RECOMMENDATION ITU-R S.1323-1

MAXIMUM PERMISSIBLE LEVELS OF INTERFERENCE IN A SATELLITE NETWORK (GSO/FSS; NON-GSO/FSS; NON-GSO/MSS FEEDER LINKS)* 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)

(1997-2000)

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 and its operator should have control over the overall performance of a network and have the capability to provide the required quality of service;

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 and that the inclusion of additional link margin above that necessary to compensate for rain fading, e.g. to compensate for equipment aging, is not to be considered as part of that protection;

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 and this single entry interference should allow accommodation of an appropriate number of interfering systems;

f) that in frequency bands above 10 GHz where very high signal 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;

g) 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;

h) that the long-term interference allowance from non-GSO systems to GSO FSS networks should be a small percentage of the existing long-term allowance into a GSO FSS network; and in addition to that allowance;

j) that if not limited short-term interference events may cause loss of synchronization or other unstable conditions even under clear sky 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;

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* 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.

l) that the effect of non-GSO interference into GSO systems that employ adaptive downlink coding is not the same as the effects due to rain, and that studies performed so far indicate the need to consider these non-GSO interference effects on at least a per-beam basis (in the GSO system) rather than on a per-link basis;

m) that propagation effects should account for no more than 90% of the unavailability of an FSS link,

recommends

1 that a GSO 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 link performance objectives can be met when the aggregate interfering power from the earth and space station emissions of all other GSO 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 GSO network in the FSS as mentioned in *recommends* 1, the internetwork interference caused by the earth and space station emissions of any one other GSO 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 interference of time-varying nature, should:

3.1 be responsible for at most 10% of the time allowance for the BER (or C/N value) specified in the short-term performance objectives of the desired network and corresponding to the shortest percentage of time (lowest C/N value);

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);

3.3 in the case of networks using adaptive coding, provisionally be responsible for at most a 10% (until review by further studies) decrease in the amount of spare capacity available to links that require heavy coding to compensate for rain fading, on the assumption that the network maintains, with the use of this spare capacity (the definition of spare capacity for systems using adaptive coding has yet to be developed in the context of this Recommendation), the same level of performance as it did with no time-varying interference present. Further studies are needed to validate this approach;

4 that, when applying Methodologies A and A' described in Annex 1 or Procedure D described in Annex 2, there is no need for a long-term allowance to be defined because, since simultaneous effects of fading and interference are taken into consideration, then a full characterization of the interference mask results from the conditions in *recommends* 3;

5 that, when applying Methodology B described in Annex 1, a long-term allowance should be additionally defined because simultaneous effects of fading and interference are not taken into account;

6 that this allowance corresponding to long-term interference, when used in addition to *recommends* 3, should be expressed by requiring that the aggregate interference should not exceed 6% of the total system noise power for more than 10% of the time;

7 that the verification of whether the internetwork interference caused by the earth and space station emissions of any given satellite network meets the requirements of *recommends* 3 (and *recommends* 6, where applicable) or the derivation of an interference mask (interference levels and maximum percentages of time for which such levels could be exceeded) that would lead to *recommends* 3 (and *recommends* 6, where applicable) being met may be conducted using the methodologies described in Annexes 1 and 2 in connection with an appropriate, assumed number of interfering networks;

8 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:

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

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

for non-GSO to GSO interference, the antenna patterns contained in Recommendation ITU-R S.1428;

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

NOTE 1 – For the interference between GSO FSS networks, *recommends* 1 and 2 apply but *recommends* 3 does not apply.

NOTE 2 – The term "interference of time-varying nature" in *recommends* 3 includes the constant component that may be present throughout time.

NOTE 3 – For the calculation of the limits quoted in *recommends* 1.1, 1.2, 2, 3 and 6 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.

NOTE 4 – For the calculation of interference, in respect of *recommends* 1, 2, 3 and 6 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 5 – It is assumed in connection with *recommends* 1 and 2 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 6 – When interfering signals are 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 7 – For networks using 8-bit PCM encoded telephony see Recommendation ITU-R S.523.

NOTE 8 – 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 9 – There is a need for study of the acceptability of an increase in the maximum total interference noise values recommended in *recommends* 1.

NOTE 10 – 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 11 – 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 or adaptive coding is used for fade compensation.

NOTE 12 – In order to promote orbit efficiency, satellite networks operating in climates having heavy rain are encouraged to use some form of fade compensation.

NOTE 13 – Loss of synchronization due to relatively high levels of interference may cause loss of service for periods longer than the interferences themselves. 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 of *recommends* 3.1 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 determining whether interference to a network in the FSS (GSO/FSS; non-GSO/FSS; non-GSO/MSS feeder links) meets *recommends* 3 (and *recommends* 6, where applicable) or for deriving interference allowances that would meet *recommends* 3 (and *recommends* 6, where applicable)

This Annex includes three methodologies for verifying whether interference meets *recommends* 3 (and *recommends* 6, where applicable) or for deriving interference allowances that would meet *recommends* 3 (and *recommends* 6, where applicable). They are referred to here as Methodologies A, A' and B. Application of these methodologies in the context of interference from an individual network (i.e., single-entry interference) requires allocation of the aggregate interference allowance of *recommends* 3 among the interfering networks. Determination of the appropriate number of interfering systems is beyond the scope of this Recommendation.

Methodologies A and A' consider simultaneous effects due to fading and interference. Verification of compliance with *recommends* 3 or 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, modelling fading may be difficult, specially for links to or from non-GSO satellites where elevation and azimuth vary with time. Methodology A' is a special case of Methodology A in the sense that particular parametric models for the probability density functions of the degradations due to fading and interference are assumed. In Methodology A, the parametric representation of these probability density functions remains undefined and can be chosen to best fit the particular situation under consideration.

