3.00
5	0.170	0.255	0.340	0.424
10	0.339	0.509	0.679	0.849
25	0.849	1.273	1.698	2.122
50	1.697	2.546	3.395	4.244
100	3.394	5.093	6.790	8.488
200	6.789	10.185	13.581	16.976

Table 13: Distance *x* [km] of the ESV from the FSR at point QC

The variations of the value of $GLG(\varphi)_{[dB]}$ are given in Table 14 and shown in **Figure 32**.

	Parameter (p)			GLG = ESV gain + FSR gain - Free space loss [dB]			dGLG [dB]	
	p_{min}	p_{nom}	p_{max}	GLG (p_{min})	GLG (p_{nom})	GLG (p_{max})	GLG(p_{min}) - GLG(p_{nom})	GLG(p_{max}) - GLG(p_{nom})
FSR height [m]	41	90	140	-47.47	-81.45	-87.47	33.98	-6.02
ESV height [m]	10	40	50	-85.53	-81.45	-79.51	-4.08	1.94
FSR antenna diameter [m]	1.20	3.00	3.30	-80.87	-81.45	-81.48	0.58	-0.03
FSR antenna efficiency	60.0%	64.6%	70.0%	-81.77	-81.45	-81.10	-0.32	0.35
ESV antenna diameter [m]	2.40	2.40	3.20	-81.45	-81.45	-81.45	0.00	0.00
ESV antenna efficiency	60.0%	65.8%	70.0%	-81.45	-81.45	-81.45	0.00	0.00
ESV pattern degradation [dB]	0.00	3.00	6.00	-84.45	-81.45	-78.45	-3.00	3.00
ESV elevation [°]	20	20	70	-81.45	-81.45	-88.30	0.00	-6.85

Table 14: Variations of the value of $GLG(\varphi_{QC})_{[dB]}$

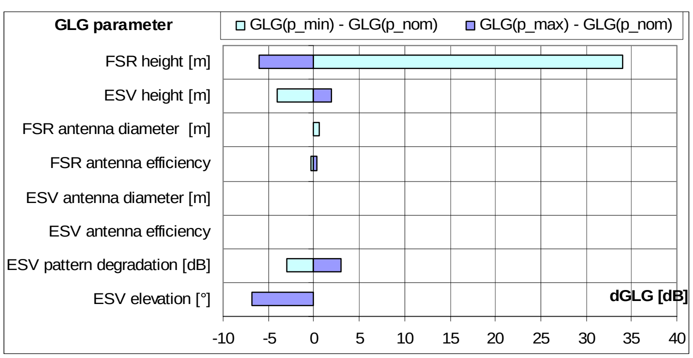


Figure 32 Variations of the value of $GLG(\varphi_{QC})_{[dB]}$

Additionally the level of interference varies with the ESV e.i.r.p., the ESV antenna gain and the NFD.

6.4.5 Minimum distances (d_0) *below the FSR main beam axis*

The minimum distances (d_0) computed within this section are only valid for stationary ESVs below the FSR main beam axis.

For moving ESVs lower minimum distances (d_0) are obtained in later sections (see § 6.6).

With the following equation the minimum distance (d_0) of the ESV below the FSR main beam axis may be determined:

$$\text{(69)}: \quad \left\{ G_{ESV}\left(\left|El_{[\circ]}-\theta_{[\circ]}\right|\right)_{[dBi]} - L(d)_{[dB]} + G_{FSR}\left(\varphi_{[\circ]}\right)_{[dBi]} \right\} = \left\{ \begin{matrix} I_{\max\,[dBW]} - EIRP_{ESV}\left(0°\right)_{[dBW]} \\ +G_{ESV}\left(0°\right)_{[dBi]} + NFD(df)_{[dB]} \end{matrix} \right\}$$

For given values of the parameters on the left hand side of the sign " = " and of the ESV main beam elevation, the determination of the parameters d, θ and φ is obtained by successive iterations. In fixing the value of one of the parameters of d, θ or φ the values of the other parameters are determined. In some cases there may be no solution, e.g. when the level of interference from the ESV is very low.

<u>Computation method:</u>

For the computation, at the n^{th} step the parameter d was given the value d_n and the resulting value of the GLG function was GLG_n. The goal was that the value of the GLG function comes as close as possible to a value (GLG*) of the left hand side of equation 66. The following algorithm was used:

d_{n+1} = Max(1 km , Min(600 km, d_n+ (GLG_n - GLG*).(d_{452}(p, L_n + 3 dB) - d_n) / 6 dB))

where:

d_{452}(p, L) is the function giving the distance where the propagation loss is lower than ($L_{[dB]}$) for no more than p% of the year, and

L_n is the propagation loss computed at the n^{th} step with distance d_n.

For example, in the case of an I/N ratio of -19 dB, for the following conditions:

FS link		
Frequency	6175	MHz
FS Receiver (FSR)		
Antenna altitude (h_{FSR})	90	m
Distance to coast	0	km
Antenna diameter	3.00	m
Antenna efficiency	64.6%	
Antenna temperature	300	K
Feeder loss	3	dB
Receiver noise figure	4.125	dB
Receiver bandwidth	22906	kHz
Interfering ESV		
Antenna altitude (h_{ESV})	40	m
Antenna diameter	2.40	m
Antenna efficiency	65.8%	
NFD	35	dB
Pattern degradation	3.00	dB
Modulation rate	2	bit/Hz
Typical e.i.r.p. spectral density	24.90	dBW/kbit/s
Interference criterion		
I/N	-19	dB
FS Receiver (FSR)		
FSR on-axis gain	43.86	dBi
FSR half beamwidth	0.561	°
FSR noise temperature	750	K
FSR system temperature	2085	K
N	-121.81	dBW
(N+I)/N	0.054	dB
I	-110.8	dBm
Interfering ESV		
ESV on-axis gain	42.00	dBi
ESV half beamwidth	0.701	°
ESV gain at 7°	7.87	dBi

Table 15: Typical FSR and ESV parameters

the following minimum distances (d_0) below the FSR main beam axis are obtained:

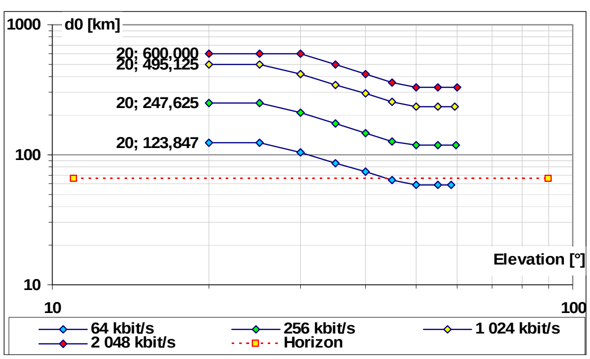


Figure 33: Minimum distances (d_0) below the FSR main beam axis for:
Typical e.i.r.p. spectral density = 24.90 dBW/kbit/s, I/N = -19 dB, h_{ESV} = 40 m, h_{FSR} = 90 m
with a stationary ESV, a flat Earth model and for free space loss

With a spherical Earth similar results are obtained.

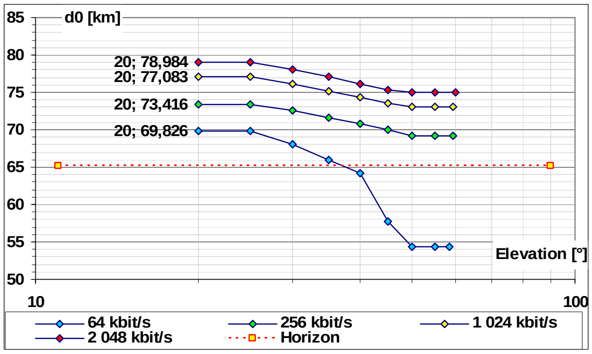


Figure 34: Minimum distances (d_0) below the FSR main beam axis for:
Typical e.i.r.p. spectral density = 24.90 dBW/kbit/s, I/N = -19 dB, h_{ESV} = 40 m, h_{FSR} = 90 m
with a stationary ESV, a spherical Earth model, and ITU-R Rec. P.452 propagation loss p = 20%

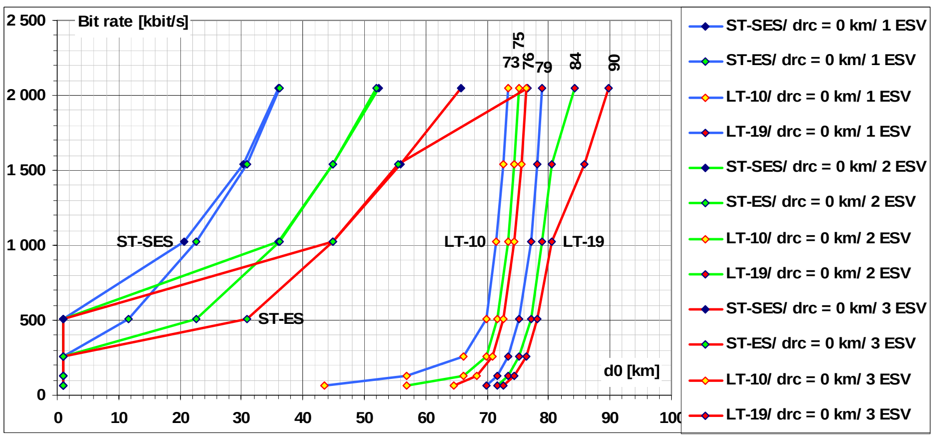


Figure 35: Minimum distances (d_0) below the FSR main beam axis for:
Typical e.i.r.p. spectral density = 24.90 dBW/kbit/s, h_{ESV} = 40 m, h_{FSR} = 90 m with a stationary ESV, a spherical Earth model, ITU-R Rec. P.452 propagation loss, 20° elevation and for various interference criteria and bit rates

drc is the distance of the receiver (i.e. the FSR) to the coast.

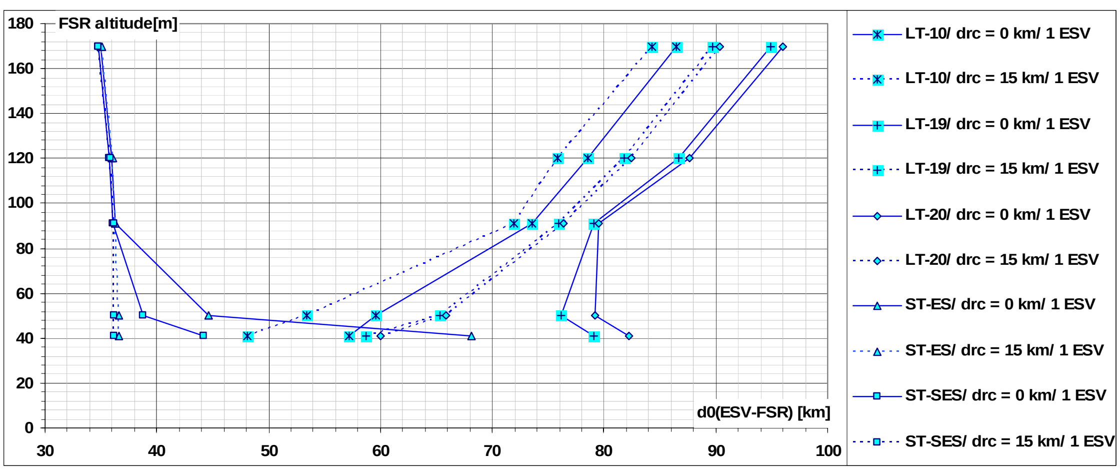


Figure 36: Minimum distances (d_0) below the FSR main beam axis for:
Typical e.i.r.p. spectral density = 24.90 dBW/kbit/s, h_{ESV} = 40 m, h_{FSR} = 90 m with a stationary ESV, a spherical Earth model, ITU-R Rec. P.452 propagation loss, 20° elevation and for various interference criteria and FSR altitudes, in the case of 1 ESV

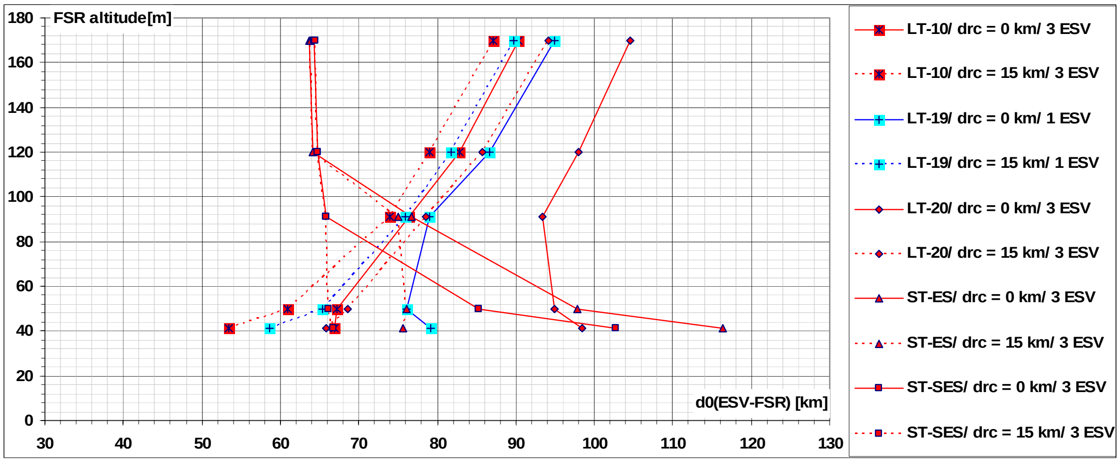


Figure 37: Minimum distances (d_0) below the FSR main beam axis for: Typical e.i.r.p. spectral density = 24.90 dBW/kbit/s, h_{ESV} = 40 m, h_{FSR} = 90 m with a stationary ESV, a spherical Earth model, ITU-R Rec. P.452 propagation loss, 20° elevation and for various interference criteria and FSR altitudes, in the case of 3 ESVs

The Excel file attached to this report (available from the ERO web site) contains within the spreadsheet "Fixed_ESV_results" computation results for various FSR altitudes and distances to the coast, ESV altitudes and ESV main beam elevations. The input data are with yellow background and the results are with blue background.

6.5 Case where the ESV is not located below the FSR antenna main beam axis

6.5.1 General

The contours computed within this section are only valid for stationary ESVs.

6.5.2 Geometry

The case of an ESV which is not located below the FSR antenna main beam axis is represented on Figure 38 in the case of a flat Earth.

