Report **SFCG 29-1R1**

GUIDELINES FOR INTERFERENCE RISK ASSESSMENT BETWEEN EARTH OBSERVATION SATELLITES IN THE BAND 8025-8400 MHz

1. INTRODUCTION

This report presents a methodology for interference assessment between EESS missions in the band 8025-8400 MHz. It was compiled based on studies conducted by SFCG member agencies in the past. Various documents presented at SFCG meetings suggested means to compute interference, in particular documents SF27-19/D, SF27-40/D ,SF26-28/D which makes reference to many other documents presented in the past by ESA, NASA and CNES) and SFCG-28 Action Item No. 28/5.

The objective is to propose default values for mission characteristics when they are not available in the SFCG databases and where no other source for missing information can be identified.

Interference analyses are necessary to prevent or minimize interference between satellite missions operating in the same frequency band. These analyses should result in estimations as close as possible to reality. Method and parameter values exposed in this document have been selected keeping in mind the goal of realism of potential simulations to assess interference risks.

The 8025-8400 MHz band is allocated to the Earth Exploration Satellite Service (EESS) for space-to-earth transmissions. To date, this band is largely used by many space agencies with earth observation programs, as well as various worldwide industry space missions. It is possible that use of the band 8025 – 8400 MHz will increase in the future.

Mission planning requires checking whether the new mission would generate harmful interference to any other current or future mission operating in the same frequency band. Such a study typically helps determining the new mission frequency plan, its RF link characteristics and orbit In addition, mission coordination requires assessment of the impact of mission plan changes on an identified case of interference between missions. For both cases, preliminary studies can be conducted based on available data on current missions, and also for future missions in the case of a general interference risk assessment.

The SFCG has created a database with the objective to record all existing missions and future missions when their planning is sufficiently advanced. This database is considered as the main reference for missions information. Nevertheless, the database is not complete and many satellite missions are not referenced or not completely described in the database. In addition, another database dedicated to X-band EESS missions is available and kept up to date by the SFCG. The latter is also considered as a reference for information on earth observation missions, in case of missing information in the SFCG Database.

The values and models in this report have been compiled to assist in the harmonization of interference risk assessment amongst SFCG member agencies. Considerable efforts were put into proposals for models and default input parameters for interference risk assessments in the 8025-8400 MHz band. In order to remain as realistic as possible when proposing default values and models for interference computations, it was assumed that current EESS missions operating in X-band are representative of the existing technologies for payload data transmission. The technologies broadly applied in the field of image data transmission are proposed to be considered as default characteristics for missions for which those are not available either in none of the SFCG databases, or from any other source of information.

The following values and models can be applied to conduct interference risk analyses. The first part introduces default values for parameters, when they are neither available in the SFCG databases nor from any other sources. The second part lists models which may be used for link budget and interference computations. These values and models in this report are not to be considered as a mandatory methodology for interference computations. The intention of this document is to provide reference information which can be considered in the modelling effort and default parameters that can be used when the required information needed is missing in the SFCG Databases and can also not be obtained from any other source of information. SFCG member agencies may make an explicit reference in their interference risk assessment studies to the source of information for scenarios configuration, when different from the SFCG databases and main models used when different from the ones described in the present report.

2. DEFAULT VALUES FOR COMPUTER SIMULATIONS

This section contains default values for most of the parameters that are needed for running interference computations.

Based on the existing missions the following values appear appropriate for consideration as default parameter values for simulation of future missions or current missions when the reference databases do not provide sufficient technical information.

a) Orbital parameters:

   i. Semi-major axis: For most of the missions the semi-major axis may be a random value between 6978 km and 7203 km (apogee between 600 and 825 km). Additionally, for sun synchronous missions the semi-major axis must be set so that the computed orbit matches the sun synchronous orbit equation which defines the orbit precession rate.

   ii. Inclination: For most of the missions the inclination value may be a random value between 97° and 99°. Additionally, for sun synchronous orbit (SSO) missions the inclination value must be set in order to make the computed orbit match the sun synchronous orbit equation. As an example, for SSO missions, if the altitude is 700 km (semi-major axis is 7078 km), then the inclination would have to be 98.2°.