For systems operating in clear-sky with relatively small margins and relying heavily on power control or adaptive coding to combat fading, simultaneous effects due to fading and interference become less significant and may be neglected if the affected system so wishes. Methodology B explores 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.

A procedure implementing verification of compliance with *recommends* 3.1 and refinement of the interference mask is described in Annex 2. This procedure can be applied to verify compliance with *recommends* 3.1 for interference masks developed using any of the methodologies described in Annex 1.

Further study is needed to determine the nature of both short-term 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 verifying whether interference meets the requirements in *recommends* 3 or for determining the interference allowances associated with any given desired carrier that would meet *recommends* 3.

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.

The total C/N for a given carrier is:

$$C/N = C/(N_T + I)$$

where:

C: wanted power (W), which varies as a function of the uplink and downlink fades and also as a function of the transmission configuration (multiple access, use of uplink power control, etc.) Thus C can be described as a function of $A_\uparrow$, the uplink rain attenuation, and $A_\downarrow$, the downlink rain attenuation as:

$$C = C_{cs} / F(A_\uparrow, A_\downarrow)$$

C_{cs}: wanted power in clear sky conditions (long-term condition)

N_T: total system noise (W) (i.e. the thermal power including uplink and downlink contributions at the demodulator input, the noise power resulting from the multi-carrier operation of the involved power amplifier – in the earth stations and in the space stations – , the cross polarization isolations of the different transmit and receive antennas, the thermal power increase due to the rain fades, Sun – and Moon if applicable – temperature), which also varies as a function of the transmission configuration and with the uplink and downlink fades. N_T also includes the long-term contributions from other networks. Thus N_T can be described as a function of $A_\uparrow$ and $A_\downarrow$ as:

$$N_T = N_{T,cs} \cdot G(A_\uparrow, A_\downarrow)$$

$N_{T,cs}$: noise power in clear sky conditions (long-term condition) (W)

I: time-varying interference power (W) generated by other networks.

Assumption 2: Due to fading plus other time variations in the characteristics of the link, carrier power reduction due to the uplink fade $A_\uparrow$ and the downlink fade $A_\downarrow$ i.e. $F(A_\uparrow, A_\downarrow)$, and the noise increase, $G(A_\uparrow, A_\downarrow)$, can be accounted for by substituting C/X for C, with $X = H(A_\uparrow, A_\downarrow) = F(A_\uparrow, A_\downarrow) \cdot G(A_\uparrow, A_\downarrow)$, and the corresponding degradation x (dB), is:

$$x = 10 \log X = 10 \log \left(H(A_\uparrow, A_\downarrow)\right) \quad (1)$$

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:

$$y = 10 \log Y \quad (2)$$

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

$$z = x + y \quad (3)$$

The random variables x and y are assumed to be statistically independent and therefore the probability density function (pdf) of z is the convolution of the pdf 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.

In order to permit the computation of the probability density function of the degradation x, it is necessary to identify, prior to the application of this methodology, the exact carrier parameters of the considered network, as well as the necessary parameters required to develop the computation of the uplink and downlink fades as well as the power reduction and noise increase functions (F and G).

Assumption 3: The time allowances for each interference entry are obtained by dividing by N the time allowances associated with the total interference. This number N is related to the number of networks that can potentially cause time-varying interference and will be referred to as the equivalent number of networks. N may also vary with the time percentage considered.

Assumption 4: This analysis assumes that, during a fading event, the wanted carrier is attenuated but the interfering carrier is not. This assumption results in some over-estimation of the total downlink degradation under circumstances where interference peaks and downlink fading occur simultaneously.

2 Input data

The following data is required to verify compliance with *recommends* 3 or to determine the interference allowances that would meet *recommends* 3, 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 pdf, $p_x(X)$ 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 pdf is highly dependent on the presence of power control and its characteristics. This pdf 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 (6) for an expression of this condition).

d) The equivalent number N of interfering networks that can potentially cause time-varying interference and that will be sharing the same frequency band with the desired network. For a GSO/FSS desired network, N is related to the number of non-GSO systems sharing the same frequency band. For a non-GSO desired network, N is related to 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.

In addition, to verify compliance, the pdf, $p_y(Y)$, of the degradation due to interference must be provided. This pdf can be derived by the application of any of the methodologies described in this Recommendation or indeed by any other means that may be seen fit.

3 Proposed procedure

3.1 Verification of compliance with *recommends* 3

For verification of compliance with *recommends* 3, it is necessary to obtain the pdf $p_z(Z)$, of the total degradation, given by:

$$p_z(Z) = p_x \; p_y(Z) \tag{4a}$$

where $p_x(X)$ and $p_y(Y)$ were given as input data. Conditions to be verified are:

$$P(z \geq z_j) \leq (0.9 + 0.1 / N)\, p_j / 100 \qquad \text{for } j = 1, \ldots, J \tag{4b}$$

Detailed procedures to implement this verification of compliance with *recommends* 3 can be found in Annex 2, where examples of the application of these procedures are also given.

3.2 Derivation of interference allowances

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:

$$z_j = (C/N)_{cs} - (C/N)_j \qquad \text{for } j = 1, ..., J \tag{5}$$

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

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

Step 2: A parametric representation is chosen for the pdf, $p_y(Y)$, corresponding to the degradation due to interference. 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 $p_y(Y)$ 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:

$$p_y(Y) = f(Y, \alpha_1, \ldots, \alpha_K) \tag{7}$$

Step 3: A parametric representation for the total degradation z is obtained from:

$$p_z(Z) = p_x * p_y(Z) \tag{8}$$

where $p_x(X)$ is given in c) of the input data and $p_y(Y)$ was defined in Step 2. As $p_y(Y)$ depends on the parameters α_1, ..., α_K, according to equation (7), so does $p_z(Z)$. This function can therefore be written as:

$$p_z(Z) = \mathrm{h}(Z, \alpha_1, \ldots, \alpha_K) \tag{9}$$

Step 4: From equation (9), 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 $\alpha_1, \ldots, \alpha_K$ and can be written:

$$P(z \geq z_j) = r_j(\alpha_1, \ldots, \alpha_K) \qquad \text{for } j = 1, \ldots, J \tag{10}$$

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

$$r_j(\alpha_1, \ldots, \alpha_K) \leq (0.9 + 0.1 / N)\, p_j / 100 \qquad \text{for } j = 1, \ldots, J \tag{11}$$

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 and n is the number of interference entries.

