RECOMMENDATION ITU-R S.1323

MAXIMUM PERMISSIBLE LEVELS OF INTERFERENCE IN A SATELLITE NETWORK (GSO/FSS; NON-GSO/FSS; NON-GSO/MSS FEEDER LINKS) * FOR A HYPOTHETICAL REFERENCE DIGITAL PATH** IN THE FIXED-SATELLITE SERVICE CAUSED BY OTHER CODIRECTIONAL NETWORKS BELOW 30 GHZ

(Questions ITU-R 205/4, ITU-R 206/4 and ITU-R 231/4)

(1997)

The ITU Radiocommunication Assembly,

considering

a) that emissions from the earth stations as well as from the space station of a satellite network (geostationary-satellite orbit (GSO)/fixed-satellite service (FSS); non-GSO/FSS; non-GSO/mobile-satellite service (MSS) feeder links) in the FSS may result in interference to another such network when both networks operate in the same bands;

b) that the system designer should control the overall performance of a network and be entitled to provide a quality of service that meets ITU-R-recommended performance objectives which are expressed in terms of a bit error ratio (BER) (or a C/N value);

c) that it is necessary to protect a network of the FSS (GSO/FSS; non-GSO/FSS; non-GSO/MSS feeder links) from interference by other such networks;

d) that to allow an operator to exercise control over the quality of service there needs to be a limit on the aggregate interference a network must be able to tolerate from emissions of all other networks;

e) that to limit the aggregate interference from all other networks, there needs to be a limit on the interference a network should be expected to tolerate from any one other network;

f) that it is desirable that the increase in interference from other satellite networks should be a controlled fraction of the total noise that would give rise to a BER, as set out in ITU-R performance Recommendations;

g) that in frequency bands above 10 GHz where very high propagation attenuation may occur for short periods of time, it may be desirable for systems to make use of some form of fade compensation to counteract signal fading;

h) that in interference situations involving non-GSO systems, FSS networks (GSO/FSS; non-GSO/FSS; non-GSO/MSS feeder links) are potentially exposed to high levels of interference for short periods of time which could affect the short-term performance or availability of these networks;

j) that short-term interference events may cause loss of synchronization or other unstable conditions which may cause a degradation or loss of service for periods longer than the interference event;

k) that the permissible interference resulting from short-term interference events has to be specified differently for FSS operation in different frequency bands due to the different propagation characteristics of signals in these different bands,

* The methodologies for determination of short-term interference criteria contained in this Recommendation are intended to address interference to GSO/FSS, non-GSO/FSS and non-GSO/MSS feeder links. However, the applicability of these methodologies for all such networks requires further verification.

** Example HRDPs applicable to GSO/FSS and non-GSO/FSS networks are contained in Recommendation ITU-R S.521. HRDPs for other situations are currently under study.

recommends

1 that a geostationary network in the FSS operating in the frequency bands below 30 GHz should be designed and operated in such a manner that in any satellite hypothetical reference digital path (HRDP) performance objectives can be met when the aggregate interfering power from the earth and space station emissions of all other geostationary FSS networks operating in the same frequency band or bands, assuming clear-sky conditions on the interference paths, does not exceed at the input to the demodulator:

1.1 25% of the total system noise power under clear-sky conditions when the network does not practice frequency reuse;

1.2 20% of the total system noise power under clear-sky conditions when the network does practice frequency reuse;

2 that for a geostationary network in the FSS as mentioned in *recommends* 1, the internetwork interference caused by the earth and space station emissions of any one other geostationary FSS network operating in the same frequency band or bands should be limited to 6% of the total system noise power under clear-sky conditions;

3 that for a network in the FSS (GSO/FSS; non-GSO/FSS; non-GSO/MSS feeder links), the internetwork interference caused by the earth and space station emissions of all other satellite networks operating in the same frequency band and that can potentially cause short-term interference, should:

3.1 provisionally, be responsible for at most 10% of the time allowance for the given BERs (or C/N values) as specified in the short-term performance objectives of the desired network. (See Annex 1, Methodology A, § c) for input data and equation (6a) for a description of the implications of this interference allowance);

3.2 not lead to loss of synchronization in the desired network more than once per x days; (the possible inclusion of this requirement in the methodologies described in Annex 1 and an appropriate value of x are for further study);

4 that for a GSO/FSS network, a long-term interference allocation of 6% of the total system noise power should be provisionally made to account for interference from any one non-GSO interfering system (a long-term interference allocation for a non-GSO desired network requires further study);

5 that for a network as mentioned in *recommends* 3, the internetwork interference caused by the earth and space station emissions of any one satellite network operating in the same frequency band, and that can potentially cause short-term interference, should be determined using the methodologies described in Annex 1;

6 that the maximum level of interference noise power caused to a GSO/FSS network should be calculated on the basis of the following values for the receiving earth station antenna gain, in a direction at an angle φ (degrees) referred to the main beam direction:

for GSO to GSO interference:

$$G = 32 - 25 \log \varphi \quad \text{dBi} \quad \text{for} \quad 1° \le \varphi < 48°$$

$$G = -10 \quad \text{dBi} \quad \text{for} \quad 48° \le \varphi \le 180°$$

for non-GSO to GSO interference:

$$G(\varphi) = \begin{cases} G_{max} - 2.5 \times 10^{-3} \, (D\varphi/\lambda)^2 & \text{dBi} \quad \text{for} \quad 0° \le \varphi < \varphi_m \\ G_1 & \text{dBi} \quad \text{for} \quad \varphi_m \le \varphi < \varphi_r \\ 29 - 25 \log \varphi & \text{dBi} \quad \text{for} \quad \varphi_r \le \varphi < 36.3° \\ -10 & \text{dBi} \quad \text{for} \quad 36{,}3° \le \varphi < 180° \end{cases}$$

with:

$$G_1 = -1 + 15 \log (D/\lambda)$$

$$\varphi_m = (20\lambda/D) \sqrt{G_{max} - G_1}$$

$$\varphi_r = 15{,}85 \, (D/\lambda)^{-0{,}6}$$

(antenna patterns applicable to GSO satellites and non-GSO systems require further studies);

7 that the following Notes should be regarded as part of this Recommendation.

NOTE 1 – For the calculation of the limits quoted in *recommends* 1.1, 1.2, 2, 3 and 4 it should be assumed that the total system noise power at the input to the demodulator is of thermal nature and includes all intra-system noise contributions as well as interference noise from other systems.

In the event that the interference cannot be assumed to be thermal in nature the permissible level of interference into a digital carrier should be based upon the degradation of the BER (or *C*/*N*) performance objectives.

NOTE 2 – For the calculation of interference, in respect of *recommends* 1, 2, 3 and 4 as applied to satellite networks operating in a fading environment, it should be assumed that the carrier power level of the interfered system is reduced, until the system performance coincides with the above long-term BER (or *C*/*N*) and percentage of month (see Annex 1 of Recommendation ITU-R S.735 for clarification).

NOTE 3 – It is assumed in connection with *recommends* 1 and 2 in that the interference from other satellite networks is of a continuous nature at frequencies below 10 GHz: further study is required with respect to cases where interference is not of a continuous nature above 10 GHz.

NOTE 4 – When interference is characterized by a non-uniform spectral distribution there may be cases where, for design purposes, a greater interference allocation of total system noise may be made to narrow-bandwidth carriers by the system designer. One model developed to address this is presented in detail in Annex 2 of Recommendation ITU-R S.735.

NOTE 5 – For networks using 8 bit PCM encoded telephony see Recommendation ITU-R S.523.

NOTE 6 – In some cases it may be necessary to limit the single entry interference value to less than the value quoted in *recommends* 2 in order that the total value recommended in *recommends* 1 may not be exceeded. In other cases, particularly in congested arcs of the GSO, administrations may agree bilaterally to use higher single entry interference values than those quoted in *recommends* 2, but any interference noise power in excess of the value recommended in *recommends* 2 should be disregarded in calculating whether the total value recommended in *recommends* 1 is exceeded.

NOTE 7 – There is a need for study of the acceptability of an increase in the maximum total interference noise values recommended in *recommends* 1, 3 and 4.

NOTE 8 – For frequencies above 10 GHz short-term propagation data are not available uniformly throughout the world and there is a continuing need to examine such data to confirm an appropriate interference allowance to meet the applicable performance objectives.

NOTE 9 – There is a need to continue the study of the interference noise allowances appropriate to systems operating at frequencies above 15 GHz. There is an urgent need to study the effect on the interference noise allowances when power control is used at frequencies above 15 GHz for fade compensation.

NOTE 10 – In order to promote orbit efficiency, satellite networks operating in heavy rain environments are encouraged to use some form of fade compensation.

NOTE 11 – Although this Recommendation addresses codirectional sharing situations, the principles of the methodologies in Annex 1 are applicable to situations where reverse band sharing occurs.

NOTE 12 – Short-term performance objectives refer to those BERs (or *C*/*N* values) associated with 1% of the time or less.

NOTE 13 – Loss of synchronization due to short-term interference may cause loss of service for periods longer than the interferences themselves. The loss is especially severe for multiple access systems such as TDMA and CDMA. Frequent occurrence of severe but short-duration interference events, which may cause loss of synchronization, may represent a serious limitation to the service quality provided by satellite networks even if the aggregate percentage of time criteria are met. In these cases, the impact on the aggregate time as well as the mean time between occurrences of severe interference events should be evaluated. This issue requires further study.

ANNEX 1

Methodologies for deriving interference allowances in a network in the FSS (GSO/FSS; non-GSO/FSS; non-GSO/MSS feeder links) produced by a satellite network that can potentially cause short-term interference

This Annex includes 3 methodologies for deriving interference allowances, referred to here as Methodologies A, B and C.

Methodology A considers simultaneous effects due to fading and interference. Derivation of interference allowances take into account that during certain percentages of time performance objectives are violated because of the combination of the two sources of degradation, while none of them would isolatedly cause such violation. However, modeling fading may be difficult, specially for links to or from non-GSO satellites where elevation and azimuth vary with time.

For systems operating in clear-sky with relatively small margins and relying heavily on power control to combat fading, simultaneous effects due to fading and interference become less significant and may be neglected if the affected system so wishes. Methodologies B and C explore this possibility (separate consideration of interference effects).

Methodology B is indeed a simplification of Methodology A where, in addition to considering interference separately, performance objectives are summarized by a threshold BER (or C/N) and the percentage of time it can be exceeded.

Methodology C simplifies Methodology A in the sense that interference is considered separately from fading effects but is more elaborated than Methodology A in that it incorporates directly in the model trade-offs between uplink and downlink allowances. It has not been yet decided if this methodology can be applied to the systems considered in this Recommendation. Applicability of this method is still a matter for further study.

Methodologies A and B further differ in the way multiple sources of interference are addressed. Methodology A accounts for the joint effect by convolving individual probability density functions, while Methodology B apportions $(1/N)$ of the interference allowances to each of the N sources and deals separately with each of them. Methodology C, as presented here, addresses only the aggregate interference.

Further study is needed to determine the nature of both short and long term interference into a non-GSO network from multiple GSO networks.

PART 1

Methodology A

1 Basic assumptions

The following basic assumptions are made in connection with the procedure proposed here for determining the interference allowances associated with any given desired carrier.

Assumption 1: The two time-varying sources of degradation considered in the analysis are link fading plus any other time variations in the characteristics of the link and interference from other FSS networks.

Assumption 2: Due to fading plus other time variations in the characteristics of the link, carrier power reduction and noise increase can be accounted for by substituting C/X for C and the corresponding degradation x (dB) is:

$$x = 10 \log X \tag{1}$$

The effect of interference can be represented by increasing the noise power from N_T to $Y\,N_T$ and the corresponding degradation y (dB) is:

$$y = 10 \log Y \tag{2}$$

The total C/N degradation z (dB) is therefore:

$$z = x + y \tag{3}$$

The random variables x and y are assumed to be statistically independent and therefore the probability density function of z is the convolution of the probability density functions of x and y. Independence between these two random variables is an approximation because the presence of fading may increase the noise level and also lead to a reduction of I (fading in the interference path). In both respects, the assumption of independence is conservative in the sense of over-estimating the effect of interference.

Further, it follows from the definition of y that:

$$Y = 1 + (I/N_T) \tag{4}$$

where I is the interfering power. It is to be noted that the total link noise N_T includes the long-term interference associated with the interfering networks under consideration. Therefore, I is indeed the time-varying component of the interference which added to the long-term allowance gives the total interfering power.

Assumption 3: If there are N networks that can potentially cause short-term interference, the total interference power I normalized by the total noise N_T can be written as:

$$I/N_T = v_1 + \ldots + v_N \tag{5}$$

where v_n ($n = 1, \ldots, N$) is the interference power originating in the n^{th} network, normalized by the total noise N_T. The random variables v_n ($n = 1, \ldots, N$) are assumed to be statistically independent and therefore the probability density function of I/N_T is the convolution of the probability density functions of the random variables v_n ($n = 1, \ldots, N$).

2 Input data

The following data is required to determine the interference allowances corresponding to any specific desired carrier.

a) The performance requirements of the desired carrier, as expressed by the values of BER associated with different percentages of time have to be known. In general, this will be a set of values BERj ($j = 1, \ldots, J$) and the corresponding percentages of the year p_j ($j = 1, \ldots, J$) for which the BER can be worse than BERj.

b) The clear-sky carrier-to-noise ratio $(C/N)_{CS}$, as well as the carrier-to-noise ratio values $(C/N)_j$ ($j = 1, \ldots, J$) corresponding to the BER values BERj defined in a) above. In addition, if power control is used, information on the corresponding procedures is required. C/N values can be given directly without association with BER values, in which case only the values p_j ($j = 1, \ldots, J$) in a) are needed.

c) The probability density function $p_x(X)$ of the random variable x which expresses in dB the degradation in performance due to fading plus any other time variations in the characteristics of the link. This probability density function is highly dependent on the presence of power control and its characteristics. This probability density function has to be compatible with *recommends* 3.1 and therefore the degradation x cannot use more than 90% of the time allowances associated with each BER (or C/N) level (see equation (6a) for an expression of this condition).

d) The number N of interfering networks that can potentially cause short-term interference and that will be sharing the same frequency band with the desired network. For a GSO/FSS desired network, N equals the number of non-GSO systems sharing the same frequency band. For a non-GSO desired network, N equals the number of other non-GSO networks plus the number of 2° potentially interfering geostationary orbital positions visible, above the minimum elevation angle, by the earth station of the non-GSO network.

3 Proposed procedure

Based on the assumptions and required input data given above, the following steps define the procedure to determine the interference allowances corresponding to any given desired carrier.