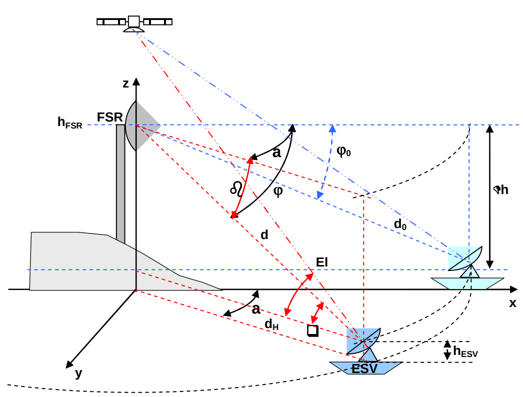


Figure 38: Case of an ESV not located below the FSR antenna main beam axis in the case of a flat Earth

The case of a flat Earth is represented on the above figure, but the following definitions and formulae apply to both the flat Earth model and the spherical model.

Let:

$d_{[m]}$ the path length between the FSR and the ESV (it is the FSR to ESV distance when the ESV is in line of sight of the FSR) ,

$d_{0[m]}$ the minimum path length between the FSR and the ESV when the ESV is below the FSR antenna main beam axis,

$d_{H[m]}$ the distance on the Earth surface between the vertical lines at FSR and at the ESV,

$\varphi_{[\circ]}$ the FSR off-axis angle of the direction towards the ESV,

$\varphi_{0[\circ]}$ the FSR off-axis angle of the direction towards the ESV when the ESV is below the FSR antenna main beam axis at the minimum distance $d_{0[m]}$ from the FSR,

$\theta_{[\circ]}$ the ESV off-axis angle of the direction towards the FSR,

$El_{[\circ]}$ the ESV main beam axis elevation,

$h_{FSR[m]}$ the FSR altitude above the sea level,

$h_{ESV[m]}$ the ESV altitude above the sea level,

$\Delta h_{[m]}$ the difference between the ESV and FSR altitudes,

$R_{[m]}$ the equivalent radius of the Earth,

$\alpha_{[\circ]}$ the angle at the Earth centre between the directions of the FSR and the ESV,

$dg_{[rad/\circ]}$ the coefficient used to convert angles in degrees into angles in radians: $dg_{[rad/\circ]} = \dfrac{\pi}{180}$

Then:

(70) : $$d_{H[m]} = R_{[m]}.\alpha_{[\circ]}.dg_{[rad/\circ]}$$

(71) : $$Cos\left(\varphi_{[\circ]}.dg_{[rad/\circ]}\right) = Cos\left(a_{[\circ]}.dg_{[rad/\circ]}\right).Cos\left(\beta_{[\circ]}.dg_{[rad/\circ]}\right)$$

In the case of a flat earth:

(72) : $$\beta_{[\circ]} = \theta_{[\circ]}$$

(73) : $$d_{[m]} = \frac{\Delta h_{[m]}}{\sin\left(\theta_{[\circ]}.dg_{[rad/\circ]}\right)}$$

(74) : $$d_{H[m]} = \frac{\Delta h_{[m]}}{\tan\left(\theta_{[\circ]}.dg_{[rad/\circ]}\right)}$$

(75) : $$Cos\left(\varphi_{[\circ]}.dg_{[rad/\circ]}\right) = Cos\left(a_{[\circ]}.dg_{[rad/\circ]}\right).Cos\left(\theta_{[\circ]}.dg_{[rad/\circ]}\right)$$

6.5.3 Contour of constant level of interference

The FSR antenna gain in the direction of the ESV is given by:

(76) : $$G_{FSR}\left(\varphi_{FSR}\right)_{[dBi]} = G_{FSR}\left(\varphi_{[\circ]}\right)_{[dBi]}$$

The ESV antenna gain in the direction of the FSR is given by:

(77) : $$G_{ESV}\left(\varphi_{ESV}\right)_{[dBi]} = G_{ESV}\left(\left|El_{[\circ]} - \theta_{[\circ]}\right|\right)_{[dBi]}$$

The level of interference received by the FSR is given by:

(78) : $$I_{[dBW]} = \begin{Bmatrix} EIRP_{ESV}\left(0^\circ\right)_{[dBW]} - G_{ESV}\left(0^\circ\right)_{[dBi]} - NFD\left(df\right)_{[dB]} \\ +G_{ESV}\left(\left|El_{[\circ]} - \theta_{[\circ]}\right|\right)_{[dBi]} - L\left(d\right)_{[dB]} + G_{FSR}\left(\varphi_{[\circ]}\right)_{[dBi]} \end{Bmatrix}$$

Below the FSR antenna main beam axis the level of interference (I) is equal to the maximum acceptable level of interference (I_{max}) at distance d_0:

(79) : $$I_{\max[dBW]} = \begin{Bmatrix} EIRP_{ESV}\left(0^\circ\right)_{[dBW]} - G_{ESV}\left(0^\circ\right)_{[dBi]} - NFD\left(df\right)_{[dB]} \\ +G_{ESV}\left(\left|El_{[\circ]} - \theta_{0[\circ]}\right|\right)_{[dBi]} - L\left(d_0\right)_{[dB]} + G_{FSR}\left(\varphi_{0[\circ]}\right)_{[dBi]} \end{Bmatrix}$$

The contour where the level of interference is maximum, i.e. equal to $I_{\max,[dBW]}$, is the contour such that:

(80) : $$I_{[dBW]} = I_{\max[dBW]}$$

or:

(81) : $$\begin{Bmatrix} G_{FSR}\left(\varphi_{[\circ]}\right)_{[dBi]} - L\left(d\right)_{[dB]} \\ +G_{ESV}\left(\left|El_{[\circ]} - \theta_{[\circ]}\right|\right)_{[dBi]} \end{Bmatrix} = \begin{Bmatrix} G_{FSR}\left(\varphi_{0[\circ]}\right)_{[dBi]} - L\left(d_0\right)_{[dB]} \\ +G_{ESV}\left(\left|El_{[\circ]} - \theta_{0[\circ]}\right|\right)_{[dBi]} \end{Bmatrix}$$

In order to plot the contour with a suitable distribution of the points in azimuth (a) around the FSR, it is preferable to successively give to φ the preferred values of a and to determine for each value of φ the corresponding value of θ, and subsequently the values of d and the exact value of a.

For the typical FSR and ESV parameters listed above, the following contours were obtained:

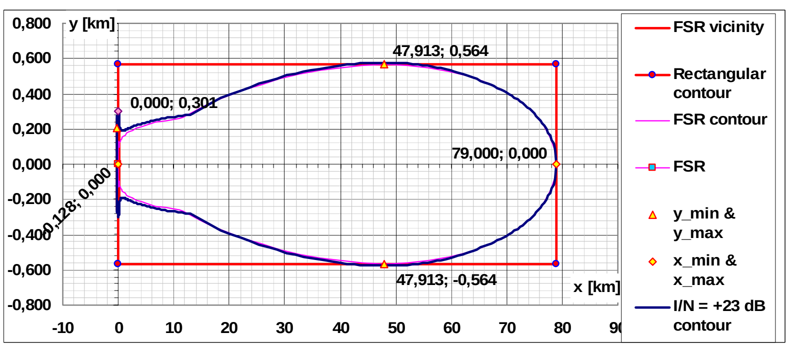


Figure 39: Example of contour for: d_0 = 79 km
for a 2.048 Mbit/s carrier, 20° elevation, I/N = -19 dB, h_{ESV} = 40 m, h_{FSR} = 90 m,
with free space loss, for stationary ESVs

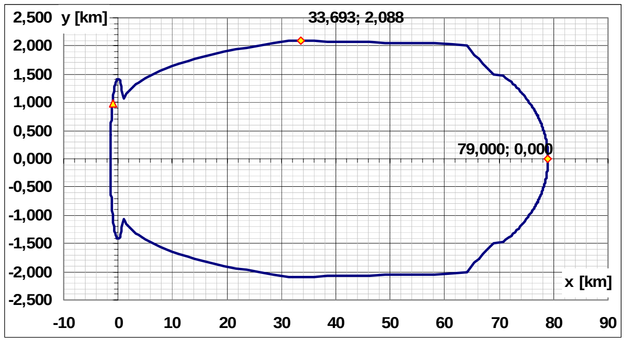


Figure 40: Example of contour for: d_0 = 79 km
for a 2.048 Mbit/s carrier, 20° elevation I/N = -19 dB, h_{ESV} = 40 m, h_{FSR} = 90 m,
with ITU-R Rec. P.452 propagation loss and p = 20%, for stationary ESVs

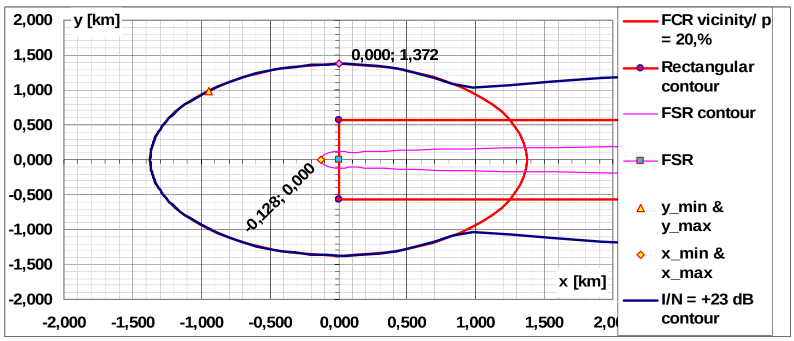


Figure 41: Example of contour in the vicinity of the FSR for: d_0 = 79 km
for a 2.048 Mbit/s carrier, 20° elevation I/N = -19 dB, h_{ESV} = 40 m, h_{FSR} = 90 m,
with ITU-R Rec. P.452 propagation loss and p = 20%, for stationary ESVs

In the case of free space loss, the size of the contour, the FSR vicinity being excluded, is mainly determined by the parameter d_0.

In the case of free space loss, the point (x_1, y_1) of the contour where the y coordinate is maximum, near the FSR antenna main beam corresponds to a □ $\varphi = \varphi_{QC}$ with:

(82) : $$\boxed{\varphi_{QC} \cong \frac{\varphi_{FSR,-3dB}}{\sqrt{0,3.Ln(10)}} = 1,203.\varphi_{FSR,-3dB}}$$

and:

(83) : $$\boxed{d_1 \cong d_0.10^{-\frac{1}{2.Ln(10)}} = 0,607.d_0} \quad \boxed{x_1 = d_1.Cos(\varphi_{Qc})} \quad \boxed{y_1 = d_1.Sin(\varphi_{Qc})}$$

(84) : $$\boxed{y_1 \approx d_0.0,607\,.\,1,203\,.\,35\,.\frac{\pi}{180}.\frac{\lambda}{D_{FSR}} = d_0.0,446.\frac{\lambda}{D_{FSR}}} \text{ km}$$

The ratio between the length (d_0) and the half-width (y_1) is respectively 1.8%, 1.2% and 0.7% for a 1.2 m, 1.80 m and 3 m FS antenna.

Figure 42 shows the FSR half power beamwidth at various distances from the FSR, assuming a flat Earth and free space loss (FSL) and for a 2.048 Mbit/s ESV carrier. For each distance, the corresponding (I/N) contribution of a single ESV is indicated in the figure.

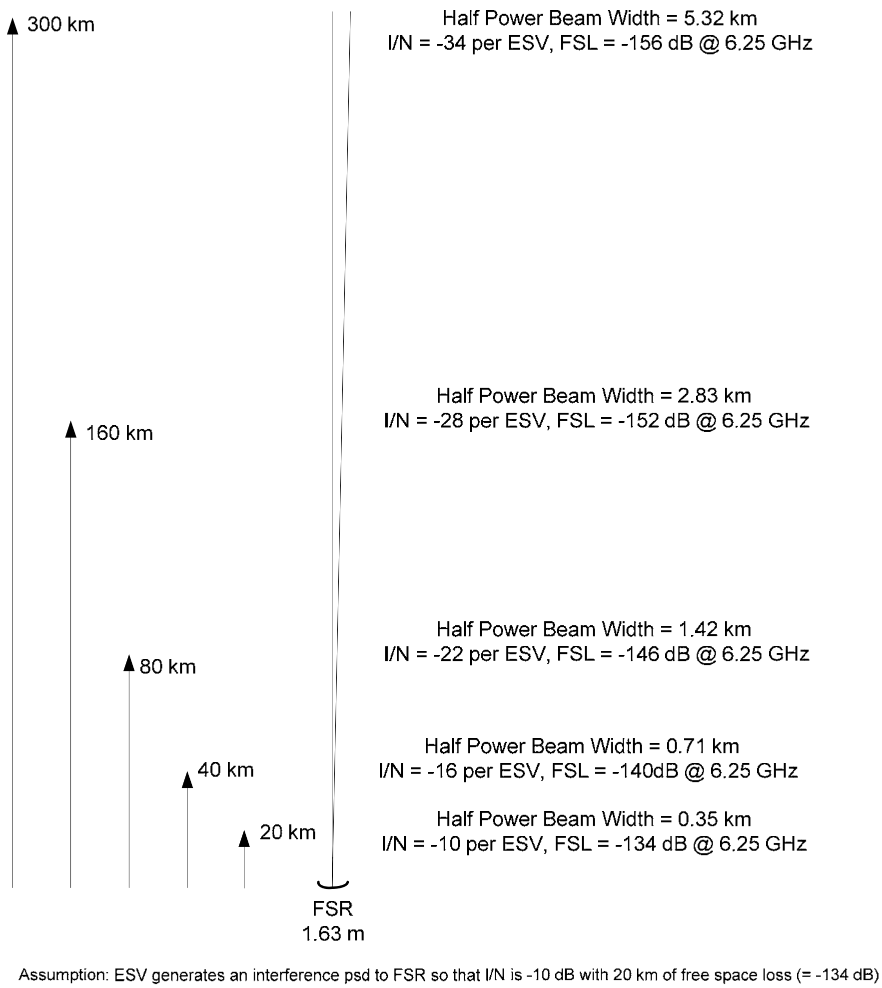


Figure 42: Example of FSR half power beamwidth and (*I/N*) ratio for a flat Earth and free space loss (FSL) and a 2.048 Mbit/s carrier

6.5.4 Zone where the short term performance criteria threshold are exceeded

The computation method used up to this point may be applied to determine the size of the zone where the short term performance criteria thresholds are exceeded.