Step 5: From the parameters $\alpha_1, \ldots, \alpha_K$ computed in Step 4, the pdf of y, as defined in (7) is obtained. This pdf 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:

$$P(y \geq Y_m) \leq q_m \tag{12}$$

it follows that:

$$P(I \geq (10^{Y_m/10} - 1)\, N_T) \leq q_m \tag{13}$$

From $p_y(Y)$, a certain number M of pairs $((10^{Y_m/10} - 1)N_T;\ q_m)$ can be computed, defining therefore a mask for the interference allowances from one interfering network.

4 Interference into systems using transparent transponders: joint effects of uplink and downlink fading and interference

Let $X_\uparrow$ denote the degradation due to fading in the uplink *C*/*N* and let $X_\downarrow$ denote the degradation due to fading in the downlink *C*/*N*. In general, $X_\uparrow$ will be made equal to the attenuation due to rain while $X_\downarrow$ will further incorporate the effects of the increase in the receive noise temperature.

If $N_\uparrow$ and $N_\downarrow$ denote the total uplink and downlink noises in clear-sky and $I_\uparrow$ and $I_\downarrow$ denote the uplink and downlink time-varying interferences, the *C*/*N* in clear-sky and in the absence of any time-varying interference can be written as:

$$\left(\frac{C}{N}\right)_{cs} = \frac{C}{N_\uparrow + N_\downarrow} \qquad (14)$$

while the *C*/*N* in the presence of uplink and downlink fading and interference can be written as:

$$\left(\frac{C}{N}\right) = \frac{1}{\dfrac{X_\uparrow(N_\uparrow + I_\uparrow)}{C} + \dfrac{X_\uparrow X_\downarrow(N_\downarrow + I_\downarrow)}{C}} \qquad (15)$$

Therefore, the degradation due to uplink and downlink fading and interference can be expressed as:

$$Z = aX_\uparrow\left(1 + \frac{I_\uparrow}{N_\uparrow}\right) + (1 - a)X_\uparrow X_\downarrow\left(1 + \frac{I_\downarrow}{N_\downarrow}\right) = X_\uparrow[aY_\uparrow + (1 - a)X_\downarrow Y_\downarrow] \qquad (16)$$

where:

$$Y_\uparrow = 1 + \frac{I_\uparrow}{N_\uparrow} \qquad (17)$$

is the degradation in the clear-sky uplink *C*/*N* due to uplink interference,

$$Y_\downarrow = 1 + \frac{I_\downarrow}{N_\downarrow} \qquad (18)$$

is the degradation in the clear-sky downlink *C*/*N* due to downlink interference and

$$a = \frac{N_\uparrow}{N_\uparrow + N_\downarrow} \qquad (19)$$

If we write:

$$V = aY_\uparrow + (1 - a)Z_\downarrow \qquad (20)$$

where:

$$Z_\downarrow = X_\downarrow Y_\downarrow \qquad (21)$$

is the total degradation, due to interference and fading, in the downlink clear-sky C/*N*, then:

$$Z = X_\uparrow V \qquad (22)$$

or (dB):

$$z = 10 \log Z = 10 \log X_\uparrow + 10 \log V = x_\uparrow + v \qquad (23)$$

Equation (22) or (23), combined with equations (20) and (21), gives the total degradation due to interference and fading as a function of the degradations in the clear-sky uplink *C*/*N* due to fading ($X_\uparrow$) and interference ($I_\uparrow$) and of the degradations in the clear-sky downlink *C*/*N* due to fading ($X_\downarrow$) and interference ($I_\downarrow$).

In order to obtain the pdf of the total degradation z (dB) as given by equation (23), the pdf of the degradation due to uplink fading $x_{\uparrow}$ (dB) has to be convolved with the pdf of the random variable v, defined by:

$$v = 10 \log\left[aY_{\uparrow} + (1 - a)Z_{\downarrow} \right] \tag{24}$$

In order to obtain the pdf of the random variable v, it is first necessary to convolve the pdfs of the random variables $aY_{\uparrow}$ and $(1 - a)Z_{\downarrow}$.

Example

As an example of the consideration of the joint effects of uplink and downlink interference and fading, interference from a non-GSO FSS system into a GSO FSS network is considered here.

The relevant parameters of the GSO link are:

– earth station location: 26° N, 128° E
– rain model: Recommendation ITU-R P.618, Region N
– elevation angle to GSO satellite (at 132° E): 59.28°
– $a = N_{\uparrow}/(N_{\uparrow} + N_{\downarrow}) = 0.0988$
– system margin: 11.5 dB

The non-GSO earth station is co-located with the GSO earth station.

The pdfs of the degradations due to uplink fading, $x_{\uparrow}$, uplink interference, $y_{\uparrow}$, downlink fading, $x_{\downarrow}$ and downlink interference, $y_{\downarrow}$, are shown in Fig. 1. Using the procedure described above allows us to obtain the pdf of the total degradation z, shown in Fig. 2, where the pdf of the downlink degradation, $z_{\downarrow}$, is also presented. From the probabilities of total degradation exceeding the system margin and downlink degradation exceeding the system margin, we note that in this case the effects of downlink degradation (fading plus interference) are dominant.