Step 1: From a) and b) of the input data, the values z_i of the total degradation z which can be exceeded at most during p_i% of the year can be determined from:

$$z_j = (C/N)_{CS} - (C/N)_j \qquad \text{for } j = 1, ..., J \tag{6}$$

As a consequence, the conditions on $p_x(X)$ given in c) of the input data can be expressed as:

$$P(x \geq z_j) \leq (0.9\, p_j) / 100 \tag{6a}$$

Step 2: A parametric representation is chosen for the probability density function $p_v(V)$ corresponding to the interference power originating in any interfering network normalized by the total noise power N_T. In the case of a transparent transponder, this includes uplink and downlink interference from all earth stations and space stations in the interfering network. When there is on-board processing, separate probability densities for uplink and downlink degradations are required. The trade-off here is, on one hand, to have a sufficiently detailed representation of $p_v(V)$ and, on the other hand, to keep computations simple enough. This representation will depend on a certain number K of parameters α_k ($k = 1, \ldots, K$) and can be expressed as:

$$p_v(V) = \mathrm{f}(V, \alpha_1, \ldots, \alpha_K) \tag{7}$$

Step 3: According to assumption 3 in the basic assumptions and given the number N of interfering networks that can potentially cause short-term interference, as discussed in d) of the input data, the probability density function of the total interference power I normalized by the total noise N_T can be written as:

$$p_{I/N_T}(U) = p_{v_1} * \cdots * p_{v_N}(U) \tag{8}$$

where * denotes convolution. In view of (7), (8) can be written as:

$$p_{I/N_T}(U) = \mathrm{f}(U, \alpha_1, \ldots, \alpha_K) * \cdots * \mathrm{f}(U, \alpha_1, \ldots, \alpha_K) \qquad N \text{ times} \tag{9}$$

or alternatively:

$$p_{I/N_T}(U) = g(U, \alpha_1, \ldots, \alpha_K) \tag{10}$$

NOTE 1 – Equation (9) implicitly assumes that equal interference allowances are associated with each of the N interference entries. If this is not the case, equation (9) would have to be modified accordingly.

Step 4: It follows from assumption 2 in the basic assumptions that:

$$y = 10 \log \left[1 + (I/N_T)\right] = 10 \log (1 + u) \tag{11}$$

and therefore:

$$p_y(Y) = \left[p_u(U) / |\mathrm{d}y/\mathrm{d}u|\right]_{U = s(Y)} \tag{12}$$

where:

$$U = s(Y) = 10^{Y/10} - 1 \tag{13}$$

As:

$$\mathrm{d}y/\mathrm{d}u = 10 / [(1 + u) \ln 10]$$

it follows that:

$$p_y(Y) = p_u\left(10^{Y/10} - 1\right) \times 10^{[(Y/10)-1]} \ln 10 \tag{14}$$

Step 5 : A parametric representation for the total degradation *z* is obtained from:

$$p_z(Z) = p_x * p_y(Z) \tag{15}$$

where $p_x(X)$ is given in c) of the input data and $p_y(Y)$ is given by equation (14). As $p_y(Y)$ depends on the parameters $\alpha_1, ..., \alpha_K$, because according to (10) $p_u(U)$ depends on these parameters, so does $p_z(Z)$. This function can therefore be written as:

$$p_z(Z) = \mathrm{h}\left(Z, \alpha_1, \ldots, \alpha_K\right) \tag{16}$$

Step 6 : From equation (16), the probability that the total degradation *z* exceeds each of the values z_j obtained in Step 1 can be computed. Each of these probabilities is a function of the parameters α1, …, α*K* and can be written:

$$P\left(z \geq z_j\right) = r_j\left(\alpha_1, \ldots, \alpha_K\right) \qquad \text{for } j = 1, \ldots, J \tag{17}$$

Finally, the parameters $\alpha_1, \ldots, \alpha_K$ can be obtained from the conditions:

$$r_j\left(\alpha_1, \ldots, \alpha_K\right) \leq p_j / 100 \qquad \text{for } j = 1, \ldots, J \tag{18}$$

where the values of p_i are those in a) of the input data which are associated with the degradations z_i computed in Step 1.

Step 7 : From the parameters $\alpha_1, \ldots, \alpha_K$ computed in Step 5, the probability density function of *v*, the interference power normalized by the total noise N_T produced by one interfering network, expressed in equation (4) as $f(V,\alpha_1, \ldots, \alpha_K)$, is defined. This probability density function allows that a mask for the interference, *I*, produced by one interfering network, and expressed as a fraction of the total link noise N_T, be defined. For instance, if:

$$P\left(v \geq V_m\right) \leq q_m \tag{19}$$

it follows that:

$$P\left[I \geq V_m \; N_T\right] \leq q_m \tag{20}$$

From $f(V,\alpha_1, \ldots, \alpha_K)$, a certain number *M* of pairs ($V_M N_T$; q_m) can be computed, defining therefore a mask for the interference allowances from one interfering network.

4 Example 1 of Methodology A

As an example of the application of Methodology A, the derivation of interference allowances for carriers Ka-3 and Ka-4 (see Table 9 of Recommendation ITU-R S.1328, is presented here.

4.1 Input Data

The input data required for these two carriers, is:

a) BER of 1×10^{-10} cannot be exceeded for more than 1% of the time

BER of 1×10^{-8} cannot be exceeded for more than 0.5% of the time

b) *Carrier Ka-3*

C/N = 6.8 dB for BER = 1×10^{-10}; C/N = 5.8 dB for BER = 1×10^{-8}

$(C/N)_{CS}$ = 8.3 dB

Carrier Ka-4

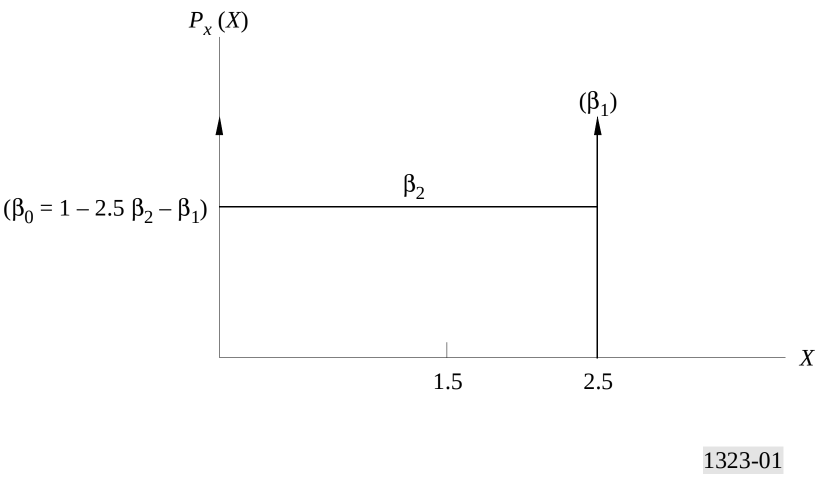
C/N = 5.8 dB for BER = 1×10^{-10}; C/N = 4.8 dB for BER = 1×10^{-8}

$(C/N)_{CS}$ = 7.3 dB

c) It is proposed that the parameterization in Fig. 1 be used to characterize the degradation due to fading.

FIGURE 1

Parameterization for the degradation due to fading

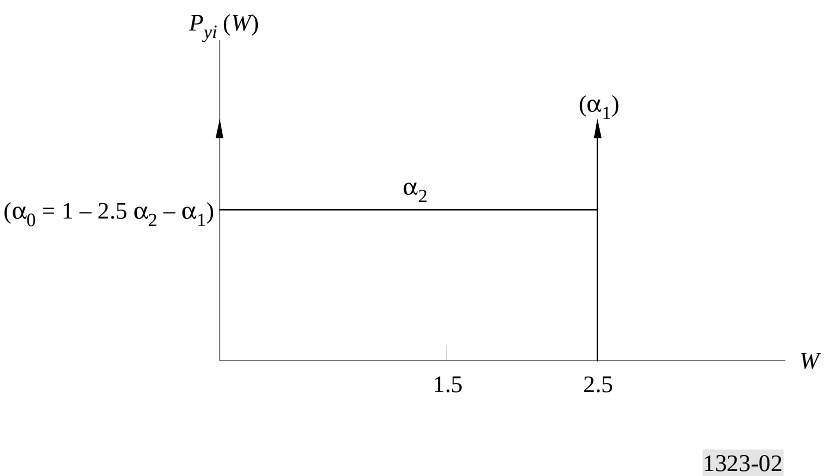


As an example calculation, let $\beta_1 = 0.0045$, $\beta_2 = 0.0022$ and $\beta_0 = 0.99$. This would be representative of an uplink with about 7 dB power control range, e.g. operating in rain climatic zone E (virtually with any elevation angle) or in zone K (with at least 30° elevation angle). It would also be representative of a downlink, e.g. operating under the same elevation angles and rain climatic zones as described above, under the additional assumption that a 7 dB downlink fading yields a 2.5 dB *C*/*N* degradation (no power control). Note that for the considered values of β_1, β_2 and β_0, condition (6a) is met with equality for $i = 1$ while it is met with margin for $i = 2$.

d) Let y_i denote the degradation due to the interference coming from the *i*th network (dB). This example assumes that the probability density function of y_i is parameterized as:

FIGURE 2

Parameterization for the degradation due to the *i*th interference entry



4.2 Calculation procedure

Methodology A leads to:

Step 1 : Degradation 2.5 dB can be exceeded at most during 0.5%.

Degradation 1.5 dB can be exceeded at most during 1%.

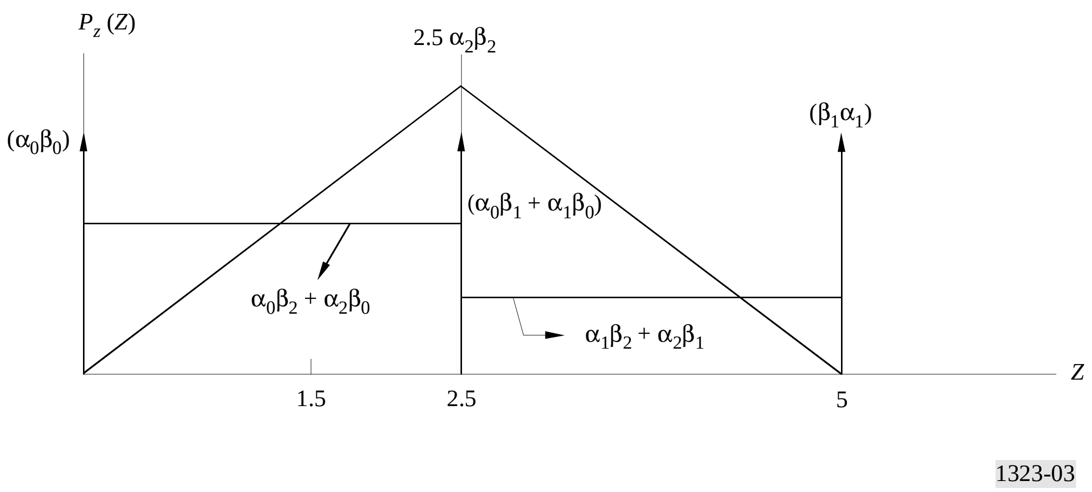
Case 1 **:** One interfering network ($N = 1$)

Steps 2, 3 and 4 : For $N = 1$, $y = y_i$ and the probability density $p_y(W)$ can be parameterized directly and it is not necessary to go through the intermediate probability density functions $p_{vi}(V)$ ($i = 1, \ldots, N$). In this case, the proposed parameterization for the total degradation due to interference is also given in Fig. 2.

Step 5 : The resulting $p_z(Z)$ is shown in Fig. 3.

FIGURE 3

Probability density function of the total degradation



Step 6 : The inequalities to be met according to equation (18) are:

$$P(z \geq 2.5) \leq 0.005 \tag{21}$$

$$P(z \geq 1.5) \leq 0.01 \tag{22}$$

When equation (21) is met with equality, equations (21) and (22) lead to:

$$P(1.5 \leq z \leq 2.5) \leq 0.005 \tag{23}$$

The computation technique in Appendix 1 to Annex 1 was used to determine values of α_1 and α_2 satisfying (21) and (23), resulting in $\alpha_1 = 0.0004827$ and $\alpha_2 = 0.0028325$.

Step 7: For the values of α_1 and α_2 obtained in Step 6 and the probability density function in Fig. 2, the interference allowance mask becomes:

$$P(I \geq 0) \leq 0.76\% \tag{24}$$

$$P(I \geq 0.41\ N_T) \leq 0.33\% \tag{25}$$

$$P(I \geq 0.78\ N_T) \leq 0.0483\% \tag{26}$$

or, given that a 6% long-term interference allowance is already included in the link noise, the total interference I' (including the long-term component) would have to meet:

$$P(I' \geq 0.06\, N_T) \leq 0.76\% \quad (27)$$

$$P(I' \geq 0.47\, N_T) \leq 0.33\% \quad (28)$$

$$P(I' \geq 0.84\, N_T) \leq 0.0483\% \quad (29)$$

Case 2 **:** Two interfering networks ($N = 2$)

Steps 2, 3, 4 and 5: These steps were used to determine $P(z \geq z_j,\ j = 1, \ldots, J$ in equation (17) for given values of α_1 and α_2.

Step 6: The inequalities to be met according to equation (18) are the same as in *Case 1* and are given by equations (21) and (23). The computation technique in Appendix 1 to Annex was again used to determine values of α_1 and α_2 satisfying these inequalities, resulting in $\alpha_1 = 0.0002388$ and $\alpha_2 = 0.00142239$.