   iii. RAAN: The right angle of ascending node (RAAN) can be a random value for non-SSO missions. For SSO missions, the RAAN can be determined from the orbit's mean local time.

   iv. Mean Anomaly: For most of the missions a random value can be considered. In order to accurately model orbital train missions, specific values need to be provided.

v. Eccentricity: Since most of the missions are in circular or nearly-circular orbits, a zero value eccentricity should be considered, when not specified.

vi. Argument of perigee: The argument of perigee can be a random value.

b) RF payload characteristics:

i. Transmitted EIRP flux density: For missions identified in the SFCG X-band database the average value of the transmitted power spectral density is -63 dBW/Hz. Users may want to update this value based on the latest version of the SFCG X-band database. Whenever the actual value is not specified, this default value may be used.

ii. Signal bandwidth, BW:

1. When the BW is not specified, but the symbol rate is specified, the BW may be estimated to be twice the channel symbol rate (R in Msps). More precisely, and in order to ensure that the BW is within the allocated frequency range, the BW should be defined as follows:

2. BW (MHz) = 2 * minimum ($|f_c-f_{max}|$, $|f_c-f_{min}|$, R), with f_c the carrier frequency, f_{min} the band lower bound 8025 MHz and f_{max} the band higher bound 8400 MHz. When the BW is not specified, and the symbol rate is also not specified, the symbol rate may be estimated to be the average value in the SFCG X-Band database, which is 101 Msps. The BW may then be calculated as specified in the previous paragraph.

iii. Carrier frequency:

1. For missions operating in broadcast mode, the carrier frequency may be assumed in the lower half of the band as a consequence of recommendation SFCG Rec.14-3R7.

2. For all other missions the carrier frequency can be set randomly, between 8025+R MHz and 8400-R MHz.

iv. Signal modulation: QPSK is recommended as being the mostly used technology. However, in the case of high channel symbol rate transmissions where [f_c-R, f_c+R] would exceed the EESS allocated band, 8PSK modulation can be considered.

c) On-board antenna characteristics:

i. Size: Antenna size is needed to compute parabolic antenna gain. A typical value for payload transmission is 0.3 m.

ii. Efficiency: Antenna efficiency is needed to compute parabolic antenna gain. Typically antenna efficiency values are comprised between 55% and 60%.

iii. Maximum gain: If no antenna type is given, isoflux may be assumed, as it is the more common type in the X-band. For parabolic antennas, maximum gain value may be set between 24 and 29 dBi. For isoflux antennas, maximum gain value may be set between 4 and 8.5 dBi.

d) Ground antenna characteristics:

i. Maximum gain: A value of 58 dBi may be assumed, as this is a typical value and corresponds to an antenna diameter of about 12 m. This corresponds to an antenna efficiency of 65%, which is a typical value that may also be used with other antenna sizes.

ii. Minimum elevation for visibility: When not indicated, a 5° default value can be considered.

e) Mission lifetime: If no value is given, the mission should be assumed to be operational at any time. This is worst-case but realistic, as many missions are extended to last a long time, and others are replaced by a similar follow on mission.

3. MODELS FOR LINK BUDGET AND INTERFERENCE CALCULATIONS

This section contains some of the models that are needed in link budget and interference computations, and which are considered as the most critical models in relation with their impact on link budget results. In some cases, two options are presented, and member agencies may use either one in their analysis. It is noted that when two agencies perform analyses and compare results, they should agree to use the same options if they desire to obtain the same results.

a) Simulation step and simulation duration: These two parameters are very important for the expected statistics validity when the simulation model uses the more standard non-statistical or linear time step approach. Indeed, the interference criteria are based on low percentages of time of visibility of the useful link. In order to have representative statistics it is then important to have enough visibility points in the simulation.

Option 1: The classical simulation approach: The user must estimate the number of visibility points the simulation of duration D and time step Ts will lead to. Typically, a simulation time step between 1 and 10 seconds and a 1-year duration should be precise enough for statistics with a 10^{-3} probability, if the user expects to have a number of events in the order of magnitude of 10^{2}. Besides it has shown to be a good compromise between simulation accuracy and computation run time.