FIGURE 1

pdf of rain and interference degradation

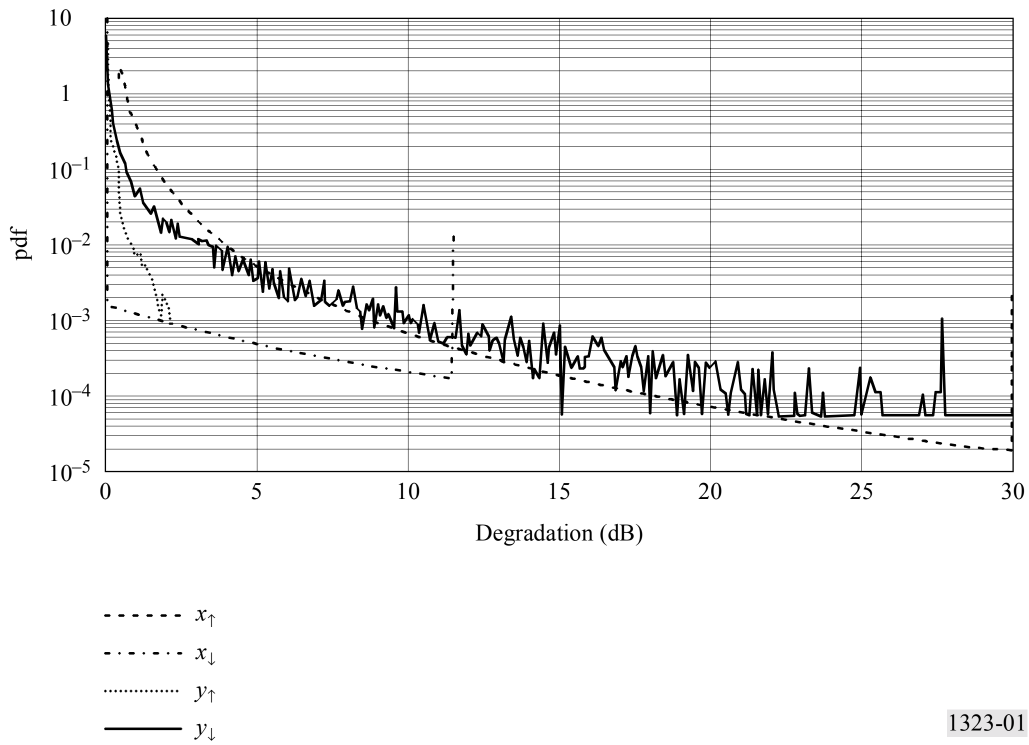
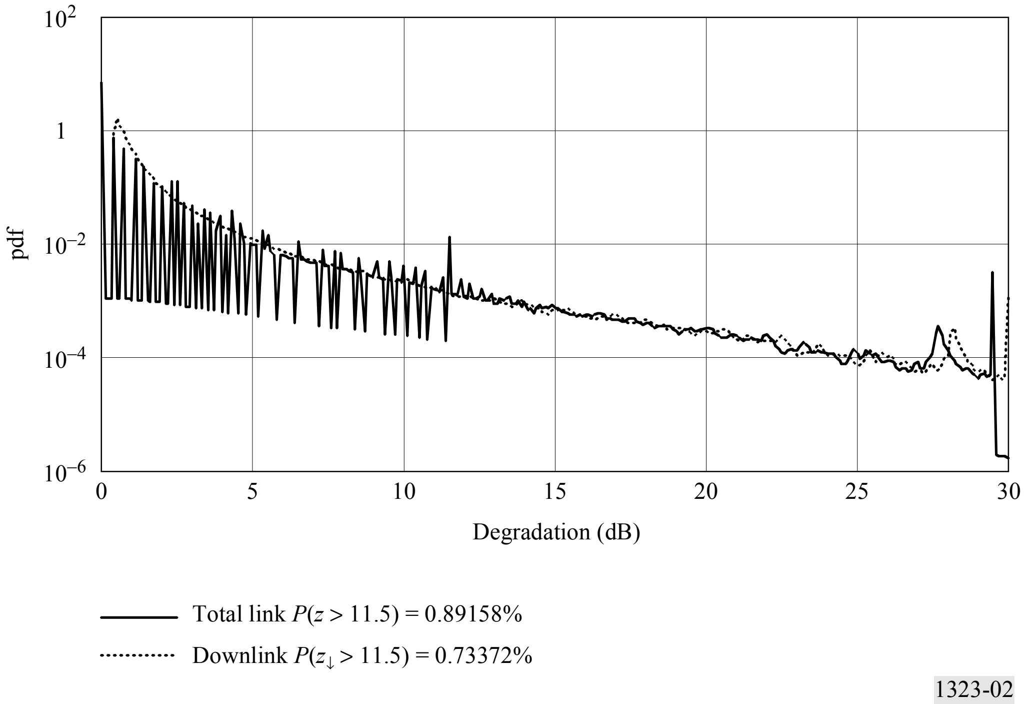


FIGURE 2

pdf of total degradation



5 Consideration of degradation due to fading in links with variable elevation angle

In links to and from non-GSO satellites the degradation due to fading is also a function of the elevation angle γ. One approximate way of taking this into account consists in determining the pdf of the degradation due to fading for the average elevation angle γ_{av}. However, a more precise approach is to obtain the pdf $p_\gamma(\Gamma)$ of the elevation angle and then express the pdf $p_x(X)$ of the degradation as:

$$p_x(X) = \int_0^{\pi/2} p_{x|\gamma}(X|\gamma = Z) p_\gamma(Z) \, \mathrm{d}Z \qquad (25)$$