Step 7: For the values of α_1 and α_2 obtained in Step 6 and the probability density function in Fig. 2, the interference allowance mask becomes:

$$P(I \geq 0) \leq 0.38\% \quad (30)$$

$$P(I \geq 0.41\, N_T) \leq 0.17\% \quad (31)$$

$$P(I \geq 0.78\, N_T) \leq 0.0238\% \quad (32)$$

or, given that a 6% long-term interference allowance is already included in the link noise, the total interference I' (including the long-term component) would have to meet:

$$P(I' \geq 0.06\, N_T) \leq 0.38\% \quad (33)$$

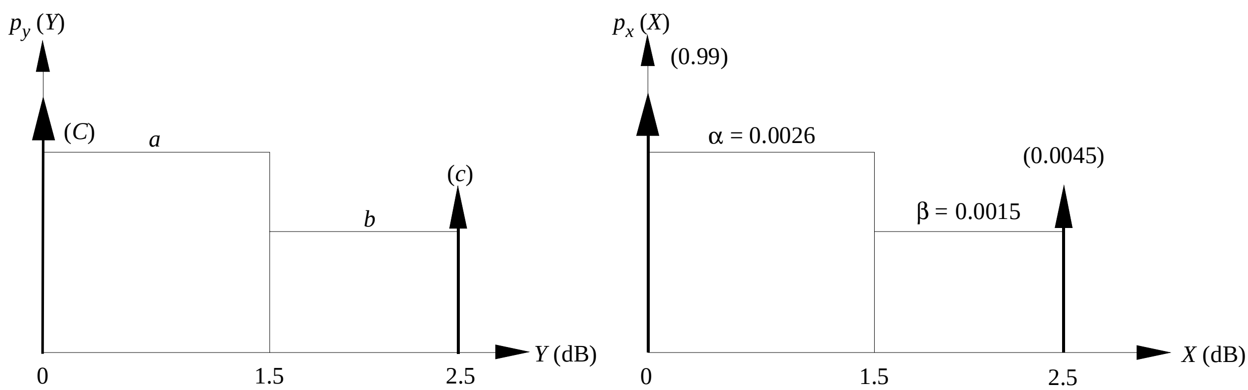
$$P(I' \geq 0.47\, N_T) \leq 0.17\% \quad (34)$$

$$P(I' \geq 0.84\, N_T) \leq 0.0238\% \quad (35)$$

5 Example 2 of Methodology A

In this example, performance requirements are the same as in example 1 of Methodology A but calculations were made with probability density functions less simple than in example 1 of Methodology A, in order to assess the impact on the interference criteria values. The probability density functions are shown in Fig. 4.

FIGURE 4



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Several possible results were obtained, with the constraints:

$$P(z \geq 2.5 \text{ dB}) \leq 0.5\%$$

$$P(z \geq 2.5 \text{ dB}) - P(x \geq 2.5 \text{ dB}) \leq 0.05\%$$

$$P(z \geq 1.5 \text{ dB}) \leq 1.0\%$$

c =	0.00050	0.000484	0.0004	0.0002	0
b =	0.00038	0.0032	0.0036	0.0038	0.001
a =	0.00038	0.0032	0.0040	0.0040	0.006
C =	0.99850	0.9910	0.99	0.9900	0.990
$P\,(z \geq 2.5$ dB)	0.5%	0.50%	0.49%	0.47%	0.45%
$P\,(z \geq 1.5$ dB)	0.69%	0.97%	1.00%	1.00%	1.00%
$P\,(y \geq 2.5$ dB)	0.05%	0.0483%	0.04%	0.02%	0.00%
$P\,(y \geq 1.5$ dB)	0.088%	0.37%	0.40%	0.40%	0.40%

And the total interference allowances could be:

$P\,(I \leq 0.06\ N_T) \geq$	99.85%		99.10%		99.00%
$P\,(I \geq 0.47\ N_T) \leq$	0.088%	or	0.37%	or	0.4%
$P\,(I \geq 0.84\ N_T) \leq$	0.05%		0.0483%		0.04%

Hence results obtained with this more accurate modelization of the probability density functions are not that much different from the ones obtained in example 1 of Methodology A.

6 Example 3 of Methodology A

This example consists in deriving interference allowances for a *GSO/FSS uplink* sharing frequencies with other FSS networks.

6.1 Input data

a) and b) Performance requirements and associated carrier-to-noise ratio values of the desired carrier

BER	E_b/N_0 (dB)	Percentage of the year (%)
1×10^{-6}	6.5	0.04
1×10^{-8}	7.6	0.6
1×10^{-9}	8.7	4.0
Clear-sky ($E_b/N_0 + I_{0\ long\text{-}term}$)	18.5	
Long-term interference allowance		Percentage of the Year
$I/N < 6\%$		Long term

The GSO/FSS network considered in this example uses power control and site diversity. Uplink power control is active only when fade depth is greater than 12 dB. A 5 dB gain allows to keep the link available when fade depth ranges from 12 to 17 dB. Concerning site diversity, the two earth stations are assumed to be 20 km apart, and to see the GSO satellite with a 10° elevation angle.

c) Probability density function of degradation in performance due to fading: $p_x(X)$

Recommendation ITU-R P.618 gives a methodology to calculate the rain fade statistics. Assuming that the earth stations are located in climatic zone E, the rain attenuation statistics at 10° elevation angle with site diversity can be faithfully approximated with a function made of five slopes:

– from 0 dB to 6 dB: slope 0.382;

– from 6 dB to 8 dB: slope 0.189;

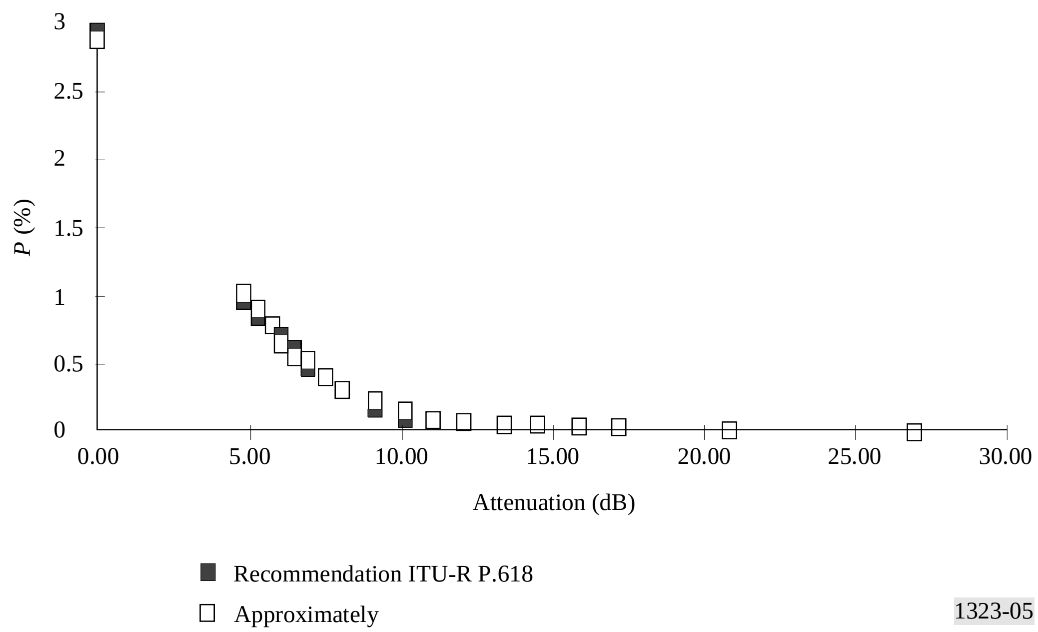
– from 8 dB to 11 dB: slope 0.076;

– from 11 dB to 17 dB: slope 0.0102;

– from 17 dB to 27 dB: slope 0.00234.

Figure 5 shows how the linear function fits the original function.

FIGURE 5



With this linear approximation, the probability density function $p_x(X)$ is as shown in Fig.6.

We stopped the function at 12 dB because this value corresponds to the system margin. We calculated besides:

$$P(x > 12 \text{ dB}) = P(\text{fading} > 17 \text{ dB}) = 0.033\%$$

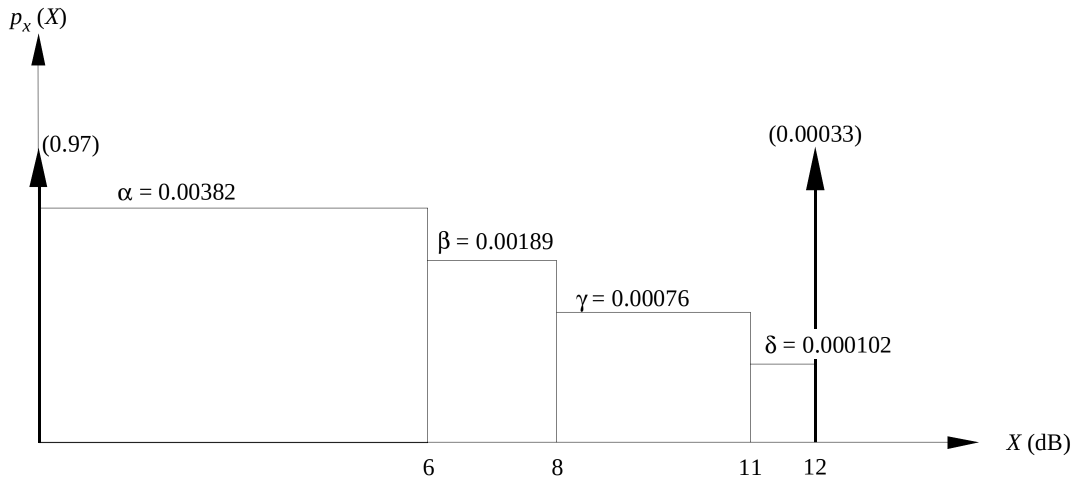
d) Number of non-GSO interfering networks: $N = 1$.

6.2 Calculation procedure

Step 1 : It consists in calculating the values z_i of the total degradation z which can be exceeded at most during p_i% of the year.

$$z_i = (C/N)_{clear\text{-}sky} - (C/N)_i = (E_b/N_0)_{clear\text{-}sky} - (E_b/N_0)_I$$

FIGURE 6



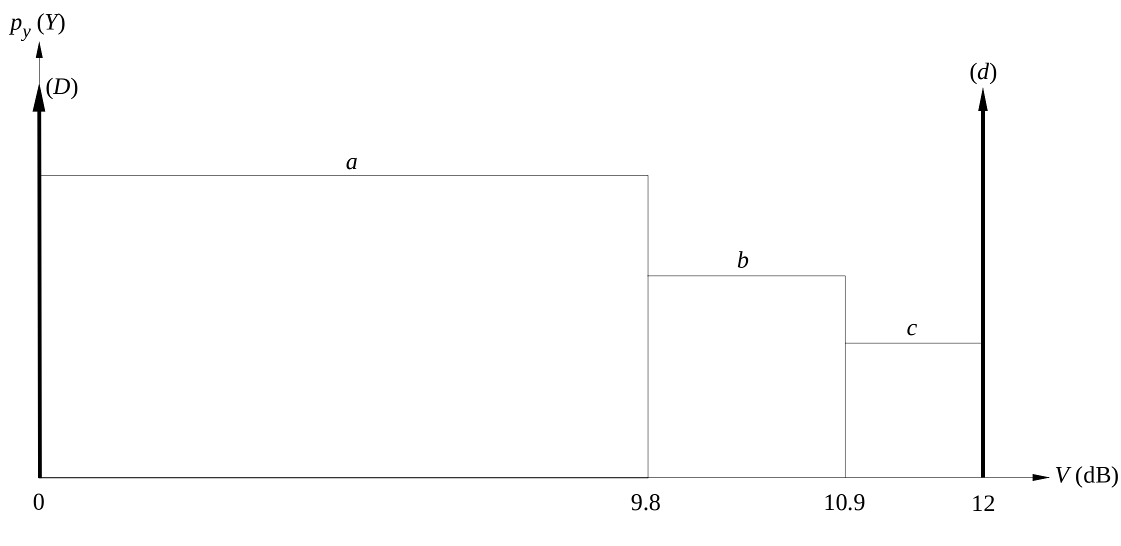
1323-06

$z_i = (C/N)_{clear\text{-}sky} - (C/N)i$ (dB)	Percentage of the year
12	0.04
10.9	0.6
9.8	4.0

Steps 2 and 3 : Probability density function of interference $p_y(Y)$

The following parametric representation is chosen for the probability density function $p_y(Y)$ corresponding to the degradation v due to the interference from any interfering network.

FIGURE 7



1323-07

The purpose of such a representation is not to account faithfully for any given real interference statistics. It is indeed impossible to know the probability function of the degradation due to interference, unless the characteristics of the interfering constellations are known. When these constellations are known, the statistics of interference can be determined by means of computer simulations or analytical methods as the one described in Recommendation ITU-R S.1257; however these statistics are still dependent on the desired earth station latitude and azimuth. Thus, as the purpose of the procedure is to calculate the percentage of the year during which each z_i value of the total degradation z can be exceeded, we chose these z_i values as steps of the parametric function.

Step 4 : Probability density function of total degradation $p_z(Z)$

$$p_z(Z) = p_x * p_y(Z)$$

Step 5 : Computation of the parameters *a*, *b*, *c*, *d* and *D*

The parameters *a*, *b*, *c*, *d* and *D* will be determined by requiring that the total degradation *z* and the degradation due to interference *y* comply with the conditions:

$$P(z \geq 12 \text{ dB}) \leq 0.04\% \qquad P(y \geq 12 \text{ dB}) \leq 0.004\% \text{ (see Note 1)}$$

$$P(z \geq 10.9 \text{ dB}) \leq 0.6\%$$

$$P(z \geq 9.8 \text{ dB}) \leq 4\%$$

and:

$$1 = D + 9.8\,a + 1.1\,b + 1.1\,c + d$$

NOTE 1 – This constraint leads to interference criteria a little less stringent than with the constraint $P(z \geq 12 \text{ dB}) - P(x \geq 12 \text{ dB}) \leq 0.004\%$ but as the purpose of this example is only to compare results obtained with two different modelizations of the rain fade statistics, this issue is not important here.

An Excel spread sheet was used for calculating convolutions of rectangle functions and probabilities that *z* exceeds 12, 10.9 and 9.8 dB.

Then the use of a solver (with the conditions «$P(z \geq 12 \text{ dB}) = 0.04\%$», «$a \geq b \geq c$» and «maximize $P(y \geq 10.9 \text{ dB})$») led to several sets of solutions:

d =	0.00004	0.00003	0.00002	0.00001	0
c =	0.00025	0.00034	0.00042	0.00051	0.00059
b =	0.00025	0.00034	0.00042	0.00051	0.00059
a =	0.00025	0.00034	0.00042	0.00051	0.00059
D =	0.9969	0.9959	0.9949	0.9939	0.9929
$P(z \geq 12$ dB)	0.04%	0.04%	0.04%	0.04%	0.04%
$P(z \geq 10.9$ dB)	0.09%	0.10%	0.11%	0.12%	0.125%
$P(z \geq 9.8$ dB)	0.20%	0.21%	0.23%	0.26%	0.27%
$P(y \geq 12$ dB)	0.004%	0.003%	0.002%	0.001%	0.000%
$P(y \geq 10.9$ dB)	0.03%	0.04%	0.05%	0.06%	0.065%
$P(y \geq 9.8$ dB)	0.06%	0.08%	0.10%	0.11%	0.13%

Case $d = 0$ would particularly be relevant when the degradation due to interference from a given non-GSO network never exceeds 12 dB.