With the following conditions:

Interfered FSR	
FSR altitude	90 m
NFD	35 dB
Interfering ESV	
ESV height	40 m
ESV elevation	20°
Nominal e.i.r.p. density	24.90 dBW/ kbit/s
ST-ES interference criterion	
I/N	+19.0 dB
p	0.00045%

the following contour was obtained:

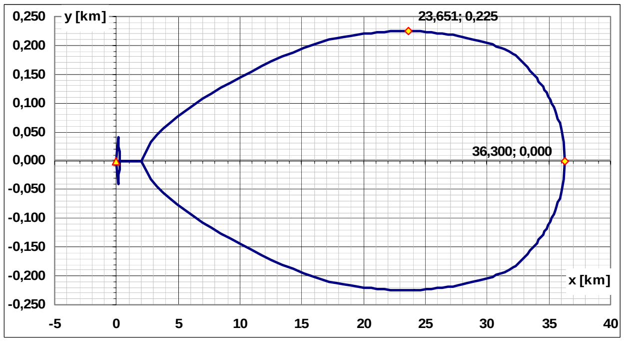


Figure 43: Contour for I/N = +19 dB during less than 0.00045% of the year for a 2.048 Mbit/s carrier with elevation = 20° and NFD = 35 dB, for stationary ESVs

Similarly for:

ST-SES interference criterion	
I/N	+23.0 dB
p	0.000012%

the following contour was obtained:

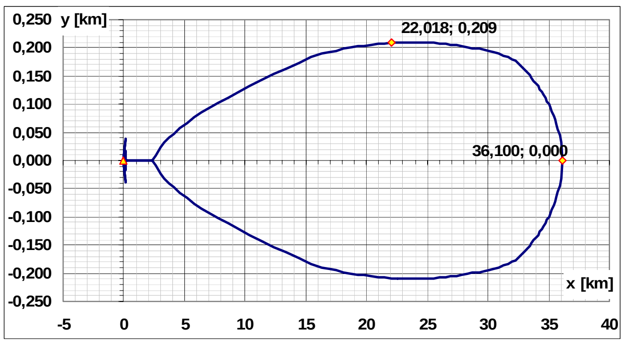


Figure 44: Contour for I/N = +23 dB during less than 1,2x10^{-7} of the year for a 2.048 Mbit/s carrier with elevation = 20° and NFD = 35 dB, for stationary ESVs

The contour in Figure 44 is represented below on Figure 45 with the same scale for both x and y axes.

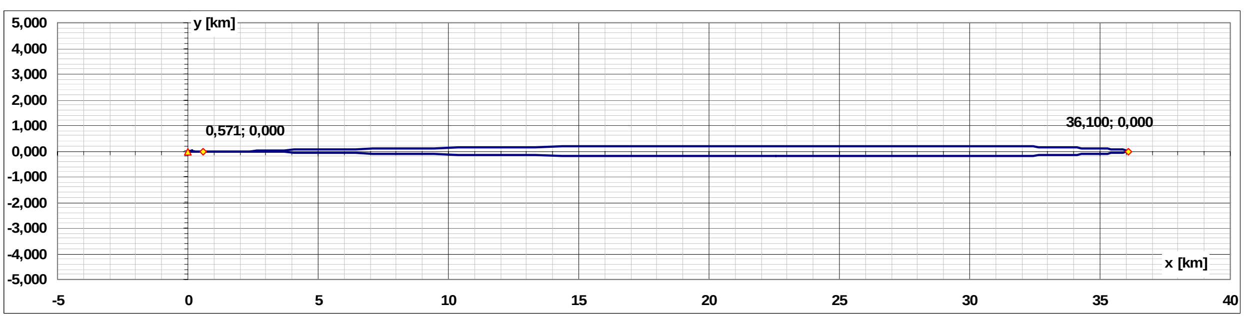


Figure 45: Contour for I/N = +23 dB during less than 1,2 x10^{-7} of the year for a 2.048 Mbit/s carrier with elevation = 20° and NFD = 35 dB, for stationary ESVs

For a FSR antenna with a higher antenna gain, the sizes of these contours will be greater.

6.6 Minimum distance in the case of moving ESVs

6.6.1 General

In the previous section it was assumed that there were permanently 1, 2 or 3 ESVs on the contours corresponding to each interference criterion.

In the present section a more realistic assumption is made: it is assumed that the ESVs are either moving within or crossing those contours.

6.6.2 Description of the method

ITU-R Rec. P.452 [7] describes a method for computing the propagation loss (*L*) at distance (*d*) such that the probability Pr($L \leq l$) that the propagation loss (*L*) is lower than or equal to a given value (*l*) is equal to a given percentage (*p*): Pr($L \leq l$) = *p*. This probability is the "cumulative distribution function" $F_L(l)$ of the random variable *L* of probability density $p_L(l)$:

(85) : $$F_L(l_1) = \Pr(L \leq l_1) = \int_0^{l_1} p_L(l).dl$$

The relationship between the (I/N) ratio, the GLG function and the other parameters of the FSR and ESV is the following:

(86) : $$\left(\frac{I}{N}\right)_{[dB]} = GLG + \left\{ \begin{array}{l} EIRP_{ESV}(0°)_{[dBW]} - G_{ESV}(0°)_{[dBi]} \\ -k_{[dBW/Hz/K]} - T_{S[dBK]} \\ -\left(NFD(df)_{[dB]} + B_{FSR[dBHz]}\right) \end{array} \right\}$$

with:

(87) : $$GLG = \left\{ G_{ESV}(\varphi_{ESV})_{[dBi]} - L(d)_{[dB]} + G_{FSR}(\varphi_{FSR})_{[dBi]} \right\}$$

The successive steps for the determination of the minimum distance (d_0) are the following:

- The ESV is assumed to move along a line either parallel or perpendicular to the FSR main beam and the line is at a distance d_{min} from the FSR.
- The ESV moves between two circles of radius R_{min} and R_{max} around the FSR (e.g. $R_{min} = d_{min}$ and R_{max} = 500 km).
- The space around the FSR is divided into cells as shown in Figure 49 by:
  - circles such that the free space loss increases by 0.25 dB steps up to the horizon and by 0.025 dB beyond the horizon, from R_{min} to R_{max},
  - radius such that the FSR antenna gain increases by 0.25 dB steps,
- for the point of each cell which is closest to the FSR:
  - The distance *d* between the FSR and the ESV is determined.
  - The cumulative distribution function $F_L(l)$ of the propagation loss (*l*) is determined for the distance *d* and the selected percentage of time *p*, using the ITU-R Recommendation P.452-7 [7] propagation model.
  - The cumulative distribution function of GLG is then computed.
  - For each GLG value, every 0.5 dB, the corresponding probability is multiplied by the duration of the ESV within the cell and divided by the end-to-end travel duration, and the result is then cumulated.
- The probability density of the (*I/N*) ratio is equal to the probability density of (GLG plus an appropriate constant).
- The probability density of the (*I/N*) ratio for a single interferer is then used to compute the probability density of the (*I/N*) ratio for the number of interferers which are expected to move by the FSR during the same day.

- The probability density of *(I/N)* for the number of interferers is then plotted and compared with the thresholds.
- The "I/N margin" and the "p margin" for each criterion are determined.
- The minimum distance (d_0) is the distance such that the margins are positive or null and minimum.

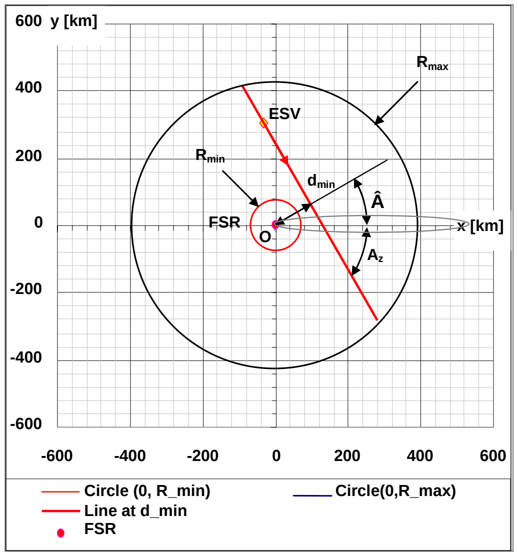


Figure 46: ESV moving on a straight line in a given direction relative to the FSR main beam axis

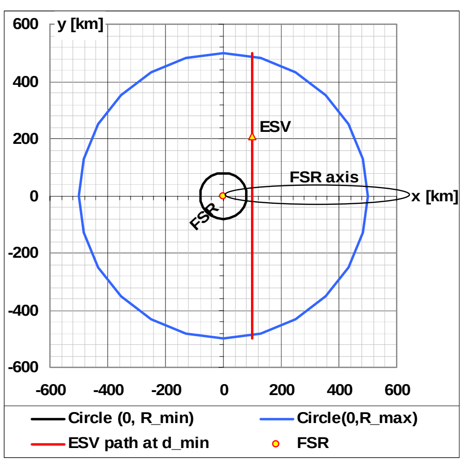


Figure 47: ESV moving on a straight line in a direction orthogonal to the FSR main beam axis ($\hat{A}$ = 90°, d_{min} = 100 km, R_{min} = 80 km)

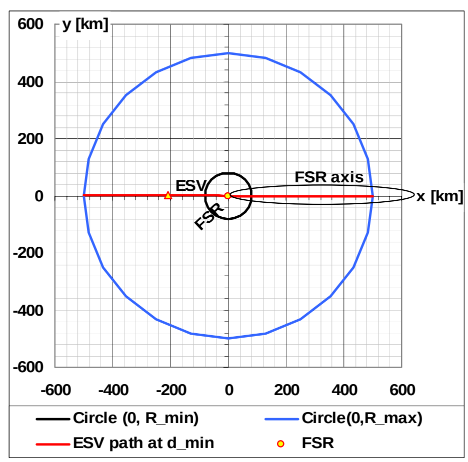


Figure 48: ESV moving on a straight line below the FSR main beam axis ($\hat{A}$ = 0°, d_{min} = 0 km, R_{min} = 80 km)

The ESV does not transmit within the circle (O, R_{min}).

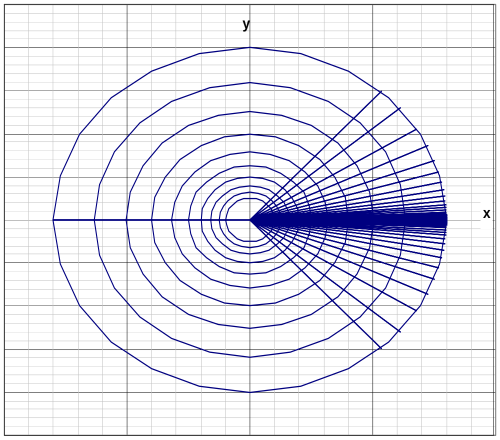


Figure 49: Cells around the FSR for the determination of the minimum distances (d_0)

6.6.3 Propagation loss versus the ESV distance

The ITU-R Rec. P.452-7 [7] methodology has been use to determine the propagation loss versus the ESV distance for each configuration considered such as the following:

Frequency	6175 MHz
Propagation parameters:	
N_0	330
Delta_N	50
Beta_e	1.35
ESV antenna altitude	40 m
FSR ground altitude	50 m
FSR antenna height	40 m
Max. distance of the ESV from FSR	500 km
Distance of the FSR to the coast	15 km

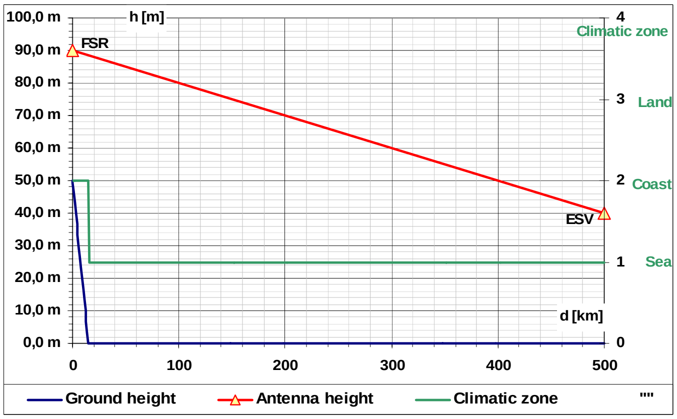
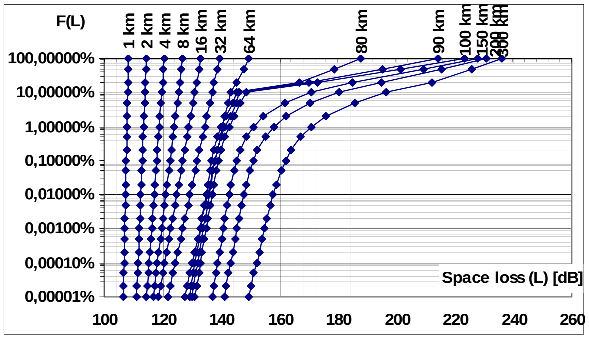


Figure 50: FSR to ESV profile

For this case the following propagation loss distributions were obtained.



(l)

Figure 51: Cumulative distribution function FL(l) of propagation loss

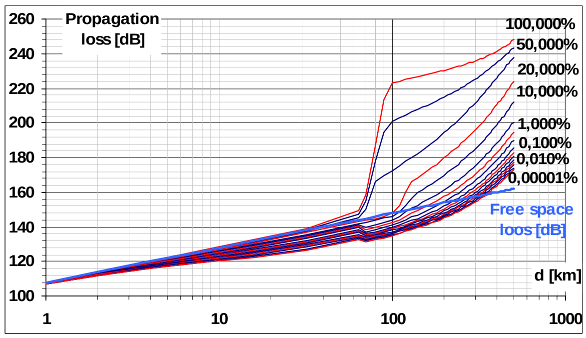


Figure 52: Propagation loss versus the ESV distance from the FSR

The propagation loss was computed for the following distances: 1 km, 2 km, 4 km, 8 km, 16 km, 32 km, 64 km, 80 km and every 10 km up to 500 km and for the following probabilities: $1x10^{-n}$, $2x10^{-n}$,

$5x10^{-n}$, from $1x10^{-0}$ to $1x10^{-5}$. It has been linearly interpolated in dBs down to $1x10^{-7}$.

For each distance *d* of the ESV to the FSR, the propagation loss is linearly interpolated from the 4 closest points, using the logarithms of the distances and the logarithms of the probabilities.