Example

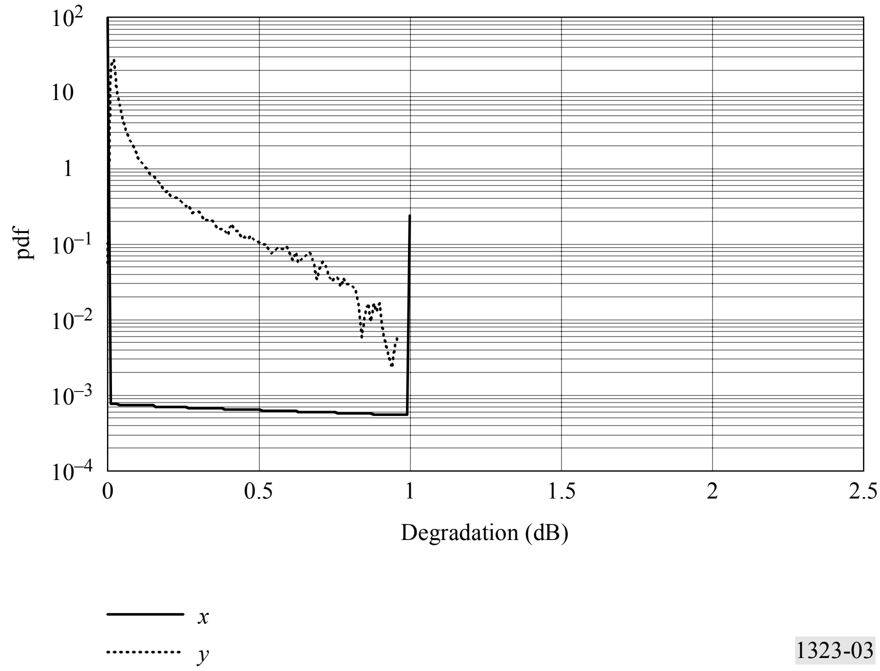
As an example, consider the interference between the uplinks of two non-GSO satellite systems. The interfered with non-GSO system avoids in-line events employing a 10° avoidance angle. This avoidance angle is just sufficient for the total degradation z to meet the allowable time percentage. The victim uplink uses power control with a dynamic range of 6.8 dB with a clear sky link margin of 1 dB and a heavy rain link margin of 0 dB. The corresponding pdf for the rain fading was therefore represented with an impulse at 0 dB corresponding to the probability of x (degradation due to fading) being between 0 and 5.8 dB and a second impulse at 1 dB corresponding to the probability of x exceeding 6.8 dB.

Figure 3 shows the rain fade x and interference degradation y pdfs for the uplink interference, where the x distribution is based on the average elevation angle. The Crane rain model is used. Figure 4 shows the corresponding total degradation z, derived from the convolution of the x and y pdfs.

FIGURE 3

pdf of rain fade, *x*, and interference degradation, *y*, using Crane model and weighted average elevation angle

(LEOSAT-2 uplink, 10° avoidance angle)



$P(x > 1) < 0.24113\%$

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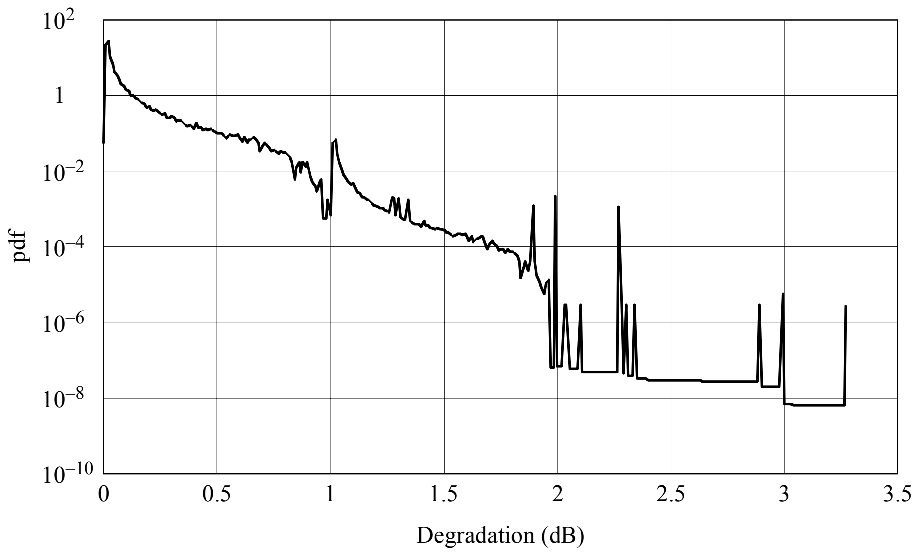
FIGURE 4

pdf of total degradation, *z*, using Crane model and weighted average elevation angle

(LEOSAT-2 uplink, 10° avoidance angle)



Threshold = 0.26792%

$P(z > 1) = 0.25783\%$

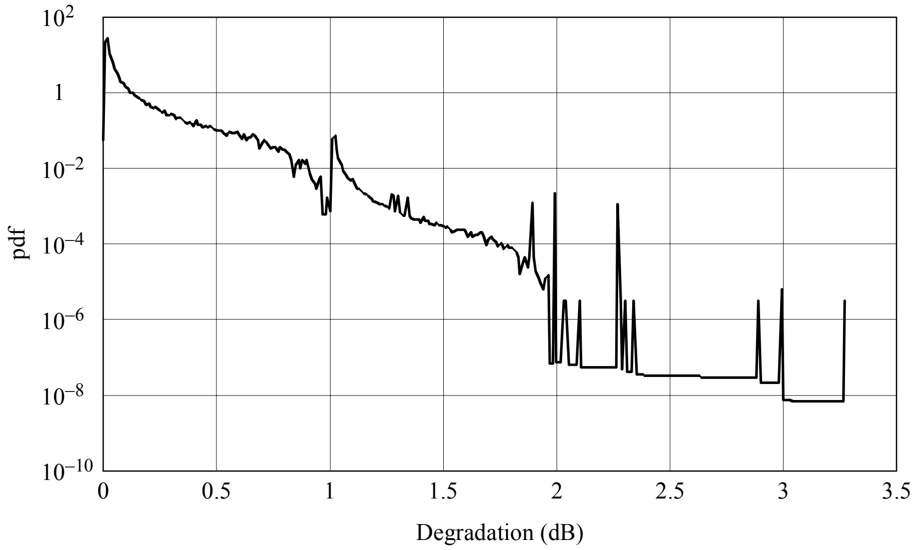
1323-04

Figure 5 shows the total degradation z distribution when the elevation angle distribution is used in generating the rain fade rather than using the average elevation angle. The total degradation just meets the time allowance, similarly to the results shown in Fig. 2.