We also notice that the most stringent criterion is $P(z \geq 12 \text{ dB}) \leq 0.04\%$, since the two other criteria $P(z \geq 10.9 \text{ dB}) \leq 0.6\%$ and $P(z \geq 9.8 \text{ dB}) \leq 4\%$ are met with a large margin.

Finally as for every set of solutions $a = b = c$, the probability density function of degradation due to interference could have been approximated a simpler way (with a single step instead of three).

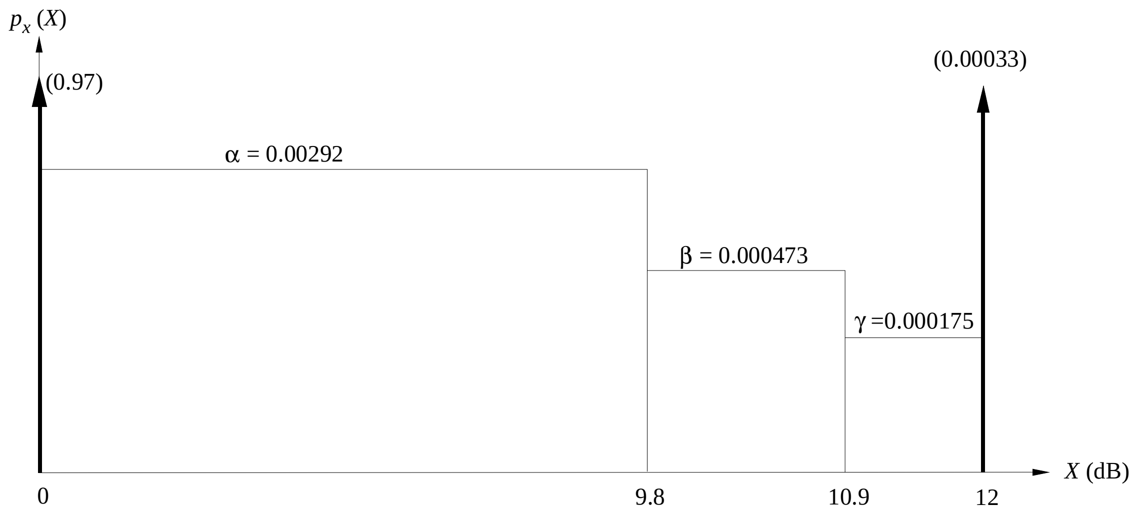
Hence the total interference allowances could be:

$P(I \leq 0.06\ N_T) \geq$	99.69%	or	99.29%
$P(I \geq 8.61\ N_T) \leq$	0.06%		0.13%
$P(I \geq 11.36\ N_T) \leq$	0.03%		0.065%
$P(I \geq 14.91\ N_T) \leq$	0.004%		0.000%

6.3 Results obtained with another model of the fading function

To assess the impact of the accuracy with which the probability density function of fading is represented, we made the same calculations with the function $p_x(X)$ shown in Fig. 8:

FIGURE 8



1323-08

The solutions are then:

d =	0.00004	0.00003	0.00002	0.00001	0
c =	0.00020	0.00027	0.00034	0.00041	0.00047
b =	0.00020	0.00027	0.00034	0.00041	0.00047
a =	0.00020	0.00027	0.00034	0.00041	0.00047
D =	0.9975	0.9967	0.9959	0.9951	0.9943
$P(z \geq 12$ dB)	0.04%	0.04%	0.04%	0.04%	0.04%
$P(z \geq 10.9$ dB)	0.08%	0.09%	0.10%	0.10%	0.11%
$P(z \geq 9.8$ dB)	0.16%	0.17%	0.18%	0.20%	0.21%
$P(y \geq 12$ dB)	0.004%	0.003%	0.002%	0.001%	0.000%
$P(y \geq 10.9$ dB)	0.03%	0.03%	0.04%	0.05%	0.05%
$P(y \geq 9.8$ dB)	0.05%	0.06%	0.07%	0.09%	0.10%

The interference criteria are a little more stringent in this case. It is no surprise since probabilities of fading have been slightly over-estimated. Hence the accuracy with which the probability density function of degradation due to fading is represented impacts directly on the interference criteria.

7 Example 4 of Methodology A

In this example, Methodology A was used for the derivation of interference allowances for carriers Ka-1 and Ka-2. The characteristics of these carriers (see Table 9, Annex 3 of Recommendation ITU-R S.1328 are quite different from those of Ka-3 and Ka-4, since they correspond to point-to-point high data rate transmissions intended to meet performance objectives of ITU-T Recommendation G.826. As opposed to Ka-3, Ka-4, which refer to uplink and downlink for transmission through a regenerative transponder, Ka-1 and Ka-2 correspond to transmission through a transparent transponder.

The steps defined in Methodology A are followed below for each of these carriers.

7.1 Carrier Ka-1

7.1.1 Input data

The input data required for deriving the interference allowances is:

a) BER of 1×10^{-9} cannot be exceeded for more than 4% of the time.

BER of 1×10^{-8} cannot be exceeded for more than 0.6% of the time.

BER of 1×10^{-6} cannot be exceeded for more than 0.04% of the time.

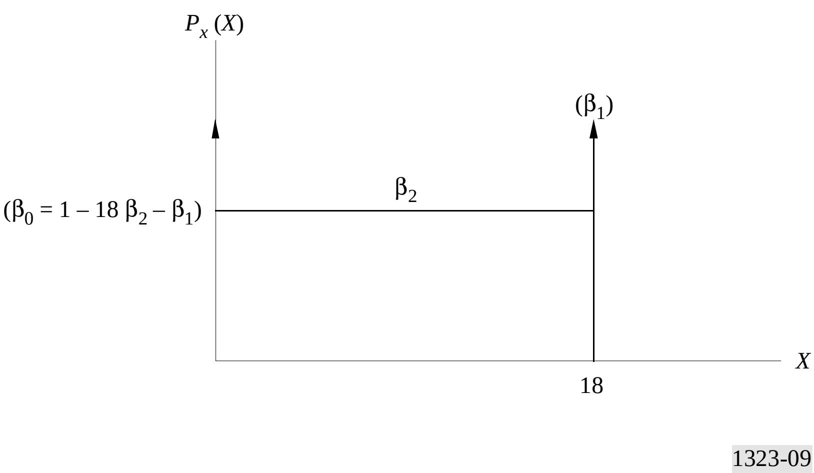
b) C/N = 8.9 dB for BER = 1×10^{-9}; C/N = 7.9 dB for BER = 1×10^{-8}

C/N = 6.9 dB for BER = 1×10^{-6}; $(C/N)_{CS}$ = 24.9 dB.

c) It is proposed that the parameterization in Fig. 9 be used to characterize the degradation due to fading.

FIGURE 9

Parameterization for the degradation due to fading for carrier Ka-1

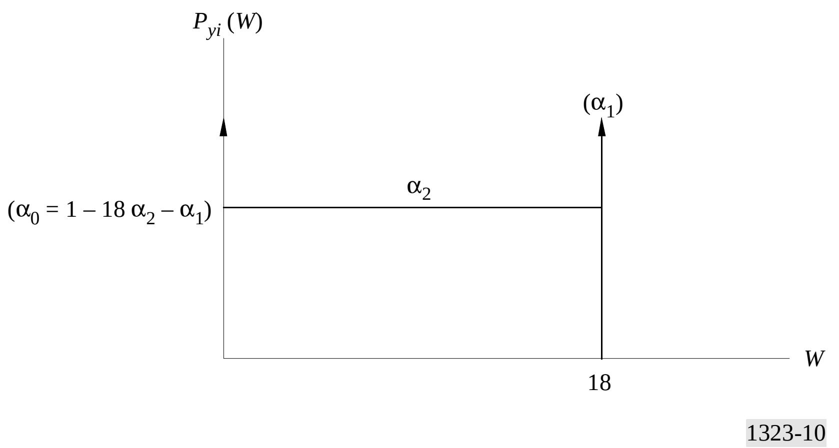


As an example calculation, let $\beta_1 = 0.00036$, $\beta_2 = 0.0002$ and $\beta_0 = 0.996$. This would be representative of an uplink with about 10 dB power control range, e.g. operating in rain climatic zone K (with at least 30° elevation angle). It can be verified that, for a downlink under the same conditions with respect to rain climatic zone and elevation angle, the available downlink margin (about 25 dB) would be sufficient to cope with downlink fading, except for percentages of time that can be neglected with respect to 0.036%. Note that for the considered values of β_1, β_2 and β_0, condition (6a) is met with equality for $i = 1$ while it is met with margin for $i = 2$ and $i = 3$.

d) Let y_i denote the degradation due to the interference coming from the *i*th network (dB). This example assumes that the probability density function of y_i is parameterized as shown in Fig. 10.

FIGURE 10

Parameterization for the degradation due to the *i*th interference entry for carrier Ka-1



7.1.2 Calculation procedure

Methodology A leads to:

Step 1 : Degradation of 18 dB can be exceeded at most during 0.04%.

Degradation of 17 dB can be exceeded at most during 0.6%.

Degradation of 16 dB can be exceeded at most during 4%.

One interfering network (*N* = 1)

Steps 2, 3 and 4 : For $N = 1$, $y = y_i$ and the probability density $p_y(W)$ can be parameterized directly, without going through the intermediate probability density functions $p_{vi}\ (V)$ ($i = 1, \ldots, N$). In this case, the proposed parameterization for the total degradation due to interference is also given in Fig. 10.

Step 5 : The resulting $p_z(Z)$ is shown in Fig. 11.

Step 6 : The inequalities to be met according to equation (18) are:

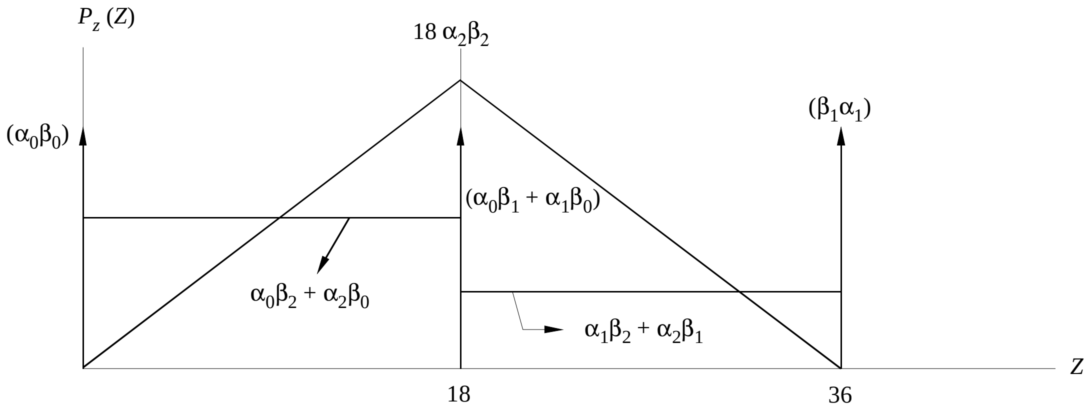
$$P(z \geq 18) \leq 0.0004 \tag{36}$$

$$P(z \geq 17) \leq 0.006 \tag{37}$$

$$P(z \geq 16) \leq 0.04 \tag{38}$$

FIGURE 11

Probability density function of the total degradation for carrier Ka-1



When (36) is met with equality, (37) and (38) can be rewritten as:

$$P(17 \leq z \leq 18) \leq 0.0056 \tag{39}$$

$$P(16 \leq z \leq 17) \leq 0.0396 \tag{40}$$

One possible solution for (36), (39) and (40) is:

$$\alpha_0 = 0.9944; \quad \alpha_1 = 0.00003; \quad \alpha_2 = 0.00031$$

Step 7: For the values of α_0, α_1, and α_2 obtained in Step 6 and the probability density function in Fig. 10, the interference allowance mask becomes:

$$P(I \geq 0) \leq 0.56\% \tag{41}$$

$$P(I \geq 38.8\ N_T) \leq 0.065\% \tag{42}$$

$$P(I \geq 49.1\ N_T) \leq 0.034\% \tag{43}$$

$$P(I \geq 62.1\ N_T) \leq 0.003\% \tag{44}$$

or, given that a 6% long-term interference allowance is already included in the link noise, the total interference I' (including the long-term component) would have to meet:

$$P(I' \geq 0.06\ N_T) \leq 0.56\% \tag{45}$$

$$P(I' \geq 38.86\ N_T) \leq 0.065\% \tag{46}$$

$$P(I' \geq 49.16\ N_T) \leq 0.034\% \tag{47}$$

$$P(I' \geq 62.16\ N_T) \leq 0.003\% \tag{48}$$

7.2 Carrier Ka-2

7.2.1 Input data

The input data required for deriving the interference allowances is:

a) BER of 1×10^{-9} cannot be exceeded for more than 4% of the time.

BER of 1×10^{-8} cannot be exceeded for more than 0.6% of the time.

BER of 1×10^{-6} cannot be exceeded for more than 0.04% of the time.

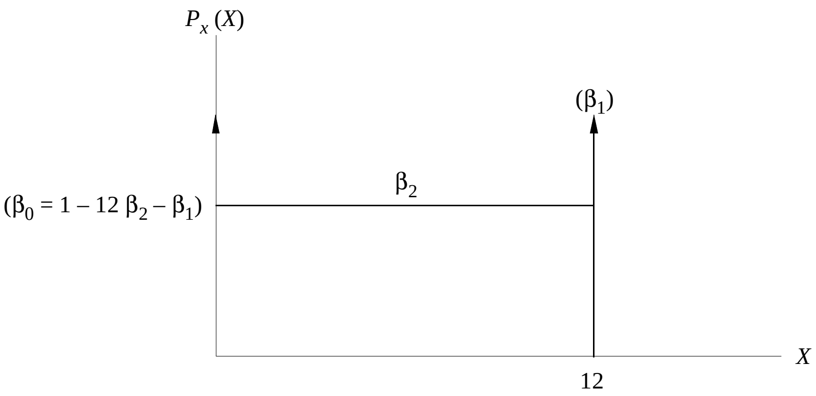
b) C/N = 8.9 dB for BER = 1×10^{-9}; C/N = 7.9 dB for BER = 1×10^{-8}

C/N = 6.9 dB for BER = 1×10^{-8}; $(C/N)_{CS}$ = 18.9 dB.

c) It is proposed that the parameterization in Fig. 12 be used to characterize the degradation due to fading.