6.6.4 Cumulative distribution functions ($F_I(i/n)$) of the (I/N) ratio

Figure 53 contains an example of the complement of the cumulative distribution function *F(I/N)* of the ratio (*I/N*) which was computed for a single ESV per day, and also for 3 ESVs per day travelling on the same route in a direction orthogonal to the FSR main beam axis at a minimum distance of 40 km from the FSR. The FSR and ESV parameters were those given in **Table 15** and for the scenario the following parameters were used:

ESV		
Elevation	20.00	°
Speed	18.30	km/h
Nb. of ESVs per day	3.00	ESV/day
Zone around the FSR		
R_{max}	500	km
R_{min}	39	km
d_{min}	40	km
Azimuth (A_z)	0	°
Â	90	°

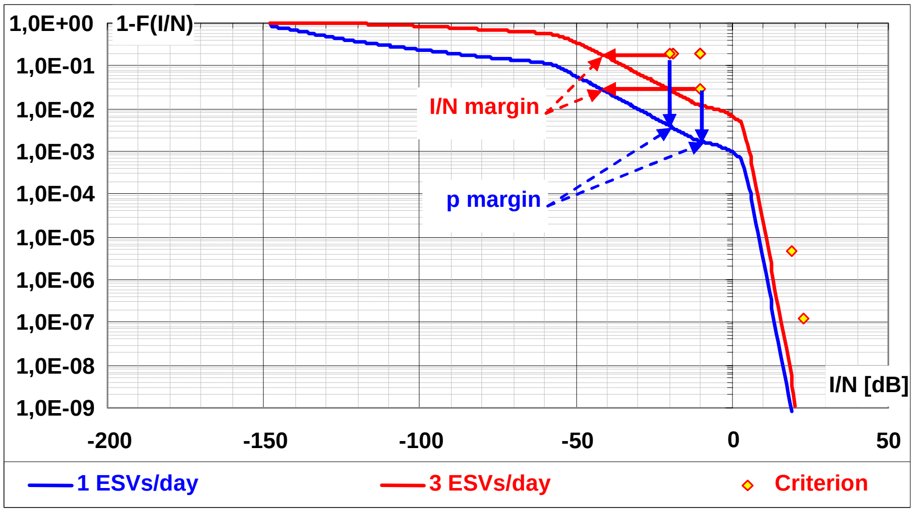


Figure 53: Complement of the cumulative distribution function (*F(I/N)*) of the (*I/N*) ratio

The criteria are indicated by yellow diamonds; some criteria apply to a single interferer, some others apply to the interferers all together (see **Error! Reference source not found.**).

For each criterion the "I/N margin" and the "p margin" were determined:

- The "I/N margin" is defined as the difference in dBs between the corresponding threshold point (*I/N*, percentage of time (p)) and the curve of the complement of the cumulative distribution function of the I/N ratio, measured along an axis parallel to the I/N axis.
- The "p margin" is defined as the difference in dBs between the corresponding threshold point (*I/N*, percentage of time (p)) and the curve of the complement of the cumulative distribution function of the I/N ratio, measured along an axis parallel to the axis of percentage of time.

6.6.5 Scenarios and results

The percentage of time during which each I/N ratio of the interference criteria is exceeded has been computed for various combinations of the following parameters:

- the FSR distance to coast was either 0 km or 15 km,
- the combinations of the FSR ground altitude and antenna height above ground were:

Antenna ground altitude	m	10	50	50	50
Antenna height	m	31	70	41	120
Antenna altitude	m	41	120	91	170

- the FSR antenna diameter and efficiency were:

Antenna diameter	m	1,20	3,00
Antenna efficiency		64,0%	64,6%
FSR on-axis gain	dBi	35,50	43,50
FSR half beamwidth	°	1,462	0,585

- ESVs were moving either below the FSR main beam axis (Â = 0°) or in a direction orthogonal to the FSR main beam axis (Â = 90°),
- the number of ESVs per day was either 1, 1.5 or 3,
- the minimum distance (d_{min}) of the ESV linear trajectories from the FSR were 5, 6, 8, 10, 12, 16, 20, 24, 32, 40, 48, 64, 80, 96, 128, 160, 192, 256, 320 km.

The other parameters were the following:

FS link		
Frequency	5925	MHz
FS Receiver (FSR)		
Pattern type	F.1245	
Antenna temperature	300	K
Feeder loss	3	dB
Receiver noise figure	4.125	dB
Receiver noise bandwidth	22906	kHz
At the LNA input		
FSR LNA noise temperature	750	K
At the antenna flange		
FSR system temperature	2085	K
N	-91.81	dBm
"	-121.81	dBW
Interfering ESV		
Antenna height	40.00	m
Pattern type	IESS601	
Antenna diameter	2.40	m
Antenna efficiency	64.6%	
Pattern degradation	3.00	dB
ESV on-axis gain	41.50	dBi
ESV off-axis gain towards the horizon	-3.50	dBi
ESV half beamwidth	0.731	°
NFD	35	dB
Bit rate	2 048	kbit/s
Nominal e.i.r.p. density	24.90	dBW/kbit/s
ESV e.i.r.p.	58.01	dBW
ESV HPA power	16.51	dBW
Elevation	20.00	°
Speed	18.30	km/h

The computations have been performed for the lower frequency of the FS L6 frequency band, i.e. at 5925 GHz. For 6175 GHz the free space loss would be 0.3 dB higher and at the other end of the L6 frequency band, i.e. at 6425 GHz the free space loss would be 0.6 dB higher.

For each criterion the margins were determined and for each set of criteria the minimum value of the margins were determined.

The attached Excel file (available from the ERO web site) contains:

- within the spreadsheet "Moving_ESV_results" computation results for various configurations of FSRs characteristics and ESVs characteristics and trajectories. The data are with yellow background and the results are with blue background,
- within the spreadsheet "Moving_ESV_graphs" graphic representations of the margins for each criterion and each set of criteria,
- within the spreadsheet "Moving_ESV_global_result" the minimum distance (d_0) for each set of criteria.

Each curve is labelled such as "Case 5: FSR: drc = 15 km, h = 50+120 m, D = 3 m, Â = 90°, 3 ESV/day" where:

- Case is the case number within the sheet "Moving_ESV_results",
- drc is the distance of the receiver (i.e. the FSR) to the coast,
- h is the FSR ground altitude plus (+) the FSR antenna height above ground,
- D is the FSR antenna diameter,
- Â = 90° when the ESV is sailing in a direction orthogonal to the FSR antenna main beam,
- Â = 0° when the ESV is sailing below the FSR antenna main beam.

Additionally, within the sheet "Moving_ESV_results"

- R_{min} is the minimum distance of the ESV to the FSR at which the ESV may transmit a signal,
- d_{min} is the distance of the ESV trajectory (i.e. a straight line) to the FSR,
- Az is the angle between the FSR main beam axis and the direction orthogonal to the ESV trajectory.

Â, A_z, R_{min}, d_{min} are shown in

The Excel file does not contain any “macros”.

An example of the value of d_0 for the criteria set #1 in a given configuration is given in Figure 54.

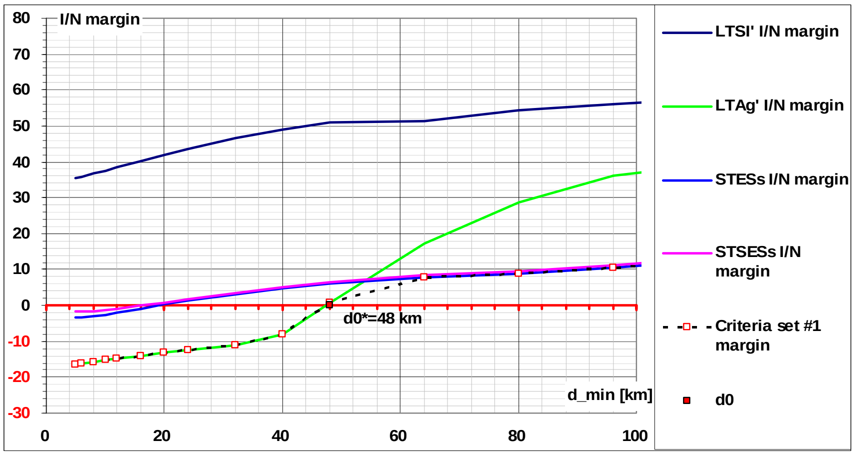


Figure 54: Example of value of d_0 for the criteria set #1 in a given configuration (FSR: drc = 15 km, h = 50+70 m, D = 3 m ESV: h = 40 m, D = 2.4 m, v = 18.3 km/h, Â = 0°, 3 ESV/day)

The minimum distances (d_0) of the ESV to the FSR and to the coast (d_c) for each set of criteria for each of the configurations considered in this report are given within the following two tables:

						Minimum ESV distance (d_0) to FSR for criteria set #1						Minimum ESV distance (d_0) to FSR for criteria set #2						Minimum ESV distance (d_0) to FSR for criteria set #3					
				Nb. of ESVs per day		1.0		1.5		3.0		1.0		1.5		3.0		1.0		1.5		3.0	
				Â		0°	90°	0°	90°	0°	90°	0°	90°	0°	90°	0°	90°	0°	90°	0°	90°	0°	90°
FSR antenna diameter	**FSR-ESV altitude difference**	**FSR antenna ground altitude**	**FSR antenna height above ground**	**ESV antenna height**	**FSR distance to coast**																		
m	m	m	m	m	km	km	Km	km	km	km	km	km	km	km	km	km	km	km	km	km	km	km	km
1.20	1	10	31	40	0	5.0	5.0	5.0	5.0	16.2	5.0	5.0	5.0	5.0	5.0	30.6	5.0	5.0	5.0	5.0	5.0	5.0	5.0
1.20	1	10	31	40	15	5.0	5.0	5.0	5.0	12.3	5.0	5.0	5.0	5.0	5.0	24.1	5.0	5.0	5.0	5.0	5.0	5.0	5.0
1.20	51	50	41	40	0	5.0	5.0	5.7	5.0	36.8	5.0	5.0	5.0	17.3	5.0	48.5	5.0	5.0	5.0	5.0	5.0	5.0	5.0
1.20	51	50	41	40	15	5.0	5.0	5.0	5.0	35.5	5.0	5.0	5.0	13.7	5.0	44.8	5.0	5.0	5.0	5.0	5.0	5.0	5.0
1.20	80	50	70	40	0	5.0	5.0	11.7	5.0	42.8	5.0	5.0	5.0	21.8	5.0	52.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
1.20	80	50	70	40	15	5.0	5.0	10.0	5.0	41.3	5.0	5.0	5.0	18.1	5.0	49.1	5.0	5.0	5.0	5.0	5.0	5.0	5.0
1.20	130	50	120	40	0	5.0	5.0	17.6	5.0	48.8	5.0	5.0	5.0	30.4	5.0	61.5	5.0	5.0	5.0	5.0	5.0	5.0	5.0
1.20	130	50	120	40	15	5.0	5.0	16.2	5.0	47.6	5.0	5.0	5.0	26.5	5.0	56.8	5.0	5.0	5.0	5.0	5.0	5.0	5.0
3.00	1	10	31	40	0	18.0	12.7	19.4	13.4	26.9	14.9	18.1	12.7	19.6	13.4	44.1	14.9	18.0	12.7	19.4	13.4	23.0	14.9
3.00	1	10	31	40	15	17.5	12.7	18.7	13.5	23.1	14.9	17.7	12.7	19.0	13.5	34.0	14.9	17.5	12.7	18.7	13.5	21.1	14.9
3.00	51	50	41	40	0	16.9	11.5	19.5	12.1	46.1	13.6	17.2	11.5	24.9	12.1	54.9	13.6	16.4	11.5	17.6	12.1	19.9	13.6
3.00	51	50	41	40	15	16.9	11.5	19.2	12.1	43.0	13.6	17.1	11.5	20.0	12.1	50.0	13.6	16.5	11.5	17.6	12.1	19.9	13.6
3.00	80	50	70	40	0	15.2	6.5	19.7	9.2	49.8	11.4	15.4	6.5	30.0	9.2	60.9	11.4	15.2	6.5	16.5	9.2	18.9	11.4
3.00	80	50	70	40	15	15.2	6.4	18.9	9.3	47.2	11.4	15.2	6.4	24.7	9.3	54.6	11.4	15.2	6.4	16.5	9.3	18.9	11.4
3.00	130	50	120	40	0	5.0	5.0	27.4	5.0	57.9	5.0	7.3	5.0	38.0	5.0	68.4	5.0	5.0	5.0	10.7	5.0	15.3	5.0
3.00	130	50	120	40	15	5.0	5.0	24.5	5.0	54.4	5.0	5.0	5.0	32.8	5.0	64.3	5.0	5.0	5.0	10.8	5.0	15.3	5.0

Table 16: Minimum ESV distance (d_0) to FSR for each criteria set

NOTE: The object of this table is to enable each Administration to select the minimum distance for ESV transmission corresponding to the combination of parameters most suited to their individual case.