Option 2: Use a number of randomly selected time increments (i.e., 10,000 time points which are randomly generated from time = 0 to time = 1 year). This allows the analyst to precisely define the degree of precision of the run. For example, if 10 error events are determined to be sufficient precision and the interference criterion is set to be a value not exceed for 0.1% of the time, then 10,000 or more time points are likely needed. Alternatively, if 100 errors events are determined to be sufficient precision, then 100,000 or more time points are likely needed.

b) Orbital extrapolators: This is a complex issue due to the many factors affecting a low earth orbit including the equatorial bulge, atmospheric drag, third body perturbations etc. However, in the context of performing analyses of the X-Band EESS interference environment, only statistical results are needed. J2 is sufficient. However, since many EESS systems are in sun synchronous orbits, and the amount of interference between two EESS systems in sun synchronous orbits is highly dependent on the relative phase between the two systems, it is very important that the model ensure they precess at exactly the same rate.

c) Antenna patterns: The use of highly directive antenna and isoflux antenna patterns is recommended as an item of SFCG Rec.14-3R7. Thus, these two kinds of patterns can be considered for link budget computation, noting that few satellites may use horn antennas.

i. Earth station antennas

Option 1: For ground earth station, Appendix 8, Annex 3 of the ITU Radio Regulations presents an earth station antenna pattern to be used for interference studies when actual patterns are not published and the number of interfering sources is small (i.e., less than 5). However, when the number of interference systems is large (i.e., 5 or greater), or when the interference constellation is changing over time, then it is appropriate to use a pattern that represents average side-lobe levels. Recommendation ITU-R F.1245 has such a pattern.

Option 2: Bessel modelling

$$\begin{cases} G(0) = \eta * \left(\dfrac{\pi * D}{\lambda}\right)^2 \\ G(\theta) = \eta * \left(\dfrac{\pi * D}{\lambda}\right)^2 * \left(\dfrac{2 * J_1(u)}{u}\right)^2, \end{cases} \quad \text{with } u = \frac{\pi * D}{\lambda} * \sin(\theta)$$

η the antenna efficiency, D the antenna diameter, λ the wavelength and θ the off-axis angle

ii. On-board antennas

Option 1: For on-board steerable directive antenna a Bessel modeling or equivalent is recommended. An equivalent model can be a simplified model similar to the one presented in Recommendations ITU-R S.672 and F.1245. It is then important to have in mind that the main lobe in the ITU-R S.672 model is quite large leading to higher link budget values that can bias the estimation of interferences. This model over estimates interference coming through the sidelobes. The antenna lobe effects are not represented but F.1245 averages the varying lobes

Option 2: For isoflux antenna, the following model is recommended as it leads to a uniform PFD in the spot beam area :

$$F_{dB}(\theta) = \begin{cases} 0 & \forall \theta \le 40° \\ k * \sin((\theta - 40) * 180/35) & \forall \theta \in [40°, 70°] \\ k * \sin((\theta - 40) * 180/35) - 3.5 * (\theta - 70) & \forall \theta > 70° \end{cases}$$

where k is the maximum gain value in dBi.

The pattern is represented in the figure hereafter with 6dBi maximum gain.

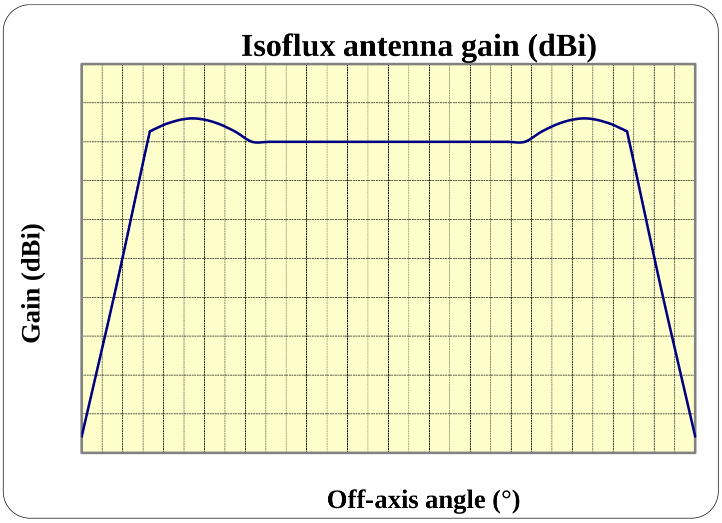


Figure 1: Isoflux antenna radiation pattern

d) Spectrum modelling:

Option 1: In many cases NRZ shaping is used and is associated with a sharp filtering, typically SRRC, with a roll-off around 0.35 . For spectrum modelling an NRZ shaping may be applied and consideration of sharp filtering beyond [f_c-R, f_c+R], with f_c being the carrier frequency and R the channel symbol rate (to be understood as: if R_B is the binary rate, taken before coding and modulation; R_B = k x R after coding and modulation and k is the number of bits inside one channel symbol).

Option 2: The assumed spectra if unknown could be a flat spectrum across the entire necessary bandwidth. If the necessary bandwidth is not known, but the symbol rate is, then the necessary bandwidth may be considered to be twice the symbol rate (i.e., the null-to-null bandwidth) for BPSK and equal to the symbol rate for QPSK. For example, if the data rate is 50 Mbps per channel and rate ½ coding is used, then the symbol rate is 100 Msps, and the necessary bandwidth is 200 MHz using BPSK.

e) Propagation models: The only propagation loss that needs to be taken into account in the EESS X-Band studies is free space loss. The other propagation losses can be ignored.

f) Interference factor:

The degradation of the victim signal due to an interfering signal depends on the spectral overlap between the victim signal and the interferer signal. Two options for computing the equivalent interference power and the equivalent interference power spectral density are given.

Option1: As spectra are not uniform the impact varies according to the overlapped area of the victim spectrum. A weighting factor may be used, which takes into consideration the spectral overlap between the victim and the interfering signals, and the actual spectral densities, and can be applied to the total power. . The following expression is a possible way to compute the weighting factor, called spectral likeness factor (SLF):

$$SLF(\Delta f) = \int_{f_v - BW_v/2}^{f_v + BW_v/2} S_i(f - \Delta f) S_v(f) df$$

with Δf the difference between the victim carrier center frequency (f_v) and the interfering carrier center frequency (f_i),

BW_v the frequency bandwidth of the victim link Earth station receiver,

$S_v(f)$ the normalised power spectral density of the victim satellite signal,

$S_i(f)$ the normalised power spectral density of the interfering signal.

A derivation of the SLF factor can be found in Annex A.

When this option is selected, the equivalent interfering power averaged over the victim receiver bandwidth is:

$$P_i = SLF(\Delta f) P_t$$

where

P_i = equivalent interfering signal power in the victim receiver

P_t = interfering signal power

Option 2: Based on the frequency overlap, it is possible to define a "Bandwidth Advantage Factor" (A_{BW}) which reduces the interfering spectral density level by that factor. The Bandwidth Advantage factor assumes that the spectral density of the interfering signal is uniform inside the interfering signal bandwidth and null outside. It is given by:

$$A_{BW}(f_i, BW_i, f_v, BW_v) = min\ (1, overlapBW_i / BW_v)$$

where

f_i and BW_i are the interfering transmitter center frequency and bandwidth, respectively

f_v and BW_v are the victim receiver center frequency and bandwidth, respectively

$overlapBW_i$ is the part of the interfering transmitter bandwidth that overlaps the victim receiver bandwidth.

Noting that with the above definition $overlapBW_i$ is always smaller or equal to BW_v and therefore that the ratio $overlapBW_i / BW_v$ is always smaller or equal to one, the formula can be further simplified as:

$$A_{BW}(f_i, BW_i, f_v, BW_v) = overlapBW_i / BW_v$$

When this option is selected, the equivalent interfering power spectral density averaged over the victim receiver bandwidth is:

$$I_i = A_{BW}\ PSD_i$$

where

I_i = equivalent interfering signal spectral density in the victim receiver

PSD_i = interfering signal peak spectral density

In case the victim receiver bandwidth BW_v is much wider than the interfering signal bandwidth BW_i or much wider than $overlapBW_i$ an additional check that PSD_i does not exceed the victim carrier recovery constraints shall be carried out.