FIGURE 12

Parameterization for the degradation due to fading for carrier Ka-2



1323-12

As an example calculation, let $\beta_1 = 0.00036$, $\beta_2 = 0.0002$ and $\beta_0 = 0.997$. This would be representative of an uplink with about 10 dB power control range, e.g. operating in rain climatic zone E (with at least 15° elevation angle). It can be verified that, for a downlink under the same conditions with respect to rain climatic zone and elevation angle, the available downlink margin (about 20 dB) would be sufficient to cope with downlink fading, except for percentages of time that can be neglected with respect to 0.036%. Note that for the considered values of β_1, β_2 and β_0, condition (6a) is met with equality for $i = 1$ while it is met with margin for $i = 2$ and $i = 3$.

d) Let y_i denote the degradation due to the interference coming from the ith network, expressed in dB. This example assumes that the probability density function of y_i is parameterized as shown in Fig. 13.

7.2.2 Calculation procedure

Methodology A leads to:

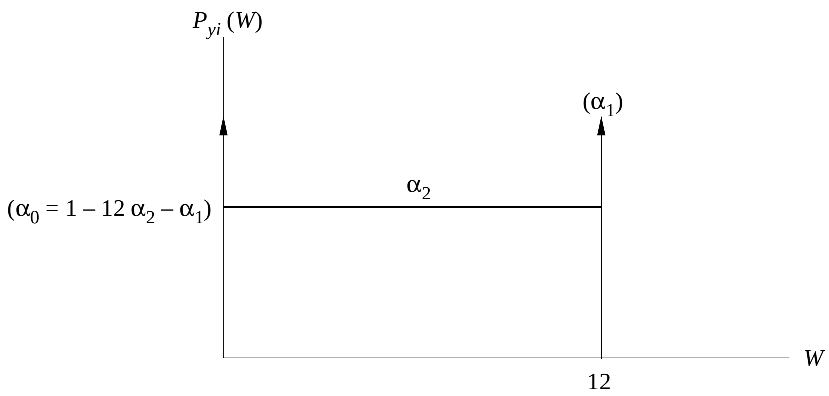
Step 1 : Degradation of 12 dB can be exceeded at most during 0.04%.

Degradation of 11 dB can be exceeded at most during 0.6%.

Degradation of 10 dB can be exceeded at most during 4%.

FIGURE 13

Parameterization for the degradation due to the *i*th interference entry for carrier Ka-2



1323-13

One interfering network ($N = 1$)

Steps 2, 3 and 4: For $N = 1$, $y = y_i$ and the probability density $p_y(W)$ can be parameterized directly, without going through the intermediate probability density functions $p_{vi}(V)$ ($i = 1, \ldots, N$). In this case, the proposed parameterization for the total degradation due to interference is also given in Fig. 13.

Step 5: The resulting $p_z(Z)$ is shown in Fig. 14.

Step 6: The inequalities to be met according to equation (18) are:

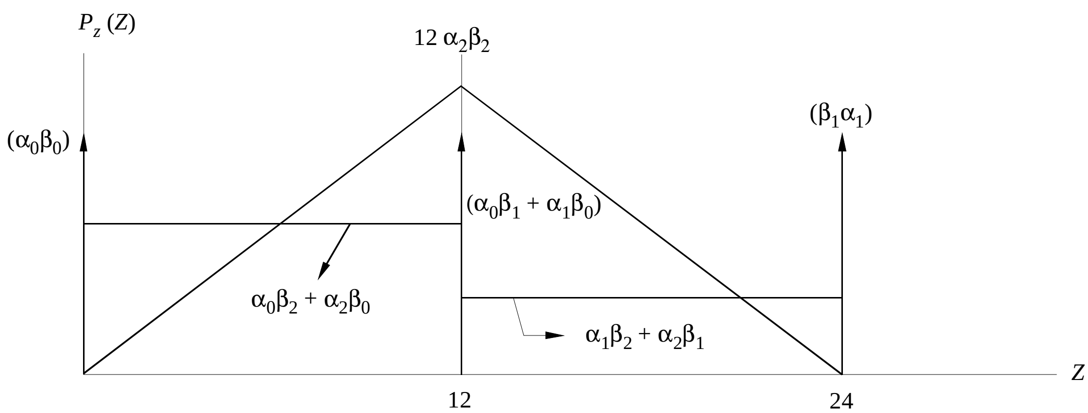
$$P(z \geq 12) \leq 0.0004 \tag{49}$$

$$P(z \geq 11) \leq 0.006 \tag{50}$$

$$P(z \geq 10) \leq 0.04 \tag{51}$$

FIGURE 14

Probability density function of the total degradation for carrier Ka-2



1323-14

When (49) is met with equality, (50) and (51) can be rewritten as:

$$P(11 \le z \le 12) \le 0.0056 \quad (52)$$

$$P(10 \le z \le 11) \le 0.0396 \quad (53)$$

One possible solution for (49), (52) and (53) is:

$$\alpha_0 = 0.9916; \quad \alpha_1 = 0.00003; \quad \alpha_2 = 0.0007$$

Step 7: For the values of α_0, α_1, and α_2 obtained in Step 6 and the probability density function in Fig. 13, the interference allowance mask becomes:

$$P(I \ge 0) \le 0.84\% \quad (54)$$

$$P(I \ge 9\, N_T) \le 0.143\% \quad (55)$$

$$P(I \ge 11.6\, N_T) \le 0.073\% \quad (56)$$

$$P(I \ge 14.8\, N_T) \le 0.003\% \quad (57)$$

or, given that a 6% long-term interference allowance is already included in the link noise, the total interference I' (including the long-term component) would have to meet:

$$P(I' \ge 0.06\, N_T) \le 0.84\% \quad (58)$$

$$P(I' \ge 9.06\, N_T) \le 0.143\% \quad (59)$$

$$P(I' \ge 11.66\, N_T) \le 0.073\% \quad (60)$$

$$P(I' \ge 14.86\, N_T) \le 0.003\% \quad (61)$$

PART 2

Methodology B

In Methodology B, interference effects are considered separately from fading, and performance objectives are summarized by a single threshold BER (or *C*/*N*) which cannot be exceeded for a given percentage of time. Since only one threshold BER (or *C*/*N*) is involved, Methodology B deems it appropriate to apportion (1/*n*) of the interference time allowance to each of the *n* considered sources of interference and to deal separately with them. Methodology B is deemed to be appropriate for considering interference to non-GSO/MSS feeder links (or non-GSO FSS) operating either with on-board processing or with transparent transponders in the 20/30 GHz band. Methodology B fits within the framework of Methodology A but, in view of the considerations above, brings substantial simplification to it.

In order to fully establish the relationship between Methodologies A and B, the latter is described here in the same framework used above to describe Methodology A; i.e. basic assumptions, input data, proposed procedure.

1 Basic assumptions

Assumption 1: When the system design relies heavily on power control, it is considered that the joint occurrence of interference and fading not fully compensated by power control, is not statistically significant. Therefore, the interference allowances can be determined by assuming that aggregate interference by itself (no simultaneous fading degradation) can use 10% of the time allowances referred to in *recommends* 3.1.

Assumption 2 : If there are n systems sharing the same spectrum with the desired system that can potentially cause interference to it, the time allowance to each system is $1/n$ of the aggregate interference time allowance or $1/n$ of 10% of the total time allowance in the performance objectives. Further, the effect of each interfering source is addressed separately.

The validity of this approach is illustrated in Fig. 15. Consider the interference into LEO A from a GSO network like GSO 13. This GSO employs adaptive power control on the up link and operates from relatively small earth stations (66 cm). Both networks have an earth station co-located at 33° N latitude. The simulation calculates the cumulative probability of interference with the relative longitude of the GSO satellite as a parameter. As can be seen from Fig. 15, the peak interference levels into LEO A are not strongly dependent on the relative longitude of the GSO satellite for about ±50° of the arc at this latitude. The maximum n for this non-GSO station would then be $100°/x$, where x is the minimum spacing in the arc for GSOs at 20/30 GHz in the bands designated for both non-GSO and GSO FSS operation.

It should be noted that the actual n would most likely not be equal to the maximum. GSO to GSO coordinations between neighbouring administrations is likely to reduce the number of visible slot positions that could have co-located earth GSO earth stations.

Assumption 3 : As a consequence of assumption 2, degradation due to single entry interference can be addressed directly. If I denotes the single entry interference power and N_T is the total link noise, the degradation y_{SE} due to a single entry interference is:

$$y_{SE} = 10 \log Y \qquad (62)$$

where:

$$Y = 1 + I/N_T \qquad (63)$$

2 Input data

a) Threshold BER_t or $(C/N)_t$ and percentage of the year p for which BER can be worse than BER_t.

b) The clear sky carrier-to-noise ratio $(C/N)_{CS}$.

c) The number n of interfering networks that can potentially cause short term interference and that will be sharing the same frequency band with the desired network. For a non-GSO desired network, n equals the number of other non-GSO networks plus the number of potentially interfering geostationary orbital positions visible, above the minimum operational elevation angle, as observed by the earth station of the non-GSO network. The maximum number of interfering GSO positions visible to the non-GSO earth station is a function of the latitude and the minimum GSO orbital spacing which can be achieved for the particular FSS band.

3 Proposed procedure

Step 1 : From a) and b) of the input data, compute:

$$z_t = (C/N)_{CS} - (C/N)_t \qquad \text{dB} \qquad (64)$$

Step 2 : From assumptions 1 and 2:

$$P(y_{SE} \leq z_t) \geq (1/n)\,(p/10) \qquad \% \qquad (65)$$

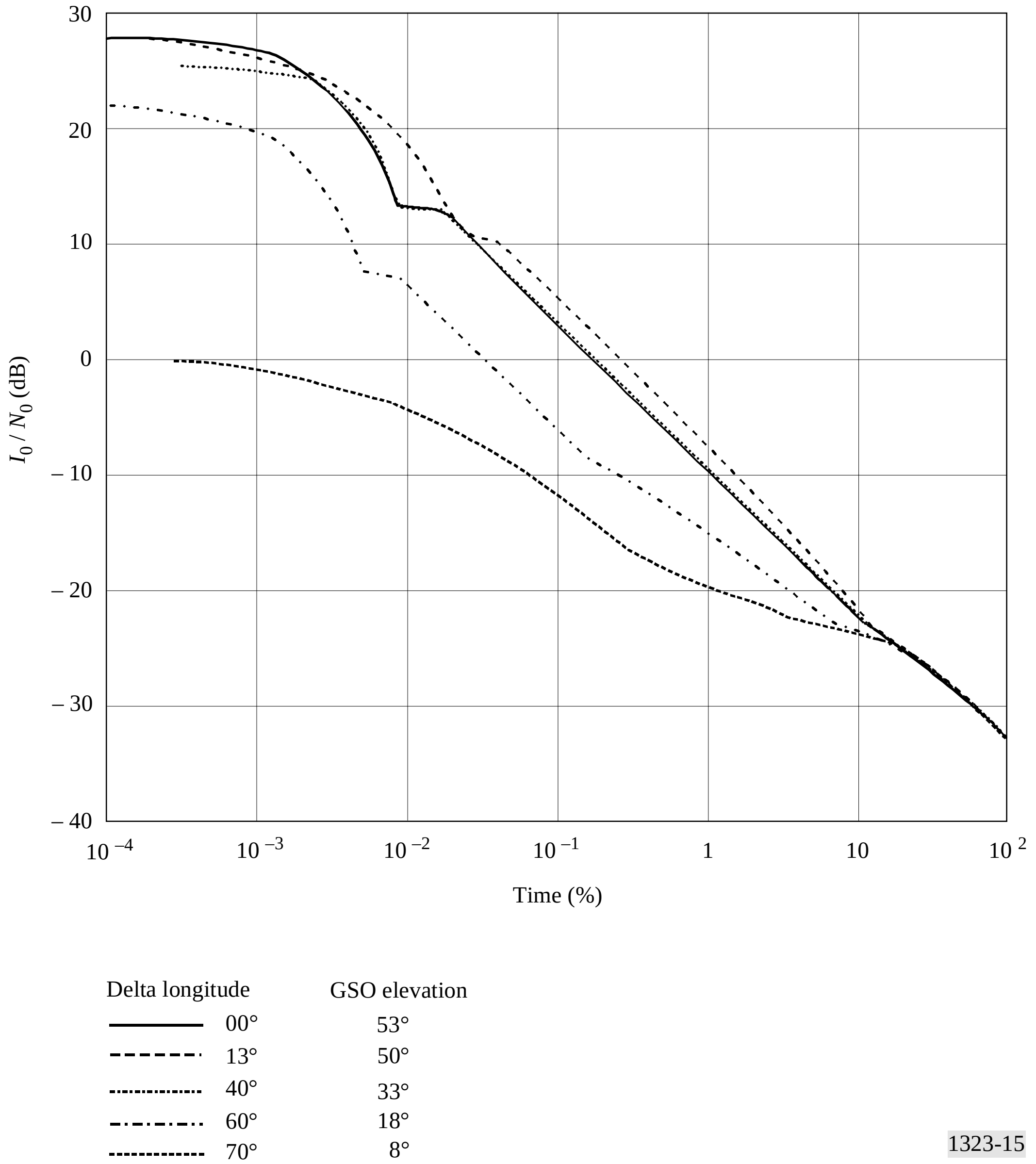
or from (62) and (63):

$$P\left[I \leq \left(10\, z_t/10 - 1\right)N_T\right] \geq (0.1/n)\,(p) \qquad (66)$$

which is the single entry permissible level of interference.

FIGURE 15

Uplink interference from GSO 13 to LEO A



1323-15

4 Example 1 of Methodology B: (LEO A)

LEO A characteristics are given in the Chairman's Report of Radiocommunication Working Party 4A of page 204 as amended in January 1997 meeting of Working Party 4A and liaison from Working Party 4B on the performance objectives of a 20/30 GHz non-GSO/MSS feeder link like LEO A. The characteristics of LEO A are summarized in Table Input data for the purpose of computing interference allowances are:

a) $BER_t = 10^{-5}$ with a $C/N = 6.4$ dB for both the up and down links.