						Minimum ESV distance to coast (d_c) for criteria set #1						Minimum ESV distance to coast (d_c) for criteria set #2						Minimum ESV distance to coast (d_c) for criteria set #3					
					Nb. of ESVs per day	1.0		1.5		3.0		1.0		1.5		3.0		1.0		1.5		3.0	
					Â	0°	90°	0°	90°	0°	90°	0°	90°	0°	90°	0°	90°	0°	90°	0°	90°	0°	90°
FSR antenna diameter	**FSR-ESV altitude difference**	**FSR antenna ground altitude**	**FSR antenna height above ground**	**ESV antenna height**	**FSR distance to coast**																		
m	m	m	m	m	km	km	km	km	km	km	km	km	km	km	km	km	km	km	km	km	km	km	km
1.20	1	10	31	40	0	5.0	5.0	5.0	5.0	16.2	5.0	5.0	5.0	5.0	5.0	30.6	5.0	5.0	5.0	5.0	5.0	5.0	5.0
1.20	1	10	31	40	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.20	51	50	41	40	0	5.0	5.0	5.7	5.0	36.8	5.0	5.0	5.0	17.3	5.0	48.5	5.0	5.0	5.0	5.0	5.0	5.0	5.0
1.20	51	50	41	40	15	0.0	0.0	0.0	0.0	20.5	0.0	0.0	0.0	0.0	0.0	29.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.20	80	50	70	40	0	5.0	5.0	11.7	5.0	42.8	5.0	5.0	5.0	21.8	5.0	52.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
1.20	80	50	70	40	15	0.0	0.0	0.0	0.0	26.3	0.0	0.0	0.0	3.1	0.0	34.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.20	130	50	120	40	0	5.0	5.0	17.6	5.0	48.8	5.0	5.0	5.0	30.4	5.0	61.5	5.0	5.0	5.0	5.0	5.0	5.0	5.0
1.20	130	50	120	40	15	0.0	0.0	1.2	0.0	32.6	0.0	0.0	0.0	11.5	0.0	41.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3.00	1	10	31	40	0	18.0	12.7	19.4	13.4	26.9	14.9	18.1	12.7	19.6	13.4	44.1	14.9	18.0	12.7	19.4	13.4	23.0	14.9
3.00	1	10	31	40	15	2.5	0.0	3.7	0.0	8.1	0.0	2.7	0.0	4.0	0.0	19.0	0.0	2.5	0.0	3.7	0.0	6.1	0.0
3.00	51	50	41	40	0	16.9	11.5	19.5	12.1	46.1	13.6	17.2	11.5	24.9	12.1	54.9	13.6	16.4	11.5	17.6	12.1	19.9	13.6
3.00	51	50	41	40	15	1.9	0.0	4.2	0.0	28.0	0.0	2.1	0.0	5.0	0.0	35.0	0.0	1.5	0.0	2.6	0.0	4.9	0.0
3.00	80	50	70	40	0	15.2	6.5	19.7	9.2	49.8	11.4	15.4	6.5	30.0	9.2	60.9	11.4	15.2	6.5	16.5	9.2	18.9	11.4
3.00	80	50	70	40	15	0.2	0.0	3.9	0.0	32.2	0.0	0.2	0.0	9.7	0.0	39.6	0.0	0.2	0.0	1.5	0.0	3.9	0.0
3.00	130	50	120	40	0	5.0	5.0	27.4	5.0	57.9	5.0	7.3	5.0	38.0	5.0	68.4	5.0	5.0	5.0	10.7	5.0	15.3	5.0
3.00	130	50	120	40	15	0.0	0.0	9.5	0.0	39.4	0.0	0.0	0.0	17.8	0.0	49.3	0.0	0.0	0.0	0.0	0.0	0.3	0.0

Table 17: Minimum ESV distance to coast (d_c) for each criteria set

NOTE: The object of this table is to enable each Administration to select the minimum distance for ESV transmission corresponding to the combination of parameters most suited to their individual case.

The lowest distance within the Tables 16&17 is 5 km, because it was the lowest distance between the ESV and the FSR used for the computations.

In some case the limits for the three criteria sets are the same because the minimum distance is dictated by the short term criteria (ST-ES and ST-SES) which are common to the three criteria sets.

6.7 ESV distances to the FSR and to the coast

As shown in Figure 31 the level of interference received by the back lobes of the FSR antenna is more than 40 dB below the level of interference received via the FSR antenna main beam.

Figure 55 shows the case of a FS link between an inland FSR and a FSR on the coast. For such a link the most sensitive FSR to ESV interference is the inland FSR pointing towards the sea.

Figure 56 shows the case of a FS link between a costal FSR and an FSR on an island, or on both sides of an estuary. Both FSRs are sensitive to the ESV interference, the northern one less so than the other.

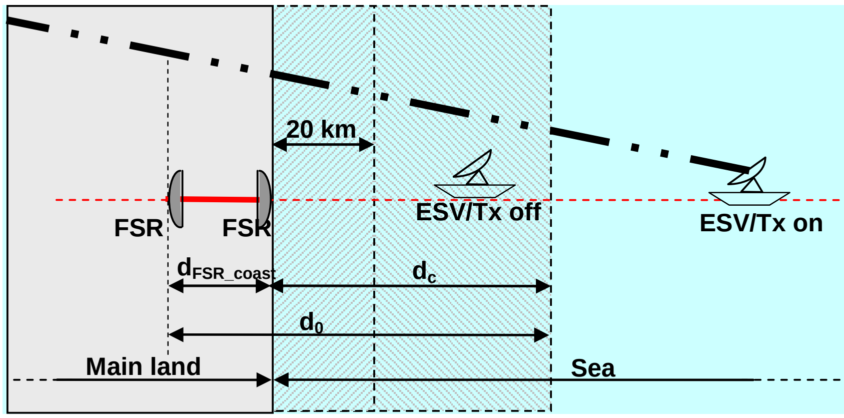


Figure 55: Case of a FS link within the main land

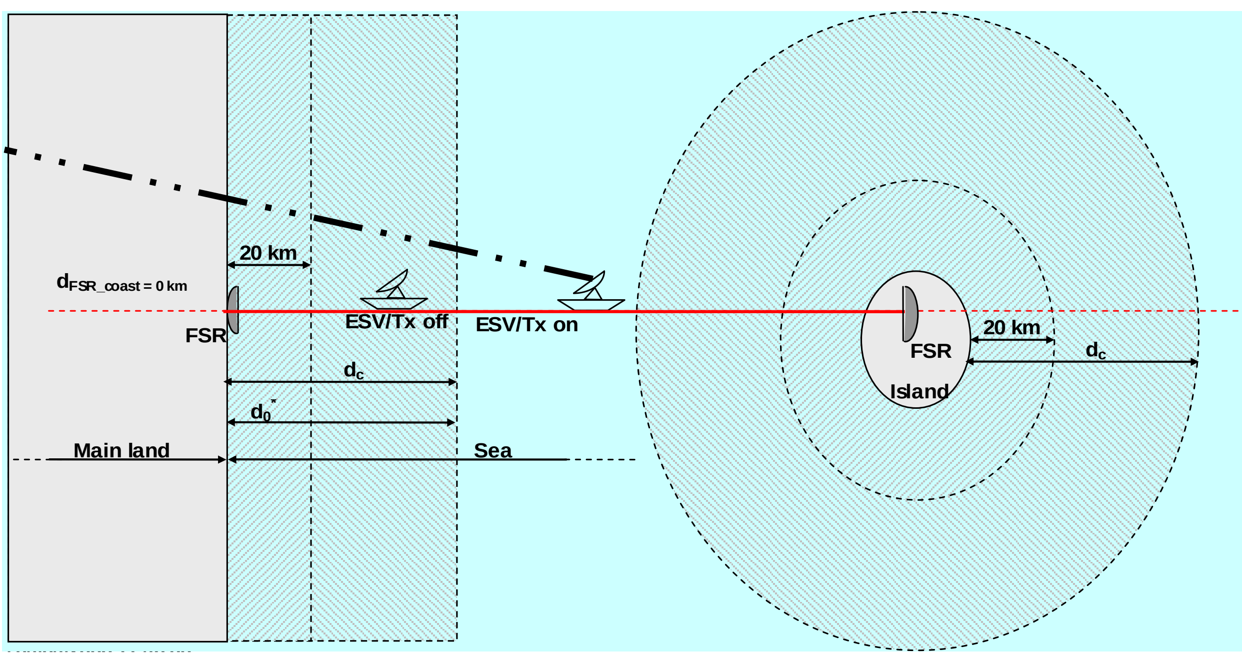


Figure 56: Case of a FS link between the main land and an island (or over an estuary)

6.8 Case of several ESVs moving in different directions

A case of 3 ESVs moving in different directions has been considered. It was assumed that during the same day two ESVs were sailing in a direction orthogonal to the FSR antenna main beam and one ESV was sailing below the FSR antenna beam. The probability of the (*I/N*) ratio has been computed by two different methods which led to the same results.

The first method consisted of:

- using the computation method presented in § 6.6.2 to separately compute the values of the probability of the (*I/N*) ratio for:
  - 2 ESVs sailing, during the same day, in a direction orthogonal to the FSR antenna main beam, and for
  - 1 ESV sailing, during the day, below the FSR antenna main beam,
- and afterwards of computing the probability of the (*I/N*) ratio in the case of the 3 ESVs sailing during the same day. It was obtained by the convolution of the probabilities of the above 2 cases.

  Remark: The probability density of the sum (*S* = *X* + *Y*) of two independent variables (*X* and *Y*) is equal to the convolution of the probability densities:

(88) :
$$p_{X+Y}(s) = p_X(s) * p_Y(s) = \int_{x=-\infty}^{x=+\infty} p_X(x).p_Y(s-x).dx$$

The second method consisted of:

- moving simultaneously each ESV on its trajectory (one ESV below the FSR main beam axis and two ESVs in a direction orthogonal to the FSR antenna main beam),
- computing every second the probability of the propagation loss and cumulating these probabilities, and
- converting the probability of the propagation loss into the distribution function of the (I/N) ratio.

On the distribution functions of the (*I/N*) ratio are plotted and displayed; the results of the first method are the blue and red curves and the results obtained by the second method is the black curve.

Using two different methods similar results have been obtained independently.

For I/N greater than 10 dB, the difference was due to the fact that Rec. ITU-R P.452 [7] gives propagation attenuations for percentages of time down to 0,001% of the time. With method 1 a linear extrapolation has been done in dBs for percentages of time lower than 0,001%.

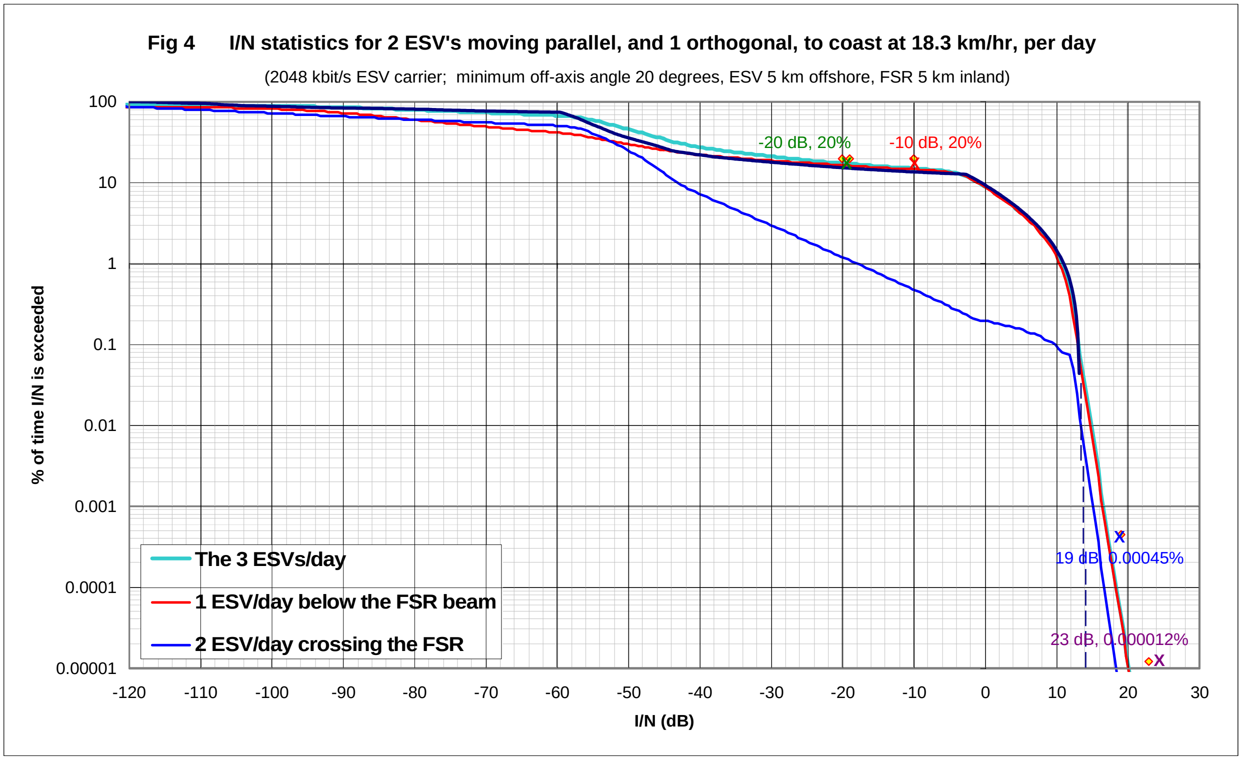


Figure 57: Distribution functions of the (*I/N*) ratio in the case of a FSR 5 km inland with its main beam orthogonal to the linear coast line (1 ESV below the FSR main beam and emitting up to 5 km off the coast and 2 ESVs moving in a direction orthogonal to the FSR main beam, at 5 km from the coast)

From the above figure it can be seen that the ESV that dominates the interference statistics is the one travels under the FSR main beam axis. This is because the (I/N) margins and p margins for the single ESV and the two other ESVs are different by several dBs.
The fact that the results obtained by the two methods are similar gives confidence in the methods used.

7 CONCLUSIONS

The aim of the present report is to define the conditions for ESVs to transmit within the gaps of the Fixed Service frequency band L6 at 6 GHz within 300 km of the European coasts, to be used as a tool for administrations wishing to develop regulations allowing ESV use within 300 km exclusion zone from their coasts.

It was not possible to consider all configurations of the FSR and ESV characteristics and locations. Nevertheless with some restrictions it was possible to determine common and simple rules for ESVs.

The following operational conditions, all together, were assumed:

- The ESV does not transmit at distances from the European country coast lower than a distance d_c, or at distances from the inland FSR lower than a distance $d_{0.}$, as described further below.
- The ESV antenna main beam axis elevation is not lower than 20°.
- The ESV antenna on-axis gain is at least 42 dBi.

Remark: It was assumed that the ESV antenna diameter was not lower than 2.4 m as recommended in ITU-R Resolution 902 (WRC-2003) and consequently that the on-axis gain of a typical ESV antenna was not lower than 42 dBi.

- The ESV transmits a single carrier per HPA.
- The phase noise floor of the ESV carrier does not exceed -120 dBc/Hz.
- The p.s.d. of the 1st spectrum side lobe of the ESV carrier is at least 27 dB below the in-band p.s.d.
- The ESV e.i.r.p. does not exceed 58 dBW.

- The ESV antenna off-axis gain pattern complies with the pattern specified within the present report for 90% of the side lobes and with 3 dB relaxation for 10% of the peaks.
- The ESV does not transmit when the vessel speed is lower than 10 knots (18.3 km/h).

  Remark: Without this constraint, the probabilities of interference will be higher in the case of ESVs staying within a zone e.g. for fishing or for oil prospecting, or in the case of a shuttle between harbours.

- The guard-band (*df*) is defined as the separation in frequency between the edge of the adjacent FS channel and the nearest edge of the ESV carrier. The edge of the ESV carrier is measured 10 dB below its maximum in-band power spectral density.
- Assuming the above maximum e.i.r.p. limit, the minimum guard-band (*df*) is equal to either:
  - 1 700 kHz with no ESV e.i.r.p. spectral density limit, or
  - 1 400 kHz if the ESV e.i.r.p. spectral density is limited to 26.65 dBW/kHz or
  - 1 500 kHz if the ESV e.i.r.p. spectral density is limited to 29.65 dBW/kHz.