FIGURE 5

pdf of total degradation, *z*, using Crane model and elevation angle distribution

(LEOSAT-2 uplink, 10° avoidance angle)



Threshold = 0.29394%

$P(z > 1) = 0.28159\%$

1323-05

Other examples have confirmed that computing the degradation due to fading as proposed in equation (25), or basing this calculation on the average elevation angle $\gamma_{av,}$ leads to essentially identical results. This justifies the use of the simpler approach i.e. to compute the degradation due to fading based on the average angle γ_{av}.

A procedure to consider the time variation of the parameters of a non-GSO link and also take into account any possible statistical dependence between fading and interference is described in Annex 3.

6 Examples of application of Methodology A

We consider here a GSO downlink that is supposed to operate in such a way that the received C/N is above a threshold value $(C/N)_{thr}$ during at least 99.9% of the time.

It is assumed that the degradation due to fading includes the rain attenuation directly obtained from the Crane two-component model plus the effect of the increase in noise temperature due to rain. It is further assumed that the total downlink noise also includes interference (both intra-system and inter-system) and that the interference is faded by the same amount as the desired signal.

The degradation X, expressed as a factor, is given by:

$$X = \frac{(1 - \alpha)\left\{L_R + \left[(T_0 - T_B)\big/T_{sys}\right]\left[(L_R - 1/L_A)\right]\right\} + (\alpha/L_A)}{(1 - \alpha) + (\alpha/L_A)} \qquad (26)$$

where:

- α: fraction of the total downlink noise in clear-sky which is due to interference
- L_R: attenuation due to rain
- T_0: mean absorption temperature (274.8 K)
- T_B: background temperature (2.76 K for the sky)
- T_{sys}: downlink thermal noise temperature
- L_A: loss due to atmospheric absorption (1.07, which corresponds to 0.3 dB).

In order to be above a certain threshold $(C/N)_{thr}$ during 99.9% of the time, the link is designed with a margin X_{max} – difference between $(C/N)_{cs}$, and $(C/N)_{thr}$ – such that $p(x > X_{max}) = 0.09\%$ (the remaining 0.01% will account for the effects of interference).

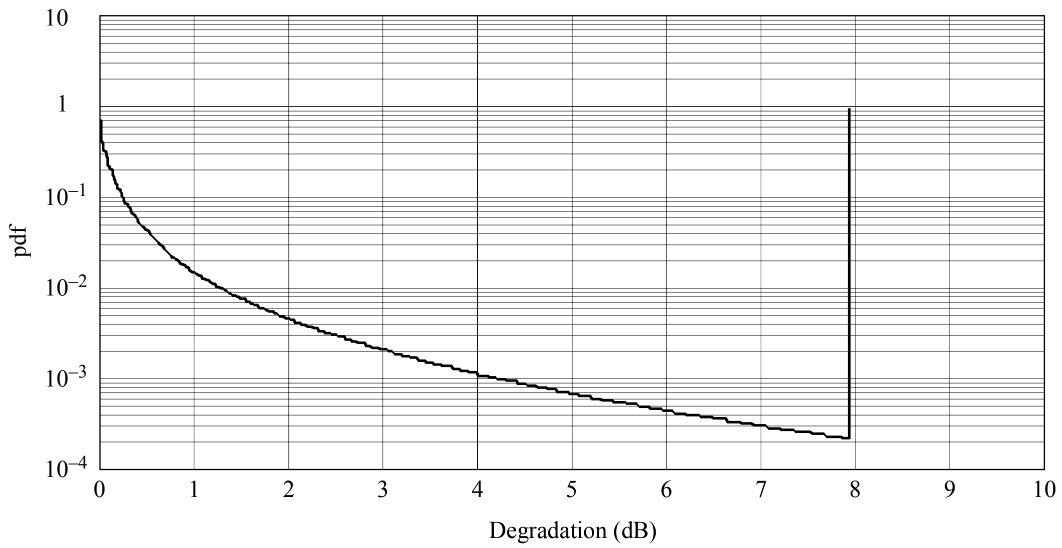
Assuming an earth-station located in New York City (latitude 41° N; longitude 74° W), receiving at 19 GHz with an elevation angle of 42.43°, $\alpha = 0.2$ and $T_{sys} = 323.6$ K; it turns out that $X_{max} = 7.923$ dB and therefore:

$$(C/N)_{cs} - (C/N)_{thr} = 7.923 \qquad (27)$$

The corresponding pdf $p_x(X)$ of the degradation x due to fading is given in Fig. 6. This pdf has been clipped at $X = X_{max} = 7.923$.

FIGURE 6

pdf of degradation, *x*, due to rain fading (for GSO receiver)



$X = 7.923$ for $P(x > X) = 0.09\%$

1323-06

It has been verified that in some representative situations, $p_y(Y)$ can be appropriately modelled by the function shown in Fig. 7.

At this point, we consider separately the use of Methodology A for the derivation of an interference mask and for the verification of whether the requirements in *recommends* 3 are met in a specific case.