The aggregate outage time objective for these two links is $p = 0.1\%$.

b) $(C/N)_{CS} - (C/N)_t = 10.7 - 6.4 = 3.1$ dB

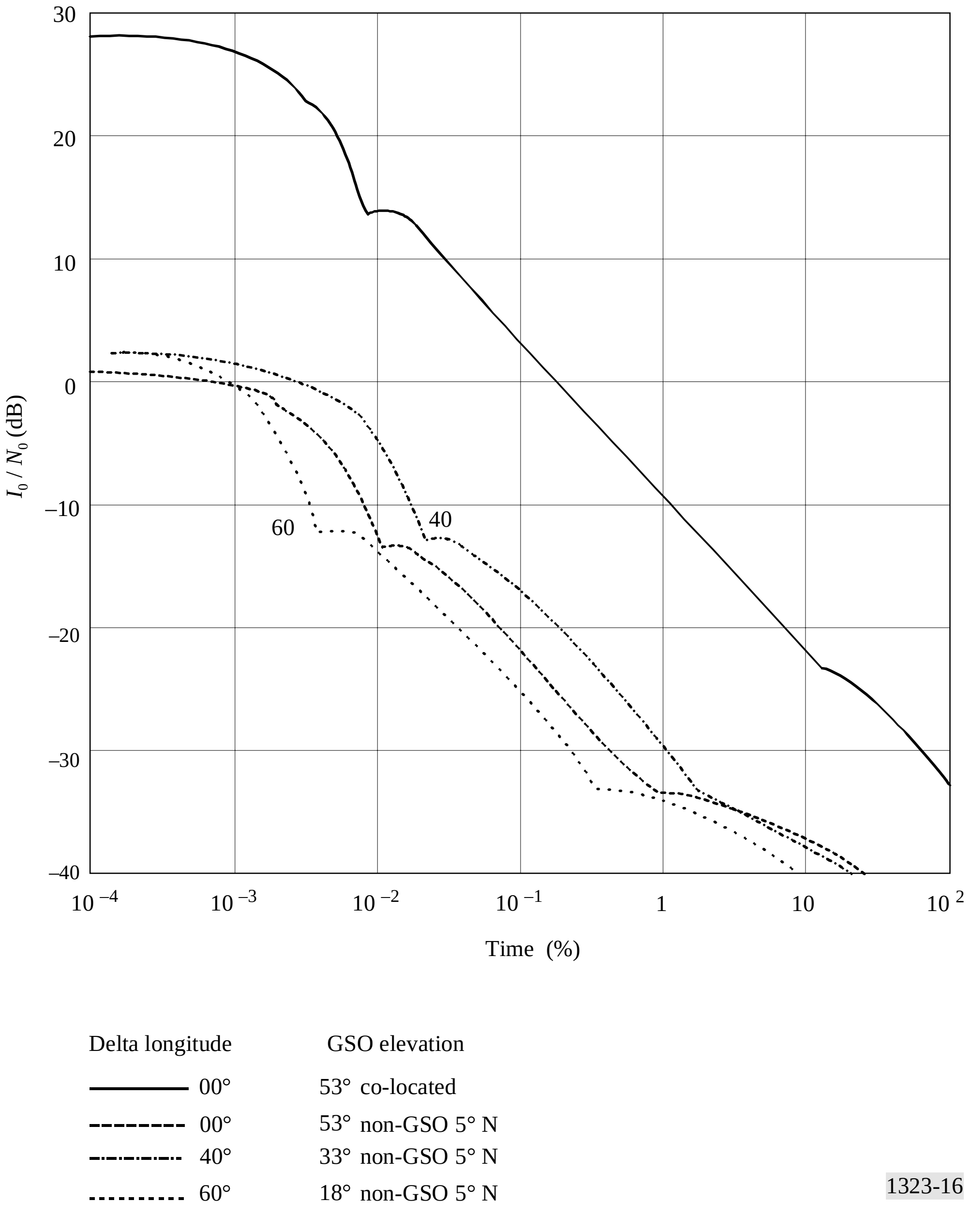
c) As a result, the single entry interference allowance becomes:

$$P\left[I/N_T \leq 0.2\,\text{dB} \right] \geq (1/n)\, 0.01\%$$

d) *n* is to be determined. Figure 16 is a sample calculation of the uplink interference from a GSO 13 terminal located 5° S of the non-GSO earth station. The interference from a single network is approximately equal to the aggregate interference for 0.01% of the time.

FIGURE 16

Cumulative probability statistics of uplink interference into LEO A from GSO 13



1323-16

TABLE 1

LEO A 20/30 GHz characteristics

Parameter	Value
System name	LEO A (Conference Preparatory Meeting (CPM) Report, 1995)
Operating band (GHz)	20/30
Number of satellites	66
Orbital height (km)	780
Types of service	Feeder links for MSS service links plus network operations and satellite control data
Inter-satellite links	Yes
Earth station antennas	3 m monopulse tracking
Number of earth stations	10-20 gateways around the world each connecting to the local PSTN
Modulation/access	QPSK TDM/FDMA
Gateway data rates	3.125 Mbit/s with growth to 6.250 Mbit/s
Channel coding	R1/2 Viterbi
Minimum operational elevation (degrees)	10
Power control	Adaptive for range and weather
Weather link margins	*Power control* : 25 dB up link, 10 dB down
Performance objectives	Long term BER $< 1 \times 10^{-7}$, availability 99.9% year. Unavailable when BER $> 1 \times 10^{-5}$ or $C/N < 6.4$ dB

5 Example 2 of Methodology B: (LEO B)

LEO B characteristics are given in the Chairman's Report of Radiocommunication Working Party 4A page 204. Input data for the purpose of computing interference allowances are:

a) $p = 0.1\%$

b) $(C/N)_{CS} - (C/N)_t = 3$

c) N is to be determined.

As a result, the single-entry interference allowance becomes

$$P\left[I \geq N_T\right] \leq (1/N)\ 0.01\%$$

TABLE 2

Performance objective/requirements for GSO FSS (non-GSO MSS feeder links)

Parameter	Value
System name	LEO B
Service description (GSO FSS, non-GSO FSS, or non-GSO MSS feeder link.)	non-GSO MSS feeder link
Frequencies (GHz) – Earth-to-space – Space-to-Earth	 29.1-29.4 19.3-19.6
Free-space path length (km) – Minimum (90° elevation angle) – Maximum (10° elevation angle)	 10 355 14 403
Earth station elevation angle to satellite (degrees) – Minimum – Maximum	 10° elevation angle 90° elevation angle
Inter-satellite links (Yes or No) (If yes, provide applicable information as above)	No
Message type (voice, data, video, paging, messaging, etc.)	Voice, data, paging, messaging
Data rate	Variable, depending on applications
Modulation	QPSK (FDMA/CDMA)
FEC (type)	Convolutional code Rate = ¾ to ½, $K = 9$
Network performance (design values) Availability (%)	 ≥ 99.9 (feeder links)
Criteria for acceptable interference	Interference threshold $I_0/N_0 > 0$ dB should not be exceeded more than 0.01% of the time

PART 3

Methodology C

The performance of the output of a satellite link, which by definition comprises uplink and downlink, in a GSO or non-GSO FSS system is degraded by interference into the uplink and/or downlink from other systems operating in the same frequencies. If a certain level of inter-system interference is accounted for in the system design, additional interferences due to other systems are tolerable provided the link degradations are still within its performance objectives. Acceptable limits of the aggregate interference for both uplink and downlink can be determined from the performance parameters for the desired FSS satellite link as indicated in § b), with the aid of some other input data for the same link as also listed below:

a) BER_0, the BER value that the desired FSS satellite link is designed to achieve under clear-sky conditions and a certain level of inter-system interference as expressed in § c);

b) BER_i and $\bar{t}_i$, $i = 1,2, \ldots, n$, $BER_i < BER_0$ where BER_i and $\bar{t}_i$ are defined such that the BER of the desired FSS satellite link can be worse than BER_i due to inter-system interference not adequately accounted for in § a) for no more than a fraction of time as given by $\bar{t}_i$, and the indices 1,2, …, n constitute the set of the (BER_i, $\bar{t}_i$) performance objectives;

c) $\alpha_0^{(u)} \equiv I_0^{(u)} / N_t^{(u)}$ and $\alpha_0^{(d)} \equiv I_0^{(d)} / N_t^{(d)}$, where $I_0^{(u)}$ and $I_0^{(d)}$ are the compensated interference levels for the uplink and downlink of the desired FSS satellite link, i.e., the BER_0 in § a) is achieved assuming the simultaneous presence of $I_0^{(u)}$ in the uplink and $I_0^{(d)}$ in the downlink, while $N_t^{(u)}$ and $N_t^{(d)}$ are the total thermal noise spectral densities, including intra-system interferences, tied exclusively to the uplink and downlink, respectively;

d) $BER_0^{(u)}$ and $BER_0^{(d)}$ for a demod-remod (on-board processing) FSS satellite link, where $BER_0^{(u)}$ and $BER_0^{(d)}$ are the BER values allocated for the uplink and downlink, respectively, out of the BER_0 defined in § a), with $BER_0^{(u)} + BER_0^{(d)} = BER_0$, or, if this is not known, $BER_0^{(u)} = BER_0^{(d)} = BER_0/2$ can be reasonably assumed;

e) $\bar{y}_{ud} \equiv [C^{(u)} / (N_t^{(u)} + I_0^{(u)})] / [C^{(d)} / (N_t^{(d)} + I_0^{(d)})]$ for a bent-pipe FSS satellite link, i.e., the ratio of the uplink CNR (carrier-to-noise ratio) to downlink CNR, where $C^{(u)}$ and $C^{(d)}$ are, respectively, the carrier powers received on the uplink and downlink under the conditions of § a) and c), or, if this is not known, $\bar{y}_{ud} = 1$ can be used.

Thus, the following aggregate interference levels caused by all other systems sharing the same spectrum are acceptable to within the performance objectives outlined above based on the derivation in Appendix 2.

Case 1 : For a demod-remod FSS satellite link:

$$\alpha_i^{(u)} \equiv I_i^{(u)} / N_t^{(u)} = \left[1 + \alpha_0^{(u)}\right] \left[\log BER_0^{(u)} \Big/ \log BER_i^{(u)}\right]^{1/c_i} - 1 \tag{67a}$$

on the uplink

$$\alpha_i^{(d)} \equiv I_i^{(d)} / N_t^{(d)} = \left[1 + \alpha_0^{(d)}\right] \left[\log BER_0^{(d)} \Big/ \log BER_i^{(d)}\right]^{1/c_i} - 1 \tag{67b}$$

on the downlink

for no more than a fraction of time, $\bar{t}_i$, subject to:

$$BER_i^{(u)} + BER_i^{(d)} = BER_i \tag{68}$$

and:

$$BER_i^{(u)} > BER_0^{(u)} \quad \text{and} \quad BER_i^{(d)} > BER_0^{(d)} \tag{69}$$

where $BER_0^{(u)}$ and $BER_0^{(d)}$, are the BER values the uplink and downlink achieve, respectively, without any inter-system interference as defined in § d). Note that a smaller $BER_i^{(u)}$ ($BER_i^{(d)}$) corresponds to a smaller interference level for the uplink (downlink) and thus allows for a larger interference level for the downlink (uplink), and *vice versa*. When $BER_i^{(u)} < BER_0^{(u)}, \alpha_i^{(u)} < \alpha_0^{(u)}$, i.e., the uplink has less interference than was initially accounted for in the link design, but the excess allocation has only marginal impact on the downlink since the demod-remod satellite carries over the bit errors, but not the noise and interference, from the uplink to the downlink. Similar comments apply to the case of $BER_i^{(d)} < BER_0^{(d)}$).

Case 2 : For a bent-pipe FSS satellite link,

$$\alpha_i^{(u)} \equiv I_i^{(u)} / N_t^{(u)} = (1 + \alpha_0^{(u)})\, \bar{x}_i^{(u)} - 1 \tag{70a}$$

on the uplink

$$\alpha_i^{(d)} \equiv I_i^{(d)} / N_t^{(d)} = (1 + \alpha_0^{(d)})\, \bar{x}_i^{(d)} - 1 \tag{70b}$$

on the downlink

for no more than a fraction of time, $\bar{t}_i$, subject to:

$$\bar{x}_i^{(u)} + \bar{y}_{ud}\, \bar{x}_i^{(d)} = (1 + \bar{y}_{ud})\, \bar{x}_i\, , \; \bar{x}_i = (\log BER_0 \,/\, \log BER_i)^{1/c_i} \tag{71}$$

$$\bar{x}_i^{(u)} \geq 1/\left(1 + \alpha_0^{(u)}\right), \; \bar{x}_i^{(d)} \geq 1/\left(1 + \alpha_0^{(d)}\right) \tag{72}$$

where:

$$\bar{x}_i^{(u)} \equiv \left(N_t^{(u)} + I_i^{(u)}\right) \Big/ \left(N_t^{(u)} + I_0^{(u)}\right) \tag{73a}$$

$$\bar{x}_i^{(d)} \equiv \left(N_t^{(d)} + I_i^{(d)}\right) \Big/ \left(N_t^{(d)} + I_0^{(d)}\right) \tag{73b}$$

Here, $\bar{x}_i^{(u)}$ $(\bar{x}_i^{(d)})$ is the ratio of the designed CNR to the changed CNR for the uplink (downlink), while $\bar{x}_i$ is this ratio but for the overall satellite link. Notice again that interference level trade-offs between uplink and downlink that are similar to the demod-remod case apply here. These tradeoffs are more profound now because the bent-pipe satellite carries over the noise and interference from the uplink to the downlink. In particular, a smaller $\bar{x}_i^{(u)}$ $(\bar{x}_i^{(d)})$ corresponds to a smaller interference level for the uplink (downlink) and thus allows for a larger interference level for the downlink (uplink), and *vice versa*. When $\bar{x}_i^{(u)} < 1$, $\alpha_i^{(u)} < \alpha_0^{(u)}$, i.e., the uplink has less interference than was initially accounted for in the link design, and the excess allocation is translated to the downlink. Again there follow analogous observations for the case in which $\bar{x}_i^{(d)} < 1$.

The number of interference sets as embodied by the index *i* in either case matches the number of performance objectives specified in § b). Moreover, the value of c_i appearing in the above equations can be derived directly from the BER versus E_b/N_0 performance curve of the desired FSS satellite link according to the following equation:

$$c_i \approx 10 \log\left(\log BER_0 \,/\, \log BER_i\right) \Big/ \left(10 \log x_0 \,/\, x_i\right) \tag{74}$$

where x_0 and x_i are the absolute values of E_b/N_0 that achieve BER_0 and BER_i, respectively, as given in § a) and b), with the index *i* defined again over the set of the performance objectives in § b). Alternatively, c_i may be taken to be 2.5. This value corresponds to the most aggressive coding schemes used in the presently available satellite modems, for which the *BER* versus E_b/N_0 curve is very steep, thus resulting in the smallest tolerable interference levels given a range of BER degradations.

To summarize, the aggregate interference limits for both uplink and downlink of a GSO or non-GSO FSS satellite link, expressed as fractions of the total thermal and intra-system interference spectral densities associated with respective links, can be determined based on the performance objectives plus some other input data. The appropriate equations for the demod-remod and bent-pipe cases are those listed under the corresponding subheadings. Further details on their derivation can be found in Appendix 2.