The minimum distances d_c and $d_{0.}$ of transmitting ESVs from the European country coast and to the inland FSR will depend on the assumptions made concerning the following parameters:

- the interference criteria set (see Table 2),
- the mean number of ESVs per day passing by the FSR and their directions of travel,
- the FSR antenna size,
- the maximum height of the FSR antenna,

Note: If administrations wish to take into account the tidal effect, the FSR height should be replaced by the FSR height plus the tide amplitude and the FSR height minus the tide amplitude.

- the minimum distance to the coast of the FSR pointed towards the sea or towards the other side of an estuary.

Table 16 and Table 17 give the values of d_0 and d_c for various values of those parameters considered within this report. Depending on the values given to the above parameters, the minimum distance of an ESV to the coast d_c, is within the range from 0 to 68 km.

The scenarios used to determine the values d_0 and d_c are described in § 6.6.5. Possibilities for reducing those minimum distances are described in Annex 4, where it is shown that reduction in distance of only 14% and 27% would be obtained by significantly increasing the guard band (df) from 1.7 MHz to 5 MHz and/or decreasing ESV maximum e.i.r.p. from 58 dBW to 43 dBW respectively.

In this report it was assumed that the latitude of the ESV was generally higher than that of the coast line concerned. It should be noted that in cases where the coast line has higher latitude than that of the ESVs, minimum distances d_0 and d_c would be considerably lower than the distances given in Table 16 and Table 17. This is because the computations were carried out for cases in which the minimum off-axis angle at the ESV of the interference path toward the FSR was equal to the minimum angle assumed for the elevation toward the satellite – i.e. 20°, whereas for coastlines to the north of an ESV in Europe the minimum off-axis angles would be substantially higher.

It should be also noted that the approach proposed in this report in general complies with the terms of ITU Resolution 902 (WRC-2003) in that it constitutes a basis for 'prior agreement', but only for those administrations that accept the terms of the report (see Clause 4, Annex 1, Res. 902). However administrations are under no obligation to accept the terms of this report and may continue to require compliance with the more restrictive limitations given in the resolution. It was made known during approval of this report that some CEPT administrations do not intend accepting the proposed measures and will continue using the original provisions of Resolution 902 (WRC-2003).

In particular, when considering the protection of primary Fixed Service systems in the lower 6 GHz band (5925-6425 MHz), administrations, if they so wish, have the sovereign right to retain the limits on ESV operation given in 'Resolution 902 (WRC-03) as expressed in the following extract from its Annex 1, item 10:

"When ESVs operating beyond the territorial sea but within the minimum distance (300 km from the coastline) fail to comply with the terms required by the concerned administration pursuant to items 2 and 4, then that administration may:

- request the ESV to comply with such terms or cease operation immediately; or
- request the licensing administration to require such compliance or immediate cessation of the operation."

ANNEX 1 : INTEGRAL OF A FUNCTION GIVEN IN DBS AND LINEAR ON SUCCESSIVE SEGMENTS

A1. 1 Introduction

For the computation of the Net Filter Discrimination (NFD) of a narrow bandwidth carrier transmitted by an ESV by the large bandwidth input filter of a FSR it is necessary to compute the integral of the product of amplitude transfer function of each filter.

The present section proposes a method for the computation of the NFD when the power transfer function of each filter is defined in dBs and is linear on successive intervals.

A1. 2 Product of transfer functions

For two functions $f_{[dB]}(x)$ and $g_{[dB]}(x)$, each defined in dBs and for a collection of points x_k and linearly interpolated on the intervals between these points, the product ($p_{[dB]}(x) = f_{[dB]}(x) + g_{[dB]}(x)$) of these two functions is also a function defined in dBs with linear segments over consecutive intervals which are the intersections of the two sets of intervals.

for $x \in [x_i, x_{i+1}[$ with $i \in I$: $$f_{[dB]}(x) = f_{i[dB]} + (x - x_i).\frac{f_{i+1[dB]} - f_{i[dB]}}{x_{i+1} - x_i}$$

for $x \in [x_j, x_{j+1}[$ with $j \in J$: $$g_{[dB]}(x) = g_{j[dB]} + (x - x_j).\frac{g_{j+1[dB]} - g_{j[dB]}}{x_{j+1} - x_j}$$

then:

for $x \in [x_k, x_{k+1}[$ with $k \in K$: $$p_{[dB]}(x) = \left(p_{k[dB]} + (x - x_k).\frac{p_{k+1[dB]} - p_{k[dB]}}{x_{k+1} - x_k} \right)$$

with:

(89) : $$p_{k[dB]} = f_{i[dB]} + g_{j[dB]}$$

and:

(90) : $$\{x_k\} = \{x_i\} \cup \{x_j\}$$

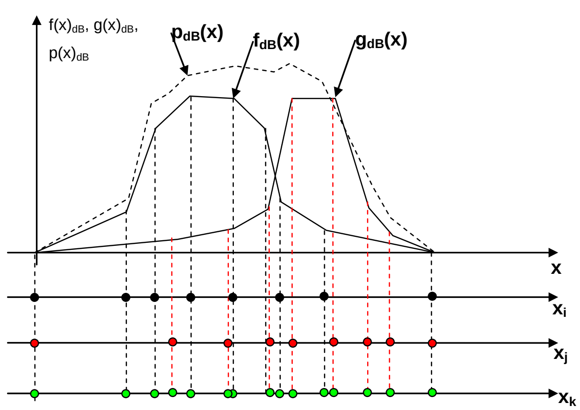


Figure 58: Example of functions *f(x)*, *g(x)* and *p(x)*

A1. 3 Integral of the product of transfer functions

For a function $p_{[dB]}\left(x\right)$ defined in dBs with linear segments over consecutive intervals, its integral function over the interval $\left[a,b\right[$ is given by:

(91) : $$I\left(a,b\right)=\int_a^b p\left(x\right).dx$$

For $a\in\left[x_k\,,\,x_{k+1}\right[$, $b\in\left[x_k\,,\,x_{k+1}\right[$ and $x\in\left[a,b\right[$:

(92) : $$p\left(x\right)=e^{\left(p_{k\,[dB]}+\left(x-x_k\right).\frac{p_{k+1\,[dB]}-p_{k\,[dB]}}{x_{k+1}-x_k}\right).Ln\left(10\right)/10}$$

(93) : $$\boxed{I\left(a,b\right)=\frac{10}{Ln\left(10\right)}.\frac{p_k}{p_{k+1\,[dB]}-p_{k\,[dB]}}.\left(\frac{p_k}{p_{k+1}}\right)^{\left(\frac{x_k-b}{x_{k+1}-x_k}\right)}.\left(1-\left(\frac{p_k}{p_{k+1}}\right)^{\left(\frac{b-a}{x_{k+1}-x_k}\right)}\right).\left(x_{k+1}-x_k\right)}$$

For $a=x_k$ and $b=x_{k+1}$:

(94) : $$\boxed{I\left(x_k\,,\,x_{k+1}\right)=\frac{10}{Ln\left(10\right)}.\frac{p_{k+1}-p_k}{p_{k+1\,[dB]}-p_{k\,[dB]}}.\left(x_{k+1}-x_k\right)}$$

For $a\in\left[x_{k_{\min}}\,,\,x_{k_{\min}+1}\right[$ and $b\in\left[x_{k_{\max}}\,,\,x_{k_{\max}+1}\right[$:

(95) : $$\boxed{I\left(a,b\right)=I\left(a,\,x_{k_{\min}+1}\right)+\sum_{k=k_{\min}+1}^{k=k_{\max}-1}I\left(x_k\,,\,x_{k+1}\right)+I\left(x_{k_{\max}}\,,\,b\right)}$$

ANNEX 2 : METHOD OF THE COMPUTATION OF F(I/N) FOR SEVERAL ESVS PER DAY

A2.1 General

For each considered scenario, the distribution of the (I/N) ratio is obtained by a simulation consisting in moving one ESV along a straight line at a distance d_{min} from the FSR, within the circle (0, R_{max}) (See Figure 59). The ESV is not allowed to transmit within the circle (0, R_{min}).

The whole space around the FSR and within the circle (0, R_{max}) is partitioned into a set of cells by circles and radius.

The complete ESV path, from end to end, is partitioned into segments (ds_k), one per cell which is crossed by the path as shown in Figure 59.

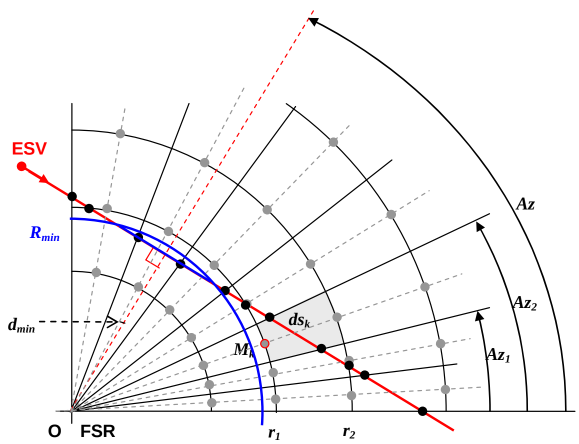


Figure 59

For the closest (M_k) point to the FSR of each cell crossed by the ESV the values of the following functions are computed:

- the probability density ($p_L\left(l_{[dB]}\right)$) of the propagation loss ($L_{[dB]}$), using ITU-R Recommendation P.452,
- the FSR antenna gain ($G_{FSR}\left(M_k\right)_{[dBi]}$) towards M_k ,
- the ESV antenna gain ($G_{ESV}\left(M_k\right)_{[dBi]}$) towards the FSR,
- the value of the GLG function: $GLG_{[dB]} = G_{ESV}\left(M_k\right)_{[dBi]} - L\left(M_k\right)_{[dB]} + G_{ESV}\left(M_k\right)_{[dBi]}$,
- the length ($d\hat{s}_k$) of the part of the segment (ds_k) where the ESV may emit a signal (i.e. outside the circle (O, R_{min})),
- the probability density ($p_{GLG}\left(G_{ESV}\left(M_k\right)_{[dBi]} - l\left(M_k\right)_{[dB]} + G_{ESV}\left(M_k\right)_{[dBi]} \middle| d\hat{s}_k\right)$) of the GLG function over the segment ($d\hat{s}_k$):

(96) : $$p_{GLG}\left(G_{ESV}\left(M_k\right)_{[dBi]} - l_{[dB]} + G_{ESV}\left(M_k\right)_{[dBi]} \middle| d\hat{s}_k\right) = p_L\left(l_{[dB]}\right)$$

- the probability density ($p_{GLG}(x_{[dB]})$) of the GLG function over the end-to-end path of length L_T :

(97) : $$p_{GLG}\left(x_{[dB]}\right) := p_{GLG}\left(x_{[dB]}\right) + p_{GLG}\left(x_{[dB]} \middle| d\hat{s}_k\right).\frac{d\hat{s}_k}{L_T}$$

(98) : $$p_{GLG}\left(GLG_{\min[dB]}\right) := p_{GLG}\left(GLG_{\min[dB]}\right) + \frac{ds_k - d\hat{s}_k}{L_T}$$ (for periods of time with no emission)

Before running the above algorithm the following initialisation is done: $p_{GLG}\left(x_{[dB]}\right)=0$.

This algorithm gives the probability density ($p_{GLG}\left(x_{[dB]}\middle|1\ ESV/T_T\right)$) of the GLG function over the end-to-end path of length L_T, followed by a single ESV during T_T days at a speed v.

The probability density $p_{GLG}\left(x_{[dB]}\middle|n\ ESV/\hat{T}_T\right)$ of the GLG function over the end-to-end path followed by an integer number n of ESVs during a travel duration $\hat{T}_T$ as close as possible to T_T at a speed v is then determined using the following intermediate probability density:

- the probability density ($p_{GLG}\left(x_{[dB]}\middle|1\ ESV/\hat{T}_T\right)$) of the GLG function over the end-to-end path followed by a single ESV during a travel duration $\hat{T}_T$ as close as possible to T_T at a speed v.

Once the value of $\hat{T}_T$ is determined (See § 0), the probability density $p_{GLG}\left(x_{[dB]}\middle|1\ ESV/\hat{T}_T\right)$ is deduced from the probability density $p_{GLG}\left(x_{[dB]}\middle|1\ ESV/T_T\right)$ by lengthening the path length. When the ESV is very far from the FSR the value of the GLG function is very low (i.e. equal to $GLG_{\min[dB]}$).

(99) : $$p_{GLG}\left(x_{[dB]}\middle|1\ ESV/\hat{T}_T\right)=\alpha.p_{GLG}\left(x_{[dB]}\middle|1\ ESV/T_T\right)+\left(1-\alpha\right).\delta\left(x_{[dB]}-GLG_{\min[dB]}\right)$$

with:

(100) : $$\alpha==\frac{T_T}{\hat{T}_T}$$

The computation of the probability density $p_{GLG}\left(x_{[dB]}\middle|n\ ESV/\hat{T}_T\right)$ from the probability density ($p_{GLG}\left(x_{[dB]}\middle|1\ ESV/\hat{T}_T\right)$ is based on the following properties:

- The "first characteristic function" $\varphi_X\left(u\right)$ of a random variable X of probability density $p_X\left(x\right)$ is defined by the following equation:

(101) : $$\varphi_S\left(u\right)=E\left[e^{i.u.x}\right]=\int_{x=-\infty}^{x=+\infty}e^{i.u.x}.p_X\left(x\right).dx$$

- If S is the sum of n independent random variables X_k each of probability density $p_X\left(x\right)$, the "first characteristic function" $\varphi_S\left(u\right)$ of S is given by the following equation:

(102) : $$\varphi_S\left(u\right)=\left(\varphi_X\left(u\right)\right)^n$$

with:

(103) : $$S==\sum_{k=1}^{k=n}X_k$$

- The "first characteristic function" $\varphi_X\left(u\right)$ for $u=2.\pi.f$ is equal to the Fourier transform ($\mathcal{F}\quad(.)$) of the probability density $p_X\left(x\right)$:

(104) : $$\varphi_X(u)\big|_{u=2.\pi.f} = E\left[e^{i.2.\pi.f.X}\right] = \int_{x=-\infty}^{x=+\infty} e^{i.2.\pi.f.x}.p_X(x).dx = \mathcal{F}\left(p_X(x), f\right)$$

- For X defined over a limited range of values the Fourier transform ($\mathcal{F}(.)$) of $p_X(x)$ may be obtained with a Fast Fourier Transform ($FFT(.)$):

(105) : $$\varphi_X(u)\big|_{u=2.\pi.f} = FFT\left(p_X(x), f\right)$$

- With the above assumptions, the probability density of S may be obtained from the probability density of X using the following formula:

(106) : $$\boxed{p_S(s) = FFT^{-1}\left(FFT\left(p_X(x), f\right)^n, s\right)}$$

Then:

(107) : $$\boxed{p_{GLG}\left(x_{[dB]}\middle| n\ ESV / \hat{T}_T\right) = FFT^{-1}\left(FFT\left(p_{GLG}\left(x_{[dB]}\middle| 1\ ESV / \hat{T}_T\right), f\right)^n, s\right)}$$

The range of variations of the GLG function values is very large, i.e. over 90 dB or more. The computation of the above formula would require the use of an FFT over 2^{30} samples ($Log_2((10^{(90/10)})/(10^{(0,5/10)})) \approx 30$) for an accuracy of 0.5 dB on X and would require about 2 hours and half of computation for the two FFTs with a computer fitted with a 2 GHz clock. Using two double precision number (i.e. over 8 bytes) for each sample (seen as complex number), the necessary memory size for the computation with a computer would be at least 16 Go (2^{30} x 2 x 8 bytes). This is not possible today with usual computers. To overcome this technical difficulty, a sliding window technique has been used (See § 0) using several 64K FFTs; the computation duration for each scenario was about 2 minutes instead of 2 hours and half.