Examples of application of this second option can be found in Annex B.

g) Protection criteria: Potentially relevant sources are Recommendation ITU-R SA.1027 and Recommendation ITU-R SA.609. It is noted that the protection criteria of SA.609 are more stringent for long term interference whereas SA.1027 is more stringent for short term interference.

Annex A – Derivation of the SLF factor

The following derivation assumes the use of a matched receiver for the victim signal.

The normalized interfering signal power at the victim receiver output can be given as:

$$P_{in}(\Delta f) = \int_{f_v - BW_v/2}^{f_v + BW_v/2} S_i(f - \Delta f) \left| H_v(f) \right|^2 df$$

with

Δf the difference between the victim carrier center frequency (f_v) and the interfering carrier center frequency (f_i),

BW_v the frequency bandwidth of the victim link Earth station receiver,

$S_i(f)$ the normalised power spectral density of the interfering signal,

$H_v(f)$ the victim receiver filter transfer function.

For a receiver matched to the transmitted signal, the normalized victim spectral density is given as:

$$S_v(f) = \left| H_v(f) \right|^2$$

yielding:

$$P_{in}(\Delta f) = \int_{f_v - BW_v/2}^{f_v + BW_v/2} S_i(f - \Delta f) S_v(f) df$$

that is hereby called Spectral Likeness Function $SLF(\Delta f)$
so that the equivalent interfering power in the receiver bandwidth can be computed by forming the following expression:

$$P_i = SLF(\Delta f)\, P_t$$

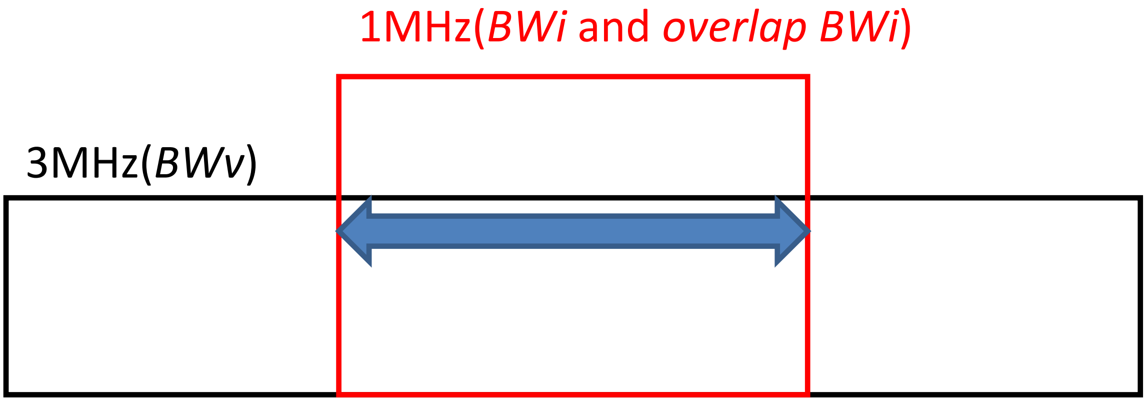
where

P_i = equivalent interfering signal power in the victim receiver

P_t = interfering signal power

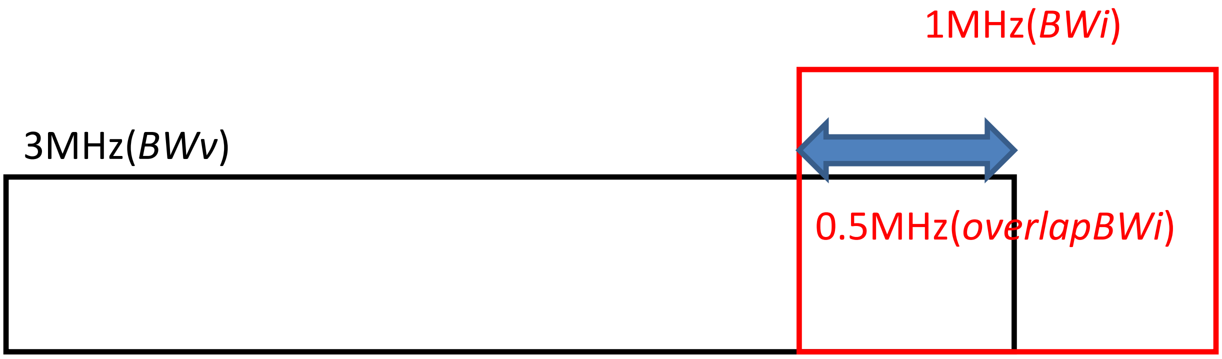
Annex B – Examples of application of option 2 for interference factor computation