In conclusion, it should be pointed out that if only uplink or downlink alone is concerned, it suffices to employ one of the two equations that immediately follow the case 1 subheading, i.e., (67a) or (67b), regardless of a demod-remod or bent-pipe satellite system. Therefore, single link analysis is merely a special case of this methodology.

1 Example 1 of Methodology C

Given the following input data for a demod-remod satellite system ($c_i = 2.5$):

a) $BER_0 = 2 \times 10^{-12}$

b) $BER_1 = 2 \times 10^{-10}$, $BER_2 = 2 \times 10^{-8}$, $BER_3 = 2 \times 10^{-6}$

$\bar{t}_1 = 1\%$, $\bar{t}_2 = 0.2\%$, $\bar{t}_3 = 0.02\%$

c) $\alpha_0^{(u)} \equiv I_0^{(u)}/N_t^{(u)} = 0.2$ and $\alpha_0^{(d)} \equiv I_0^{(d)}/N_t^{(d)} = 0.2$

d) $BER_0^{(u)} = BER_0^{(d)} = BER_0 / 2 = 1 \times 10^{-12}$.

If the bit errors are evenly split between uplink and downlink, i.e.,

$$BER_1^{(u)} = BER_1^{(d)} = BER_1 / 2 = 1 \times 10^{-10}$$

$$BER_2^{(u)} = BER_2^{(d)} = BER_2 / 2 = 1 \times 10^{-8}$$

$$BER_3^{(u)} = BER_3^{(d)} = BER_3 / 2 = 1 \times 10^{-6}$$

which indeed satisfy the constraints in (68) and (69), then the interference limits for both uplink and downlink are found from (67a) and (67b) to be:

$$I_1^{(u)} / N_t^{(u)} = I_1^{(d)} / N_t^{(d)} = 1.2 \times \left(\log 10^{-12} / \log 10^{-10}\right)^{1/2.5} - 1 = 0.29$$

$$I_2^{(u)} / N_t^{(u)} = I_2^{(d)} / N_t^{(d)} = 1.2 \times \left(\log 10^{-12} / \log 10^{-8}\right)^{1/2.5} - 1 = 0.41$$

$$I_3^{(u)} / N_t^{(u)} = I_3^{(d)} / N_t^{(d)} = 1.2 \times \left(\log 10^{-12} / \log 10^{-6}\right)^{1/2.5} - 1 = 0.58$$

for no more than the respective percentages of time as specified in § b). As anticipated, the highly coded system as described by the value of c_i leads to a small range of variations for the interference limits with respect to a wide range of bit error rates.

If the performance objective is defined in terms of a single BER value, such as the BER not to be worse than 2×10^{-10} for at least 99% of the time, i.e., the BER may be worse than $BER_1 = 2 \times 10^{-10}$ for at most $\bar{t}_1 = 1\%$ of the time, then one only has to carry out the interference evaluation corresponding to this specification. In particular, from the above calculation, it will be acceptable if the normalized interference levels for both uplink and downlink are worse than 0.29 for no more than 1% of the time.

2 Example 2 of Methodology C

With the same input data as in Example 1 of Methodology C, but assuming the uplink not to tolerate any BER degradations, i.e., $BER_1^{(u)} = BER_2^{(u)} = BER_3^{(u)} \approx BER_0^{(u)} = 1 \times 10^{-12}$, and thus, according to (68), $BER_i^{(d)} \approx BER_i$, $i = 1, 2, 3$, then (67a) gives rise to:

$$I_1^{(u)} / N_t^{(u)} = I_2^{(u)} / N_t^{(u)} = I_3^{(u)} / N_t^{(u)} = \alpha_0^{(u)} = 0.2$$

and:

$$I_1^{(d)} / N_t^{(d)} = 1.2 \times \left[\log 10^{-12} / \log\left(2 \times 10^{-10}\right)\right]^{1/2.5} - 1 = 0.31$$

$$I_2^{(d)} / N_t^{(d)} = 1,2 \times \left[\log 10^{-12} / \log\left(2 \times 10^{-8}\right)\right]^{1/2.5} - 1 = 0.43$$

$$I_3^{(d)} / N_t^{(d)} = 1.2 \times \left[\log 10^{-12} / \log\left(2 \times 10^{-6}\right)\right]^{1/2.5} - 1 = 0.62$$

Obviously, the uplink cannot tolerate more interference than accounted for in the system design. The downlink, on the other hand, has only slight increases in interference limits compared to the preceding example, even though the uplink is not to accept any additional interference to the initial design value. This confirms that the tradeoffs between uplink and downlink interference allocations for a demod-remod system are marginal.

3 Example 3 of Methodology C

Consider now a bent-pipe satellite system ($c_i = 2.5$) with the following input data:

a) $BER_0 = 1 \times 10^{-12}$

b) $BER_1 = 1 \times 10^{-10}$, $BER_2 = 1 \times 10^{-8}$, $BER_3 = 1 \times 10^{-6}$

$\bar{t}_1 = 1\%$, $\bar{t}_2 = 0.2\%$, $\bar{t}_3 = 0.02\%$

c) $\alpha_0^{(u)} \equiv I_0^{(u)} / N_t^{(u)} = 0,2$ and $\alpha_0^{(d)} \equiv I_0^{(d)} / N_t^{(d)} = 0.2$

d) $\bar{y}_{ud} = 1$.

If the CNR degradations are the same for uplink and downlink, i.e., $\bar{x}_i^{(u)} = \bar{x}_i^{(d)}$, $i = 1, 2, 3$, then $\bar{x}_i^{(u)} = \bar{x}_i^{(d)} = \bar{x}_i = (\log BER_0 / \log BER_i)^{1/c_i}$ according to (71). Consequently, from (70a) and (70b),

$$I_1^{(u)} / N_t^{(u)} = I_1^{(d)} / N_t^{(d)} = 1.2 \times \left(\log 10^{-12} / \log 10^{-10}\right)^{1/2.5} - 1 = 0.29$$

$$I_2^{(u)} / N_t^{(u)} = I_2^{(d)} / N_t^{(d)} = 1.2 \times \left(\log 10^{-12} / \log 10^{-8}\right)^{1/2.5} - 1 = 0.41$$

$$I_3^{(u)} / N_t^{(u)} = I_3^{(d)} / N_t^{(d)} = 1.2 \times \left(\log 10^{-12} / \log 10^{-6}\right)^{1/2.5} - 1 = 0.58$$

4 Example 4 of Methodology C

If in Example 3 of Methodology C, we assume that the uplink will not accept any interference, i.e., $I_1^{(u)} = I_2^{(u)} = I_3^{(u)} \approx 0$, which by (73a) corresponds to $\bar{x}_1^{(u)} = \bar{x}_2^{(u)} = \bar{x}_3^{(u)} \approx 1/(1 + \alpha_0^{(u)}) = 1/1.2$ and satisfies (72), then from (71), $\bar{x}_i^{(d)} = 2 \times (\log BER_0 / \log BER_i)^{1/c_i} - 1/1.2$, $i = 1, 2, 3.$ Thus, (70b) yields:
$I_i^{(d)} / N_t^{(d)} = 2.4 \times (\log BER_0 / \log BER_i)^{1/c_i} - 2$. Specifically:

$$I_1^{(d)} / N_t^{(d)} = 2.4 \times \left(\log 10^{-12} / \log 10^{-10}\right)^{1/2.5} - 2 = 0.58$$

$$I_2^{(d)} / N_t^{(d)} = 2.4 \times \left(\log 10^{-12} / \log 10^{-8}\right)^{1/2.5} - 2 = 0.82$$

$$I_3^{(d)} / N_t^{(d)} = 2,4 \times \left(\log 10^{-12} / \log 10^{-6}\right)^{1/2.5} - 2 = 1.17$$

Compared with Example 3 of Methodology C, the downlink interference limits are much higher as a result of zero interference on the uplink. This indicates that a bent-pipe system allows for larger interference allocation tradeoffs between uplink and downlink, at the expense of a much larger transmitted power required from the ground station, relative to a demod-remod system. Looking alternatively, if the interference levels on the downlink reach the above values, any interference on the uplink will not be acceptable even if it is seemly a small amount!

5 Example 5 of Methodology C

Suppose that the data given below are specified for an MSS feeder link (uplink or downlink):

a) $BER_0 = 1 \times 10^{-12}$

b) $BER_1 = 1 \times 10^{-10}$, $BER_2 = 1 \times 10^{-8}$, $BER_3 = 1 \times 10^{-6}$

$\bar{t}_1 = 1\%$, $\bar{t}_2 = 0.2\%$, $\bar{t}_3 = 0.02\%$

c) $\alpha_0 \equiv I_0 / N_t = 0.2$.

The interference limits on this feeder link can be found from (67a) or (67b) upon ignoring the superscript *u* or *d*, and their values normalized to the corresponding feeder link noise level are thus given by (assuming again $c_i = 2{,}5$)

$$I_1 / N_t = 1.2 \times \left(\log 10^{-12} / \log 10^{-10}\right)^{1/2.5} - 1 = 0.29$$

$$I_2 / N_t = 1.2 \times \left(\log 10^{-12} / \log 10^{-8}\right)^{1/2.5} - 1 = 0.41$$

$$I_3 / N_t = 1.2 \times \left(\log 10^{-12} / \log 10^{-6}\right)^{1/2.5} - 1 = 0.58$$

which are associated with the respective percentages of time specified in § b).

6 Example 6 of Methodology C

In Example 5 of Methodology C, suppose that the following $BER \sim E_b/N_0$ data are further given:

a) $BER_0 = 1 \times 10^{-12}$ for $x_0 = 9.0$ dB

b) $BER_1 = 1 \times 10^{-10}$ for $x_1 = 8.6$ dB

$BER_2 = 1 \times 10^{-8}$ for $x_2 = 8.2$ dB

$BER_3 = 1 \times 10^{-6}$ for $x_3 = 7.8$ dB

where x_i, $i = 0, 1, 2, 3$, denote the corresponding E_b/N_0 values on the $BER \sim E_b/N_0$ curve. c_i in (67a) or (67b) are then determined from (74) as follows (recall that x_0 and x_i in (74) represent the absolute values of E_b/N_0, i.e., $10 \log (x_0/x_i) = x_0$ (dB) – x_i (dB)):

$$c_1 = 10 \times \log\left(\log 10^{-12} / \log 10^{-10}\right) \Big/ (9.0 - 8.6) = 1.98$$

$$c_2 = 10 \times \log\left(\log 10^{-12} / \log 10^{-8}\right) \Big/ (9.0 - 8.2) = 2.20$$

$$c_3 = 10 \times \log\left(\log 10^{-12} / \log 10^{-6}\right) \Big/ (9.0 - 7.8) = 2.51$$

These values are now used in (67a) or (67b) to evaluate the interference limits, as demonstrated below:

$$I_1 / N_t = 1.2 \times \left(\log 10^{-12} / \log 10^{-10}\right)^{1/1.98} - 1 = 0.32$$

$$I_2 / N_t = 1.2 \times \left(\log 10^{-12} / \log 10^{-8}\right)^{1/2.20} - 1 = 0.44$$

$$I_3 / N_t = 1.2 \times \left(\log 10^{-12} / \log 10^{-6}\right)^{1/2.51} - 1 = 0.58$$

APPENDIX 1

TO ANNEX 1

A computation technique to implement Methodology A in Annex 1

This Appendix describes a technique to compute allowable interference levels using Methodology A in Annex 1. This technique is based on the solution of an adequately defined non-linear optimization problem. It requires a parametric representation of the probability density functions of some of the variables involved. More specifically, the degradation due to fading and other time variations in the characteristics of the link and the degradation due to each interfering network were assumed to have probability density functions well approximated by piecewise constant functions. It is worth noting that other parametric representations could also be used.

The computing technique described here assumes that the effect of the interference component coming from the *i*th network can be represented by an increase in noise power from N_T to $Y_i N_T$. So, the degradation y_i due to the *i*th interfering network (dB) is:

$$y_i = 10 \log Y_i \tag{75}$$

It further assumes that the probability density functions of the random variables x (see equation (1)) and y_i, $i = 1, \ldots, N$, were parameterized as piecewise constant functions as illustrated in Figs. 17 and 18.

Since $p_x(X)$ constitutes one of the required input data, the parameters (β_m, e_m), $m = 1, \ldots, M$ in Fig. 17 are assumed to be known. Note that β_0 can be obtained from these parameters through the relation:

$$\beta_0 = 1 - \beta_1 - \sum_{m=2}^{M} \beta_m \left(e_{m-1} - e_m \right) \tag{76}$$

In Fig. 18, the parameters d_k, $k = 1, \ldots, K$ are assumed to be known while the values of the parameters α_k, $k = 1, \ldots, K$ are to be determined by solving the set of inequalities in Step 6 of Methodology A in Annex 1. The function $f(\alpha_1, \ldots \alpha_K)$ in Fig. 18 is given by:

$$f\left(\alpha_1, \ldots, \alpha_K\right) = 1 - \alpha_1 - \sum_{k=2}^{K} \alpha_k \left(d_{k-1} - d_k \right) \tag{77}$$

The determination of the parameters $\alpha_1, \alpha_2, \ldots, \alpha_K$ is then done by solving a convenient non-linear optimization problem. Specifically it is proposed to determine the values of $\alpha_1, \alpha_2, \ldots, \alpha_K$ that minimize (77) under the constraints in equation (18) while guaranteeing that $\alpha_1, \alpha_2, \ldots, \alpha_K$ and $f(\alpha_1, \ldots \alpha_K)$ are all positive. In other words, the parameters $\alpha_1, \alpha_2, \ldots, \alpha_K$ are determined by minimizing (77) under the constraints:

$$r_j\left(\alpha_1, \ldots, \alpha_K\right) = P\left(z \geq z_j\right) \leq \frac{p_j}{100} \qquad \text{for } j = 1, \ldots, J \tag{78}$$

$$f\left(\alpha_1, \ldots, \alpha_K\right) \geq 0 \tag{79}$$

$$\alpha_k \geq 0 \qquad \text{for } k = 1, \ldots, K \tag{80}$$

FIGURE 17

Probability density function of the degradation, *x*, due to fading and other time variations in the characteristics of the link – Parametric representation