A2.2 ESV travel duration

Let:

$v_{[km/h]}$ the ESV speed (i.e. its velocity),

$L_{T\,[km]}$ the length of the travel (T),

$T_{T\,[day]}$ the duration of the travel,

then:

(108) : $$L_{T\,[km]} = 4.\pi.R_{[km]}.Arc\cos\left(\frac{\cos\left(\frac{R_{\max}}{2.\pi.R}\right)}{\cos\left(\frac{d_{\min}}{2.\pi.R}\right)}\right) \approx 2.\sqrt{R^2_{\max\,[km]} - d^2_{\min\,[km]}}$$

(109) : $$T_{T\,[day]} = \frac{L_{T\,[km]}}{24.v_{[km/h]}}$$

(110) : $$T_{T\,[day]} = 2,277\ days\ \ for \begin{cases} L_T = R_{\max} = 500\ km \\ v = 18,3\ km/h \end{cases}$$

A2.3 Determination of n and $\hat{T}_T$ corresponding to the number of ESVs per day

The number n is equal to the closest integer equal to or greater than the mean number of ESVs passing by the FSR during the travel duration:

(111) : $$\boxed{n = -Int\left(-ESV\_per\_day \;.\; Travel\_duration\right)}$$

where:

ESV_per_day is the require number of ESVs per day passing by the FSR (e.g. 1.5),

$Travel\_duration$ is the ESV travel duration ($T_{T\,[day]}$).

The new travel duration $\hat{T}_{T\,[day]}$ is given by the following equation:

(112) : $$New\_travel\_duration = Travel\_duration.\frac{n}{ESV\_per\_day \;.\; Travel\_duration}$$

or:

(113) : $$\boxed{\hat{T}_{T\,[day]} = \frac{n}{ESV\_per\_day}}$$

The following table gives some examples of the values of the above parameters:

Travel duration $T_{T\,[day]}$	2.277	2.277	2.277
Nb. of ESVs per day passing by the FSR	1.0	1.5	3.0
Number of ESVs passing by the FSR during the new travel duration $\hat{T}_{T\,[day]}$	3	4	7
New travel duration $\hat{T}_{T\,[day]}$	3.000	2.667	2.333

A2.4 Computation of the probability of a sum of random variables with a sliding window technique

The computation of the probability of the sum S of n independent and positive or null random variables of probability densities $p_X(x)$, and defined over a very large range of values may be done on successive intervals for S such that the number of samples per FFT is acceptable.

Let $\hat{X}_k$ the random variable defined on the interval $\left[\overline{x}_1, \overline{x}_2\right[$ such that:

(114) : $$\boxed{\hat{X}_k = Min\left(\overline{x}_2, Max\left(\overline{x}_1, X_k\right)\right)}$$

Then the probability density of this random variable $\hat{X}_k$ is the following:

(115) : $$p_{\hat{X}_k}(x) = \begin{cases} = p_1.\delta\left(x-\overline{x}_1\right) & for\; x < \overline{x}_1 \quad with \quad p_1 = \int_{x=-\infty}^{x=\overline{x}_1} p_X(x).dx \\ = p_X(x) & for\; \overline{x}_1 \le x < \overline{x}_2 \\ = p_2.\delta\left(x-\overline{x}_2\right) & for\; x \ge \overline{x}_2 \quad with \quad p_2 = \int_{x=\overline{x}_2}^{x=+\infty} p_X(x).dx \end{cases}$$

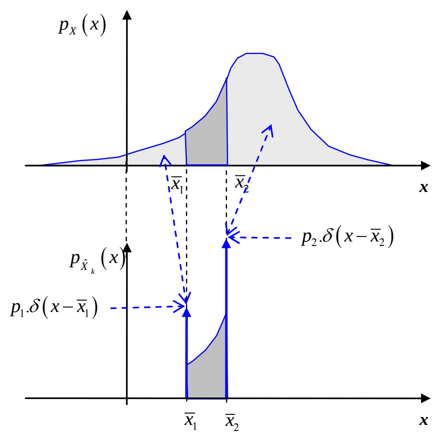


Figure 60: $p_X(x)$ **and** $p_{\hat{X}}(x)$

Let $\hat{S}$ the sum of n independent random variables $\hat{X}_k$:

(116) : $$\boxed{\hat{S} == \sum_{k=1}^{k=n} \hat{X}_k}$$

A value s of S and a value $\hat{s}$ of $\hat{S}$ correspond to any set of values $\{X_1 = x_1, X_2 = x_2, ..., X_n = x_n\}$ and:

(117) : $$p_{\hat{S}}\left(\hat{s} \middle| X_1 = x_1, X_2 = x_2, ..., X_n = x_n\right) = p_S\left(s \middle| X_1 = x_1, X_2 = x_2, ..., X_n = x_n\right)$$

When $s < \overline{x}_2$ then:

(118) : $$0 \le X_1 < \overline{x}_2, \quad 0 \le X_2 < \overline{x}_2, \ ..., \quad 0 \le X_n < \overline{x}_2$$

(119) : $$\overline{x}_1 \le \hat{X}_1 < \overline{x}_2, \quad \overline{x}_1 \le \hat{X}_2 < \overline{x}_2, \ ..., \quad \overline{x}_1 \le \hat{X}_n < \overline{x}_2$$

(120) : $$0 \le \hat{X}_1 - X_1 \le \overline{x}_1, \quad 0 \le \hat{X}_2 - X_2 \le \overline{x}_1, \ ..., \quad 0 \le \hat{X}_n - X_n \le \overline{x}_n$$

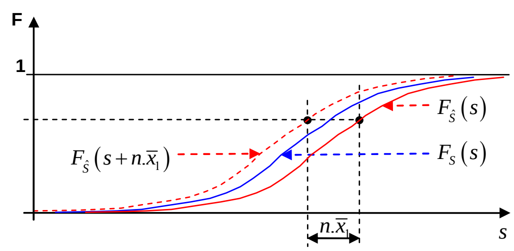
(121) : $$0 \le \hat{S} - S \le n.\overline{x}_1 \qquad \Leftrightarrow \qquad \hat{S} - n.\overline{x}_1 \le S \le \hat{S} \le S + n.\overline{x}_1$$

(122) : $$\Pr\left(S < \hat{s} - n.\overline{x}_1\right) \le \Pr\left(\hat{S} < s\right) \le \underline{\Pr\left(S < s\right) = \Pr\left(\hat{S} < \hat{s}\right)} \le \Pr\left(\hat{S} < s + n.\overline{x}_1\right)$$

or for the cumulative distribution functions:

(123) : $$\boxed{F_S\left(\hat{s} - n.\overline{x}_1\right) \le F_{\hat{S}}(s) \le \underline{F_S(s) = F_{\hat{S}}(\hat{s})} \le F_{\hat{S}}\left(s + n.\overline{x}_1\right)}$$ (when $s < \overline{x}_2$)

Figure 61: $F_S(s)$ **and** $F_{\hat{S}}(s)$



The value $\hat{s}$ of $\hat{S}$ such that:

(124) : $$F_{\hat{S}}\left(\hat{s}\right)=F_S\left(s\right)$$

and is such that:

(125) : $$s\le\hat{s}\le s+n.\overline{x}_1$$

The relative deviation of $\hat{s}$ from s is bound as indicated below:

(126) : $$0\le\frac{\hat{s}-s}{s}\le\frac{n.\overline{x}_1}{s}$$

Let a_s the required accuracy on the value of $\hat{s}$:

(127) : $$\left|\frac{\hat{s}-s}{s}\right|\le a_s$$

For the required accuracy on the value of $\hat{s}$, s must be greater than a minimum value $s_{\min}$:

(128) : $$s\ge s_{\min}\ with\quad s_{\min}==\frac{n.\overline{x}_1}{a_s}$$

The value of $F_S\left(s\right)$ is equal to $F_{\hat{S}}\left(\hat{s}\right)$ for a value of $\hat{s}$ such that $\left\|\frac{\hat{s}-s}{s}\right\|$ does not exceed a given accuracy a_s , provided that: $s\ge s_{\min}$ with $s_{\min}==\frac{n.\overline{x}_1}{a_s}$ and $s<\overline{x}_2$

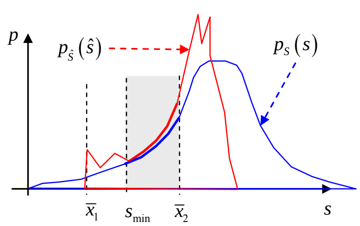


Figure 62: $p_S\left(s\right)$ **and** $p_{\hat{S}}\left(\hat{s}\right)$

When using a FFT, it is assumed that the function is periodic. The number of samples (2^N) must be such that:

(129) : $$\boxed{n.\frac{\overline{x}_2}{\Delta x}<2^N+\frac{s_{\min}}{\Delta x}}$$

where:

Δx is the sampling period of X and S .

For a FFT over 64 K samples, a given required accuracy and the value of n , Table 1 gives the values of $\frac{\overline{x}_1}{\Delta x}$, $\frac{\overline{x}_2}{\Delta x}$, $\frac{s_{\min}}{\Delta x}$ and the range $\frac{\overline{x}_2}{s_{\min}}$ in dBs over which the estimation of $F_S\left(s\right)$ is obtained. For X defined over 90 dB, it is recommended to perform the computation over 14 successive 10 dB ranges of X or S, i.e. starting 20 dB below the minimum value of X and ending 30 dB above the maximum value of X.

N	16	16	16
a_s	1%	2%	3%
n	8	11	14
$\frac{\overline{x}_1}{\Delta x}$	1	1	1
2^N	65 536	65 536	65 536
$\frac{s_{\min}}{\Delta x}$	800.0	550.0	466.7
$\frac{\overline{x}_2}{\Delta x}$	8 292.0	6 007.8	4 714.5
$\frac{\overline{x}_2}{s_{\min}}$	10.4	10.9	10.1
$\frac{\overline{x}_2}{s_{\min}}$	10.16 dB	10.38 dB	10.04 dB

Table 18: Sampling and FFT parameters

ANNEX 3 : CASE OF SEVERAL ESVS MOVING IN DIFFERENT DIRECTIONS

One of the two methods described in §6.8 for the computing the probability of the (*I/N*) ratio in the case of the 3 ESVs sailing in different directions during the same day requires the computation of the probability of the sum of:

- the (*I/N*) ratio in the case of 1 ESV sailing, during the day, below the FSR antenna main beam, and
- the (*I/N*) ratio in the case of 2 ESVs sailing, during the same day, in a direction orthogonal to the FSR antenna main beam.

The probability of the sum is obtained by the convolution of the probabilities of each ratio (I/N) by application of the following property:

- The probability density of the sum (*S* = *X* + *Y*) of two independent variables (*X* and *Y*) is equal to the convolution of the probability densities:

(130) : $$p_{X+Y}(s) = p_X(s) * p_Y(s) = \int_{x=-\infty}^{x=+\infty} p_X(x).p_Y(s-x).dx$$

The probabilities of the ratio (I/N) were obtained for (I/N) ratios every 0.5 dB, from -150 dB to +35 dB.

An approximation of the sum of these (I/N) ratios may be easily computed as shown hereafter.