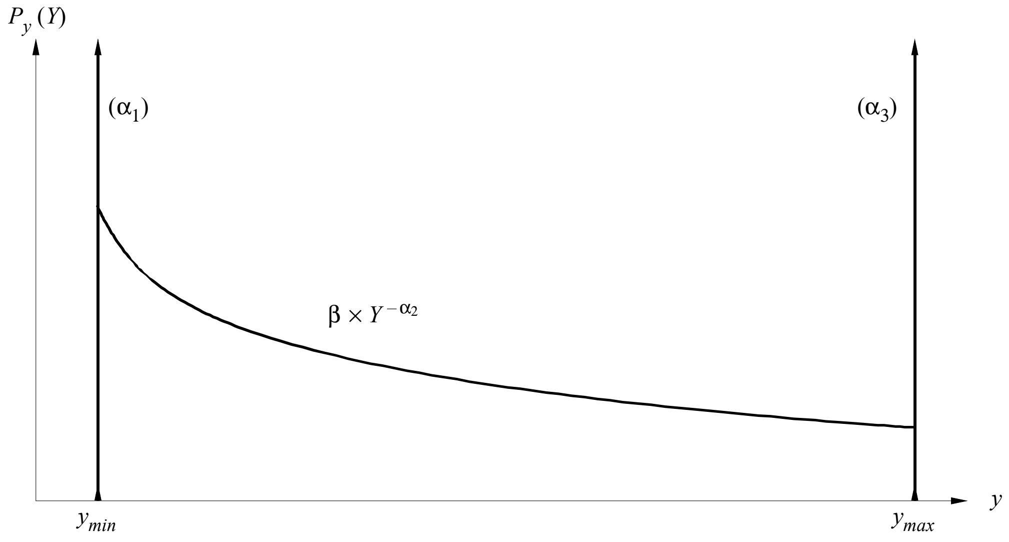
6.1 Derivation of interference mask

The derivation of a probability mask would require convolving the pdfs in Figs. 6 and 7 and ensuring that the resulting pdf $p_z(Z)$ is such that the condition in equation (11) of the description of Methodology A is met. In this example this condition becomes:

$$P(z > 7.923) \leq 0.1\% \qquad (28)$$

FIGURE 7

Parametric model for the degradation, *y*, due to interference expressed in dB



Of course, given the clear difficulties involved in analytically convolving $p_x(X)$ and $p_y(Y)$, $P(z > 7.923)$ cannot be analytically expressed as a function of the parameters α_1, α_2, α_3 (note that the parameter β in Fig. 7 is a function of α_1, α_2, α_3). Instead, the convolution has to be performed for several choices of α_1, α_2, α_3, so that sets of possible values of these parameters can be determined (when performing these convolutions y_{min} was made very small, 0.04, and y_{max} was made equal to 7.923). These possible values are those for which the inequality in equation (28) is satisfied. A sample of possible choices for α_1, α_2, α_3, is given in Table 1.

TABLE 1

Sets of values of α_1, α_2, α_3 that would meet inequality $P(z > 7.923) \leq 0.1\%$

α_1	α_2	α_3	$P(z > 7.923)$
0.25	2.5	0.00007	0.000998
	2.0	0.00002	0.000999
0.50	2.5	0.00007	0.000992
	2.0	0.00004	0.000962
0.75	2.5	0.00008	0.000996
	2.0	0.00006	0.000993
0.90	2.5	0.00008	0.000992
	2.0	0.00008	0.000999
	1.5	0.00004	0.000994
0.95	2.5	0.00008	0.000991
	2.0	0.00008	0.000994
	1.5	0.00006	0.000992
	1.0	0	0.000995

As expected, it follows from Table 1 that α_1 and α_3 by themselves do not ensure that inequality in equation (28) is met. The higher the value of α_2, the more flexible is the choice of α_1 and α_3. Therefore, conditions to be impose on $p_y(Y)$ should include some intermediate point of the distribution, according to the required value for α_2. Of course, the larger the value of α_2, the higher the probability of the occurrence of lower degradation due to interference. For example, from the set of values $\alpha_1 = 0.90$; $\alpha_2 = 1.5$ and $\alpha_3 = 0.00004$, conditions to be imposed on the interference I could be expressed as:

$$P(I \geq 0.01 N_T) \leq 10\%$$

$$P(I \geq 0.1 N_T) \leq 2.69\%$$

$$P(I \geq 5.2 N_T) \leq 0.004\%$$

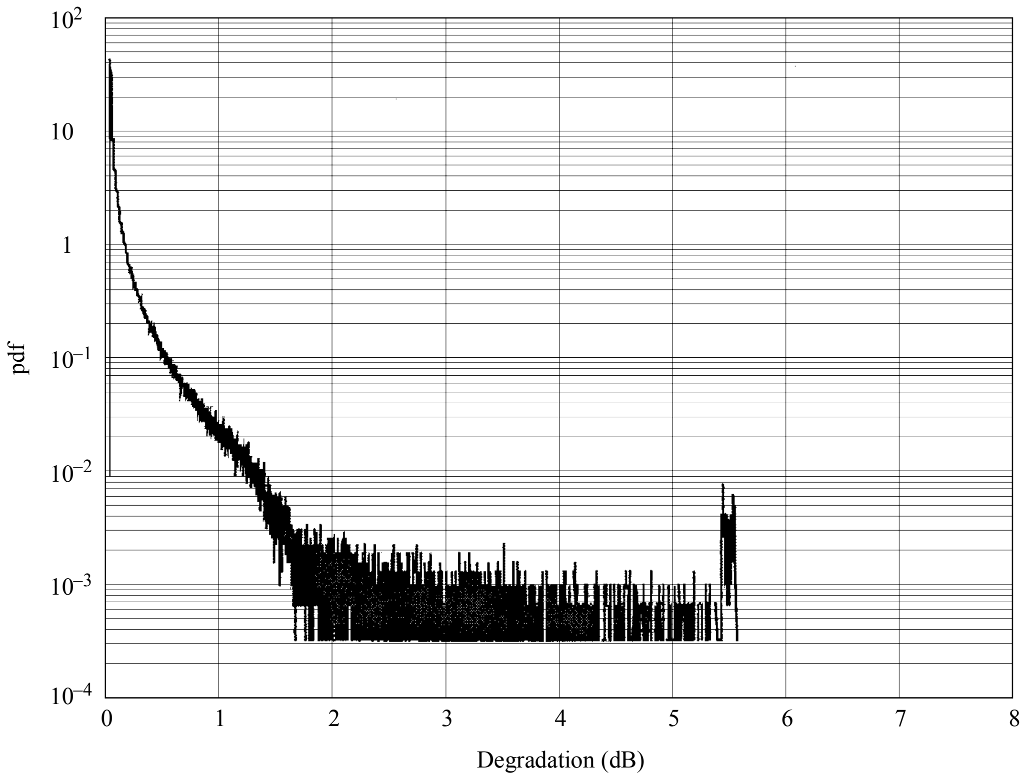
6.2 Verification of whether the requirements in *recommends* 3 are met