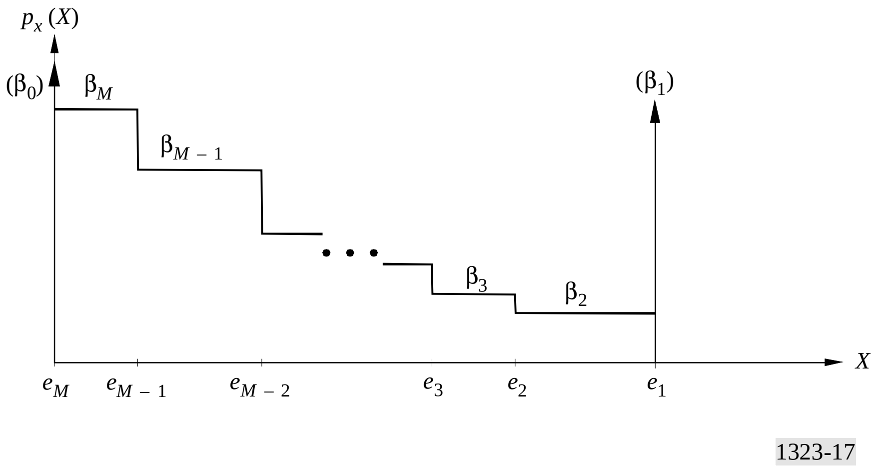
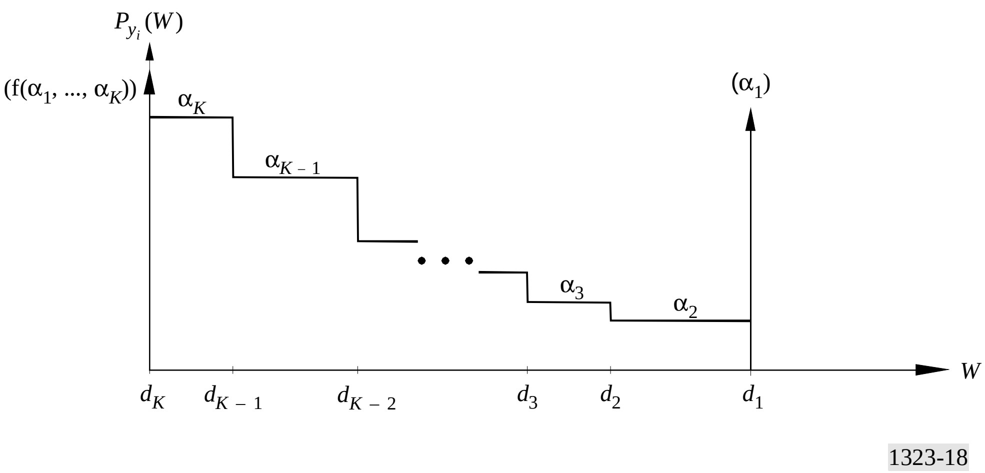


FIGURE 18

Probability density function of the degradation, y_i, due to the *i*th interfering network – Parametric representation



The computation technique described in this Annex was used to determine the allowable interference levels in Example 1 of Methodology A (cases 1 and 2) in Annex 1. In this example, the non-linear optimization problem to be solved consisted of minimizing:

$$f(\alpha_1, \alpha_2) = 1 - \alpha_1 - 2.5\,\alpha_2 \tag{81}$$

under the constraints:

$$r_1(\alpha_1, \alpha_2) = P(z \geq 2.5) \leq 0.5/100 \tag{82}$$

$$r_2(\alpha_1, \alpha_2) = P(z \geq 1.5) \leq 1.0/100 \tag{83}$$

$$f(\alpha_1, \alpha_2) \geq 0 \tag{84}$$

$$\alpha_k \geq 0 \qquad \text{for } k = 1, 2 \tag{85}$$

Considering (82) the constraint in (83) was approximated by:

$$r_2(\alpha_1, \alpha_2) - r_1(\alpha_1, \alpha_2) = P(1.5 \geq z \geq 2.5) \leq 0.005 \tag{86}$$

In case 1 of Example 1 of Methodology A, which considers only one interfering network ($N = 1$), the problem constraints (82), (86), (84) and (85) respectively become after some algebraic manipulations:

$$1.991 \ \alpha_1 + 0.01375 \ \alpha_2 \leq 0.001 \tag{87}$$

$$-0.0275 \ \alpha_1 + 12.36125 \ \alpha_2 \leq 0.035 \tag{88}$$

$$1 - \alpha_1 - 2.5 \ \alpha_2 \geq 0 \tag{89}$$

$$\alpha_k \geq 0 \qquad \text{for } k = 1, 2 \tag{90}$$

The solution of this optimization problem (linear in this case) is illustrated in Fig. 19. In this figure, constraints 1 and 2 correspond to conditions (87) and (88) respectively. Constant value contours of $f(\alpha_1, \alpha_2)$ are also shown in this figure. The proposed computation technique leads to the solution represented by point A ($\alpha_1 = 0.0004827$, $\alpha_2 = 0.0028325$). The interference allowance masks associated with this solution is presented in equations (24) through (29).

In solving case 2 of Example 1 of Methodology A, which considers two interfering networks ($N = 2$), the functions $r_1(\alpha_1, \alpha_2)$ and $r_2(\alpha_1, \alpha_2)$, appearing in constraints (82) and (86) are not linear. Their computation, using Methodology A in Annex 1, is not simple and requires some computer work. The solution to this non-linear optimization problem can be reached through usual non-linear programming techniques. Figure 20 illustrates the optimum solution to this problem. In this figure, constraints 1 and 2 correspond to conditions (82) and (86) respectively. Constant value contours of $f(\alpha_1, \alpha_2)$ are also shown in this figure. The proposed computation technique leads to the solution represented by point A ($\alpha_1 = 0.0002388$, $\alpha_2 = 0.00142239$). The interference allowance masks associated with this solution is presented in equations (30) through (35).

FIGURE 19

Solutions for α_1 and α_2 in Example 1 of Methodology A (Case 1)

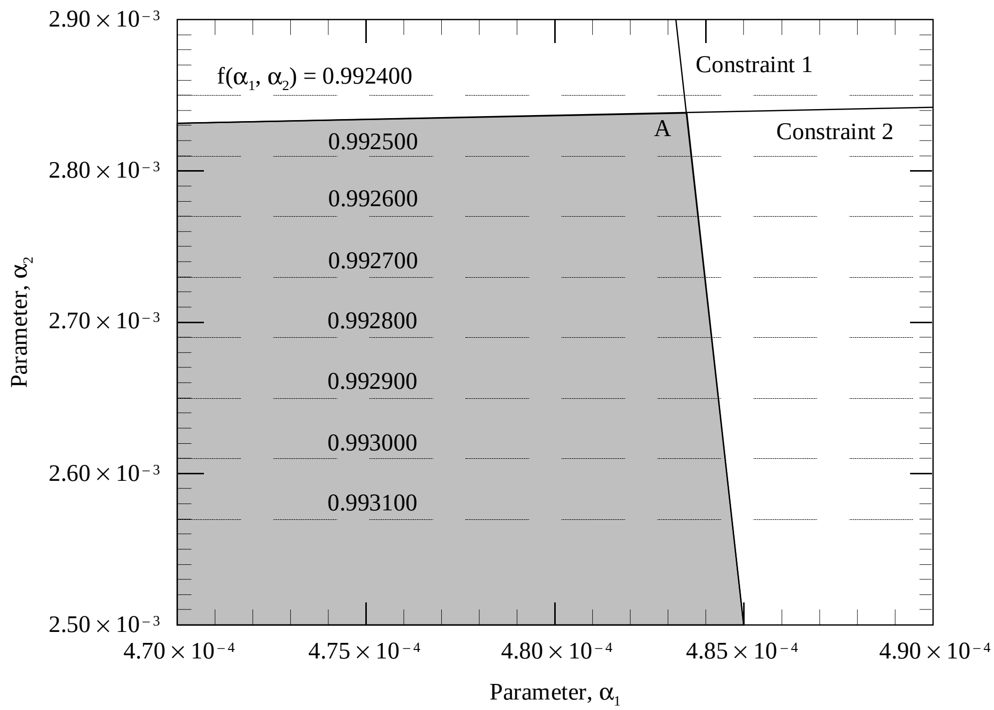


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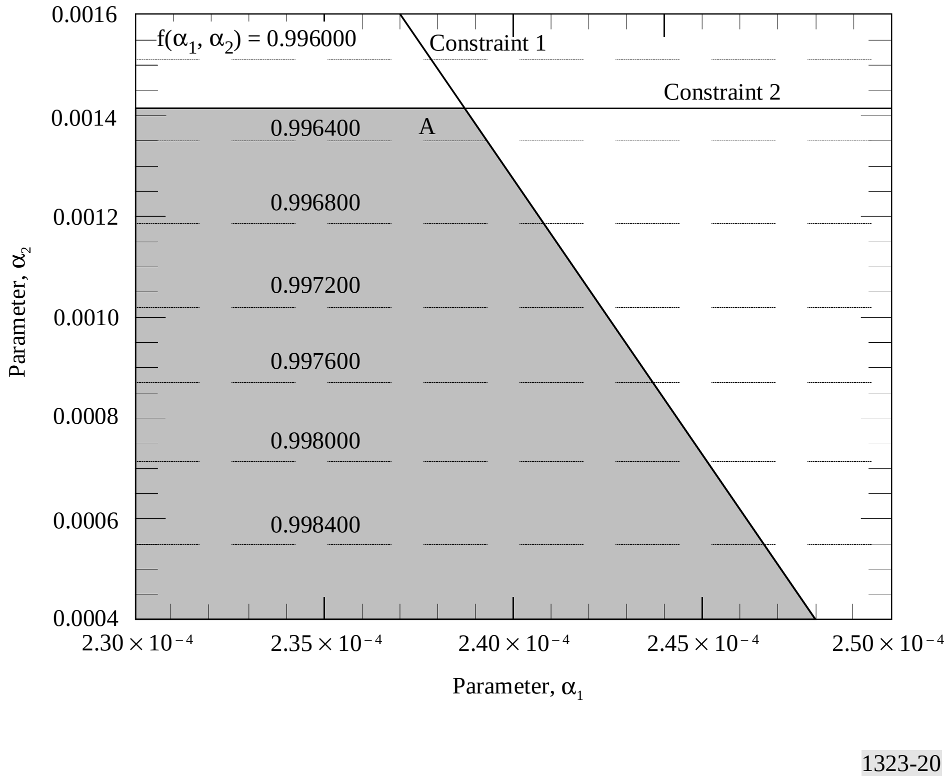
FIGURE 20

Solutions for α_1 and α_2 in Example 1 of Methodology A (Case 2)



APPENDIX 2

TO ANNEX 1

Derivation of interference equations for Methodology C in Annex 1

FSS satellite links operating in the 20/30 GHz bands can be closely approximated by an additive white Gaussian noise (AWGN) channel, whose performance is further modelled by:

$$BER \approx a \exp\left(-bx^{c}\right), \quad x = E_b / \left(N_t + I_t\right) \tag{91}$$

Here, E_b is the conventional signal energy per information bit, while N_t and I_t are the total thermal noise and interference spectral densities, respectively, at the receiver of the FSS satellite link. Moreover, a is a constant close to unity; b and c depend on the modulation and coding schemes employed for the link. b is cancelled out in the process of derivation as will become evident later on. c will be shown to be computable according to equation (74).

Since $a \approx 1$, it follows from (91) that

$$x^{c} \approx -\ (\ln BER) / b \tag{92}$$

which leads to:

$$\bar{x}_i \equiv x_0 / x_i = \left(\log BER_0 / \log BER_i\right)^{1/c_i} \tag{93}$$

where c has been denoted c_i as it is the slope between two points on the BER versus x curve on an extended log scale and has a slight dependence on the location of the point indexed by i, assuming the point indexed by 0 is a common reference point. (93) is equivalent to equation (74).

For a demod-remod FSS satellite, both uplink and downlink have a digital receiver, and are amenable to (93), with the BER of the satellite link given by the sum of those occurred on the uplink and downlink alone if they are small ($< 10^{-3}$). Associating the quantities with the appropriate links, one obtains:

$$\bar{x}_i^{(l)} \equiv x_0^{(l)} / x_i^{(l)} = \left(N_t^{(l)} + I_i^{(l)}\right) \Big/ \left(N_t^{(l)} + I_0^{(l)}\right) = \left(1 + \alpha_i^{(l)}\right) \Big/ \left(1 + \alpha_0^{(l)}\right), \; l = u, d \qquad (94)$$

Since $l = u$, d refers to the uplink and downlink, respectively, the first two equations in the demod-remod case result.

For a bent-pipe FSS satellite, on the other hand, noise and interference are accumulated through the satellite according to the well-known carrier-to-noise ratio relationship:

$$1 / y = 1 / y^{(u)} + 1 / y^{(d)} \qquad (95)$$

where y is the ratio of the carrier power to the sum of the noise and interference powers of the overall satellite link, whereas $y^{(u)}$ and $y^{(d)}$ are those associated, respectively, with the uplink and downlink only. With the uplink and downlink interference levels specified in § c) and e) of Methodology C, equation (95) can be written as:

$$1 / y_0 = 1 / y_0^{(u)} + 1 / y_0^{(d)} = 1 / y_0^{(u)} + \bar{y}_{ud} / y_0^{(u)}, \; \bar{y}_{ud} = y_0^{(u)} / y_0^{(d)} \qquad (96)$$

i.e.,

$$y_0^{(u)} / y_0 = 1 + \bar{y}_{ud} \qquad (97)$$

Moreover, assuming the interference levels that are being determined, (95) then becomes:

$$1 / y_i = 1 / y_i^{(u)} + 1 / y_i^{(d)} \qquad (98)$$

Since:

$$\bar{x}_i \equiv x_0 / x_i = y_0 / y_i \qquad (99)$$

$$\bar{x}_i^{(l)} \equiv y_0^{(l)} / y_i^{(l)} = \left(N_t^{(l)} + I_i^{(l)}\right) \Big/ \left(N_t^{(l)} + I_0^{(l)}\right) = \left(1 + \alpha_i^{(l)}\right) \Big/ \left(1 + \alpha_0^{(l)}\right), \; l = u, d \qquad (100)$$

where $l = u$, d again refers to the uplink and downlink, respectively, it follows from (98) that

$$\bar{x}_i / y_0 = \bar{x}_i^{(u)} / y_0^{(u)} + \bar{x}_i^{(d)} / y_0^{(d)} \qquad (101)$$

which, with the aid of (96) and (97), reduces to:

$$\bar{x}_i^{(u)} + \bar{y}_{ud} \, \bar{x}_i^{(d)} = \left(1 + \bar{y}_{ud}\right) \bar{x}_i \qquad (102)$$

Evidently, (160) furnishes the first two equations in the bent-pipe case, while the constraints that follow result from (102) upon recalling that (93) applies to the digital receiver of the overall satellite link.