B.1 $BW_v > BW_i$



$A_{BW}(f_i,BW_i,f_v,BW_v) = overlapBW_i/BW_v =$ 1/3 = 0.3

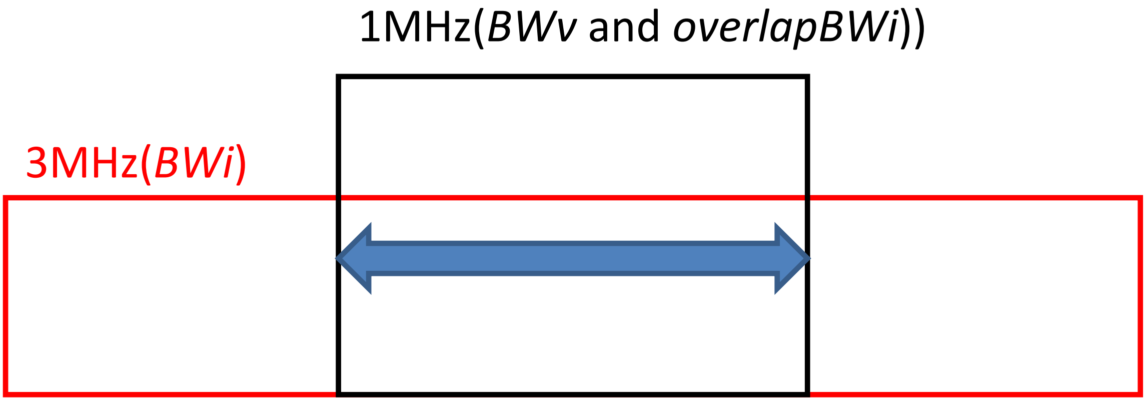
equivalent to -4.7(dB)



$A_{BW}(f_i,BW_i,f_v,BW_v) = overlapBW_i/BW_v$ = 0.5/3 = 0.17

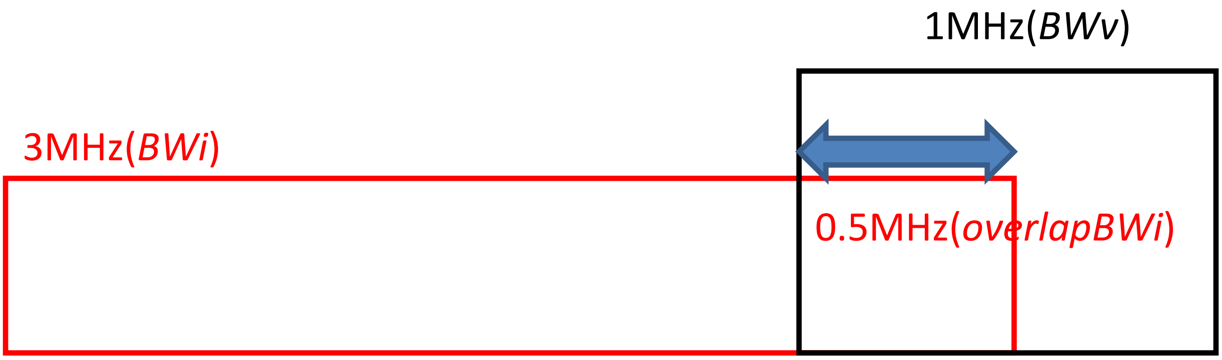
equivalent to -7.6(dB)

B.2 $BW_v < BW_i$



$A_{BW}(f_i,BW_i,f_v,BW_v) = overlapBW_i/BW_v = 1/1 = 1$

equivalent to 0(dB)



$A_{BW}(f_i,BW_i,f_v,BW_v) = overlapBW_i/BW_v = 0.5/1 = 0.5$

equivalent to -3(dB)