Let X and Y these (*I/N*) ratios and S their sum:

(131) : $$S = X + Y$$

The probability densities of X and Y may be written as it follows:

(132) : $$p_X(x) = \sum_{k'=0}^{k'=K} p_{X,k'}.\delta\left(x - x_{\min}.\alpha^{k'}\right)$$

(133) : $$p_Y(y) = \sum_{k''=0}^{k''=K} p_{Y,k''}.\delta\left(y - x_{\min}.\alpha^{k''}\right)$$

with:

(134) : $$\alpha = 10^{0,5/10}$$ for 0.5 dB steps

and:

(135) : $$x_{\min} = 10^{-150/10}$$ for 0.5 dB steps

Then:

(136) : $$p_S(s) = \int_{x=-\infty}^{x=+\infty} \sum_{k'=0}^{k'=K} \sum_{k''=0}^{k''=K} p_{X,k'}.p_{Y,k''}.\delta\left(s - x - x_{\min}.\alpha^{k''}\right).\delta\left(x - x_{\min}.\alpha^{k'}\right).dx$$

or:

(137) : $$p_S(s) = \sum_{k'=0}^{k'=K} \sum_{k''=0}^{k''=K} p_{X,k'}.p_{Y,k''}.\delta\left(s - x_{\min}.\left(\alpha^{k'} + \alpha^{k''}\right)\right)$$

Let $p_{\hat{S}}$ an approximation of p_S such that:

(138) : $$p_{\hat{S}}(s) = \sum_{k=0}^{k=K} p_{\hat{S},k}.\delta\left(s - x_{\min}.\alpha^{k}\right)$$

and:

(139) : $$\alpha^k \le \left(\alpha^{k'} + \alpha^{k''}\right) < \alpha^{k+1}$$

or:

(140) :

$$\boxed{p_{\hat{S},k} = \sum_{k'=0}^{k'=K} \sum_{k''=0}^{k''=K} \left(p_{X,k'} \cdot p_{Y,k''} \right) \Big|_{\alpha^k \le \left(\alpha^{k'} + \alpha^{k''}\right) < \alpha^{k+1}}}$$

The relationship between p_S, p_X and p_Y is given within the following frame:

$p_S(k) =$	$+ p_X(k - 0) * (F_Y(k - 25) - F_Y(0))$	$+ p_Y(k - 0) * (F_X(k - 25) - F_X(0))$
	$+ p_X(k - 1) * (F_Y(k - 16) - F_Y(k - 25 - 1))$	$+ p_Y(k - 1) * (F_X(k - 16) - F_X(k - 25 - 1))$
	$+ p_X(k - 2) * (F_Y(k - 16) - F_Y(k - 12 - 1))$	$+ p_Y(k - 2) * (F_X(k - 16) - F_X(k - 12 - 1))$
	$+ p_X(k - 3) * (p_Y(k - 10) + p_Y(k - 11) + p_Y(k - 12))$	$+ p_Y(k - 3) * (p_X(k - 10) + p_X(k - 11) + p_X(k - 12))$
	$+ p_X(k - 4) * (p_Y(k - 8) + p_Y(k - 9) + p_Y(k - 10))$	$+ p_Y(k - 4) * (p_X(k - 8) + p_X(k - 9) + p_X(k - 10))$
	$+ p_X(k - 5) * (p_Y(k - 8) + p_Y(k - 7))$	$+ p_Y(k - 5) * (p_X(k - 8) + p_X(k - 7))$
	$+ p_Y(k - 6) * p_X(k - 7)$	$+ p_X(k - 6) * p_Y(k - 6)$
	$+ p_X(k - 6) * p_Y(k - 7)$	

with:

(141) :

$$\boxed{F_{X,k} = \sum_{k'=0}^{k'=k} p_{X,k'}} \quad \text{and} \quad \boxed{F_{Y,k} = \sum_{k''=0}^{k''=k} p_{Y,k''}}$$

ANNEX 4: METHODS FOR REDUCING THE MINIMUM DISTANCES D_0 AND D_C

Some investigations have been carried out in order to find conditions under which ESVs could operate closer to the FSRs and to the coasts but no significant reductions of the minimum distances could be obtained. This analysis and the conclusion are presented below. As the question could be raised again by any other body, this analysis with the conclusion is proposed to become a new section of the report, under the following title: "§ 6.9 Solutions for reducing the minimum distances". In addition, it is proposed to replace within the conclusion (§7) the sentence: "The scenarios used to determine the values d_0 and d_c are described in (§ 6.6.5)" by the sentence: "The scenarios used to determine the values d_0 and d_c are described in (§ <6.6.5>) and the solutions for reducing the minimum distances are described in (§ <6.9>)".

A4.1. Solutions for reducing the minimum distances

A4.1.1. General

The minimum distances to the FSRs and to the coasts presented in <Table 16> and <Table 17> were obtained for a set of conditions on the ESVs which have been assumed and highlighted along the report and which are summarized within the conclusion of this report in <§ 7>.

For instance, in some areas such as the North Sea and the Channel where the distances of the ESVs from the coasts are of the order of a few kilometres, it is then questionable under which other conditions these minimum distances could be reduced in order to give the possibility to ESVs to operate.

The following operational conditions of the ESV could be classified into three categories:

- the minimum characteristics of the ESV equipment which could not be improved significantly in dBs while an improvement in the order of some dBs may increase significantly of the cost of the equipment
  - the ESV antenna off-axis gain pattern and the relaxation for 10% of the peaks,
  - the minimum phase noise floor of the ESV carrier,
  - the maximum level of the 1st spectrum side lobe of the ESV carrier.

    Remark 1: The reduction of the first side lobe level will only allow reducing the guard band (*df*) by a fraction of the necessary bandwidth. This could be verified for a 2,048 Mbit/s carrier on <Figure 26> representing the FSR filter NFD with FS systems S2 for various values the first side lobes levels (SLLs) of the ESV spectrum mask. There is no substantial difference between the bleu line for SLL = -26 dB and the green lines for SLL = -29 dB and -32 dB.

- the operational conditions which may lead to the impossibility to used the ESV:
  - the ESV antenna main beam axis elevation,

    Remark 2: In increasing the ESV antenna main beam axis elevation above 20° the reduction of the off-axis e.i.r.p. density towards the horizon is only 1,4 dB for 30°, 4, 6 dB for 40° and 6,5 dB above 48°. It will be shown that this amount of dBs is not sufficient.

    Remark 3: In increasing the ESV antenna main beam axis elevation above 20° the satellites which could be used would be limited to the satellites close to the meridian plan of the ESV. The C band satellites usually located in the middle of the Atlantic Ocean, between America and Europa and Africa will not be any more accessible, and mainly in the North of Europe.
  - the minimum vessel speed for ESV transmission,

    Remark 4: It would be necessary to considerably increase of the vessel minimum speed for obtaining a significant reduction of the minimum distances.

- the operational conditions which allow the ESV operation but with limited capability of throughput:
  - the minimum guard-band (*df*),
  - the ESV maximum e.i.r.p.

Only the variation of the minimum distances with these last two parameters has been considered.

From the following particular operational conditions which was analysed a general method of forecast for other operational conditions appeared.

A4.1.2. Reduction of the ESV maximum e.i.r.p

Let assume that for specific wide areas the ESV e.i.r.p is limited to 43 dBW instead of 58 dBW. In that case, with the same e.i.r.p. spectral density to obtain the same bit error ratio (BER) the ESV throughput is limited to 64 kbit/s. At any given distance from the FSR and for the same guard band (*df*) the level of interference received by the FSR, due to the carrier and due to the ESV phase noise, will be 15,04 dB lower than with a 2,048 Mbit/s carrier. This has been verified by computation of the I/N margin for the following case:

- FSR:
  - distance to the coast = 0 km,
  - NFD = 35 dB for (*df*) = 1,705 MHz for a 64 kbit/s carrier as indicated on <Figure 16>,
  - antenna altitude = 50 + 120 m,
  - antenna diameter = 3 m,
- ESV:
  - antenna altitude = 40 m,
  - antenna diameter = 2,4 m,
  - vessel speed = 18,3 km/h,
  - the ESV is sailing below the FSR antenna main beam axis (Â = 0°),
  - number of ESVs per day: 3,
  - distance of the ESV to the FSR de 5 km to 320 km.

The I/N margin is displayed on Figure 1 for the 64 kbit/s ESV carrier and also for a 2048 kbit/s ESV carrier. For any distance d_{min} the difference of I/N margin is exactly 15,04 dB. This difference is equal to the difference of the carriers e.i.r.p which is equal to the ratio of the bit rates (10.log(2048/64)). Then the following rule may be used:

For a maximum e.i.r.p. differing from 58 dBW and a guard band (*df*) differing from the value assumed in this report, the minimum distance d_0 of the ESV to the FSR can be determined using the I/N margins curves computed for a 2048 kbit/s carrier and for and NFD equal to 35 dB but with a I/N threshold different of 0 dB. This I/N threshold is equal to - ((e.i.r.p.$_{[dBW]}$- 58) + (NFD(*df*) -35)).

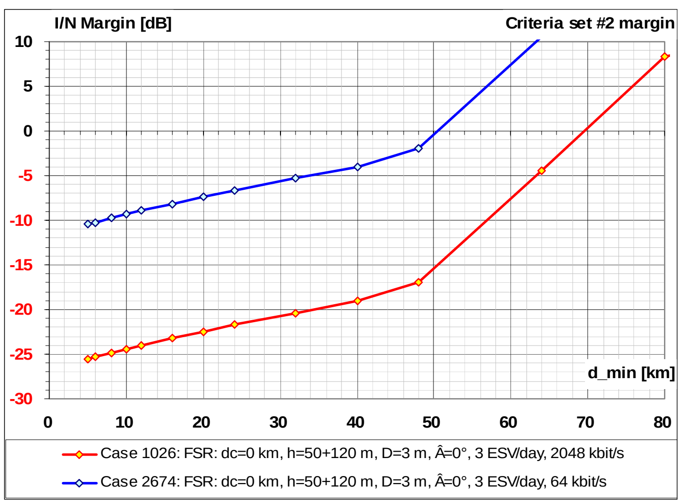


Figure A4.63: I/N margin for a 2048 kbit/s ESV carrier and for a 64 kbit/s ESV carrier

On Figure 1 it can be seen that the minimum distance (d_0) to the FSR which is equal to 70 km for a 2048 kbit/s carrier is only reduced to 51 km for a 64 kbit/s carrier. This reduction ratio is only equal to 2,75 dB (= 20.log(70/51)) instead of 15,04 dB.

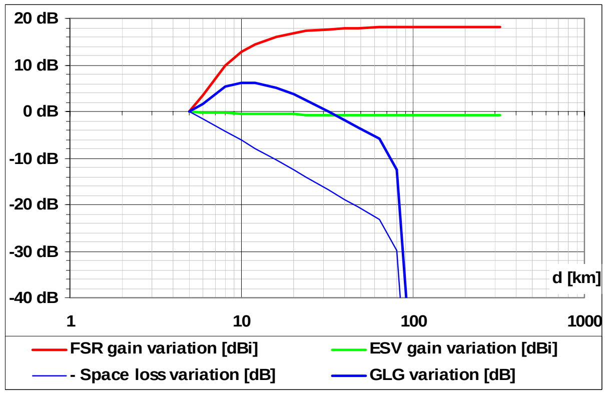


Figure A4.64: Variations of the FSR antenna gain, the ESV antenna gain, the space loss for 100% of the time and of the GLG function for a static ESV

Figure 2 shows the GLG functions variations for 100 % of the time, relative to a reference point at 5 km. The GLG value variation is equal to -6 dB at the minimum distance (70 km) for a static ESV emitting a 2048 kbit/s carrier. With a 64 kbit/s carrier, with an e.i.r.p. 15 dB lower, the GLG value variation is equal to + 9 dB (i.e. = -6 +15) and the corresponding minimum distance is lower than 5 km. At that short distance a static ESV emitting a 64 kbit/s carrier produce the same level of interference as a static ESV emitting a 2048 kbit/s carrier at 70 km. This explanation leads to a very different conclusion than Figure 1. Another phenomenon happens.

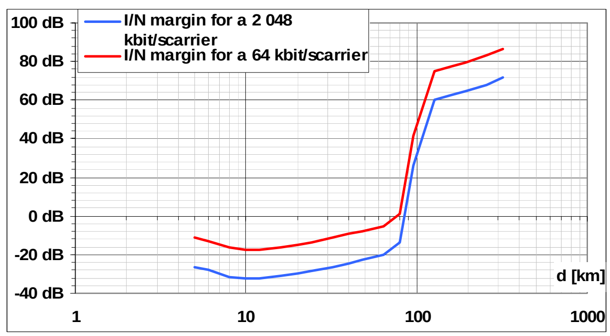


Figure A4.65: I/N margin for a 2048 kbit/s carrier and for a 64 kbit/s carrier for a static ESV and I/N = -20 dB

Figure A4.65 shows the I/N margin for a 2048 kbit/s carrier and for a 64 kbit/s carrier emitted by a static ESV and for I/N = -20 dB. With a 2048 kbit/s carrier the I/N margin becomes null or negative when the distance (*d*) becomes lower than 86 km, and with a 64 kbit/s carrier the I/N margin becomes null or negative when the distance (*d*) becomes lower than 76 km. The I/N margin rapidly increases with the distance when the ESV is beyond the FSR horizon. Assuming that there is no time variation of the propagation loss, the maximum ESV travel length with excessive level of interference (for SESs) for the FSR would be equal to 24 h * 20% * 18,6 km/h / 3 ESV/day = 30 km. The minimum distance where the ESV would have to stop its emissions would be 86 - 30 = 56 km for a 2048 kbit/s carrier and 76 - 30 = 46 km for a 2048 kbit/s carrier. In fact the propagation phenomena are more complex. Nevertheless this simplified explanation can help to understand why a reduction of 15 dB of the ESV e.i.r.p. does not leads to a reduction of the minimum distance by a factor 5,6.

A4.1.3. Increase of the guard band

The purpose of this section is to evaluate the reduction of the minimum distance (d_0) by increasing the guard band (*df*).

Figure 15 in the Report shows an ESV carrier and the FSR filter. It is noticeable that the noise floor of the ESV carrier extends over +/- 35 MHz and that the slope of the receiver filter is only 1.2 dB/MHz.

With figures <16> to <24> it can be verified that when the guard band (*df*) is increased above 1,7 MHz the Net Filter Discrimination (NDF) increases slowly. The higher is the $NFD_{[dB]}$ the lower is the level of interference ($I_{[dB]}$). The level of interference (I) received by the FSR is characterized by the NFD; its value is a function of two elements: the carrier it-self and the ESV carrier noise floor. The carrier is attenuated by the receiver filter. The attenuation of the carrier depends on the position of the carrier, i.e. of the guard band (*df*). The noise floor of the ESV carrier which extends over +/- 35 MHz always falls within the FSR filter bandwidth. For guard bands greater than 1,7 MHz, it is the noise floor element which is predominant. In order to obtain a significant improvement of the NFD it would be necessary to increase the guard band to a value greater than 35 MHz.

In <Figure 16> and <Figure 17> it can be verified that in increasing the guard band (*df*) from 1,7 MHz to 5 MHz the NFD is increased by about 8 dB. Using the assessment method defined in § A4.1.2 with Figure 13, the minimum distance could be slightly reduced: for a 2048 kbit/s carrier it would be 60 km with *df* = 5 MHz instead of 70 km with *df* = 1,7 MHz.

A4.2. Conclusion

The reduction of the minimum distance (d_0) by a reduction of the maximum ESV e.i.r.p. or by an increase of the guard band (*df*) has been assessed using the criteria set #2 and for the worst configuration in order to highlight the phenomena and to show that the reduction which could be expected may be lower than the reduction which would be obtained with only free space loss. With a 15 dB reduction of the ESV e.i.r.p., in case of free space loss only, the expected reduction of the minimum distance would be from 70 km to 70 x $10^{-15/20}$ = 12,448 km, but the phenomena are more complex than free space loss and the reduction of the minimum distance is lower.

Where criteria set #2 is applied, an increase of the guard band does not provide a substantial decrease of d_0.

For other criteria sets and other values of the maximum e.i.r.p. and of the NFD, the rule given in §A4.1.2 may be applied.