If we are dealing with a specific situation, and a pdf $p_y(Y)$ of the degradation y due to interference is made available, the verification of whether the requirements in *recommends* 3 are met is straightforward. The pdfs $p_x(X)$ and $p_y(Y)$ have to be convolved, generating a pdf $p_z(Z)$ associated with the total degradation z. Knowledge of $p_z(Z)$ allows us to compute the left-hand side of equation (28) and check therefore whether the inequality is met.

As an illustration, a pdf $p_y(Y)$, obtained by simulation and corresponding to the degradation due to interference from a non-GSO constellation into the GSO downlink considered in this example, is shown in Fig. 8.

FIGURE 8

pdf of degradation due to interference, *y*, obtained by simulation (for non-GSO/GSO)

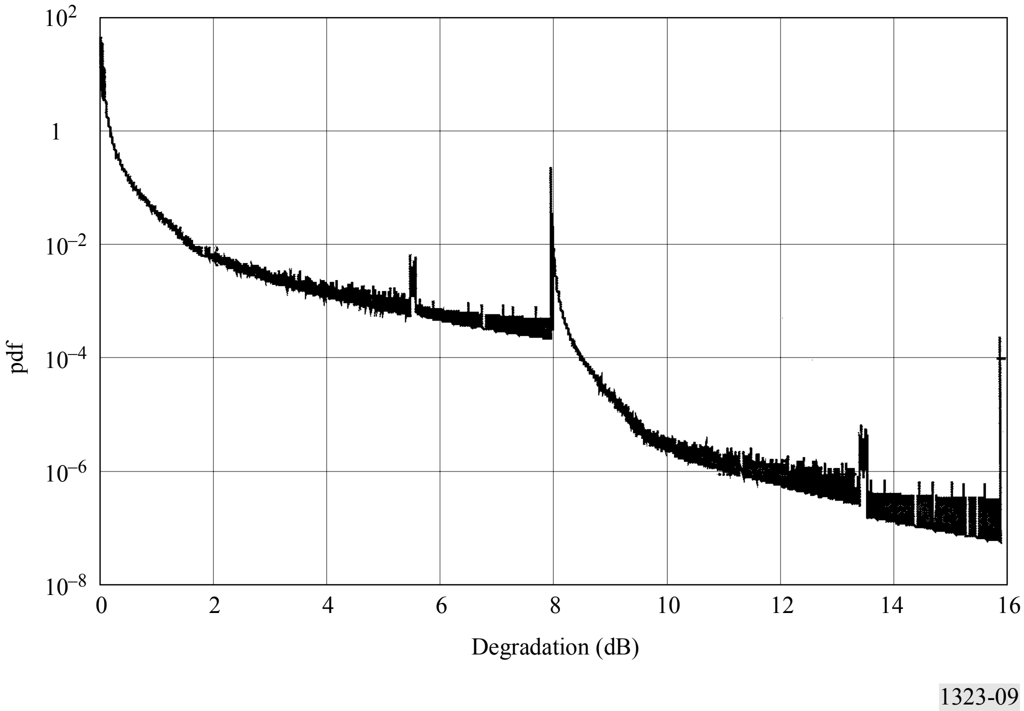


1323-08

By convolving the functions in Figs. 6 and 8, the pdf $p_z(Z)$, shown in Fig. 9, is obtained.

FIGURE 9

pdf of the total degradation, *z*, obtained by convolving the pdfs in Figs. 6 and 8 (for non-GSO/GSO)



$P(z > 7.923) = 0.12035\%$

From the pdf in Fig. 9, it can be computed that:

$$P(z > 7.293) = 0.12035\%$$

which means that the requirements of *recommends* 3, as expressed in equation (28) above, are not met.

PART 2

Methodology A'

1 Introduction

Methodology A' is a simplification of Methodology A, in which specific parametric representations are chosen for the pdfs of rain fading and interference, in order to establish the joint probability of fading and interference and to ensure that the joint cumulative probability meets the specified link performance criteria, which is characterized by a set of degradations in C/N and the corresponding fractions of time $p_i^{C/N}$ for which the degradations may be exceeded. The degradation in system performance due to rain fading is characterized by the pdf $p_x(x)$ that the degradation due to fading will be between x and $x + \delta x$ dB, and the degradation due to interference is similarly characterized by the pdf $p_y(y)$ that the degradation due to interference will be between y and $y + \delta y$ dB. The overall performance objectives of the link will be achieved provided the joint cumulative probability distribution of both fading and interference does not exceed the specified *C*/*N* degradation objectives. The probability that a degradation z exceeds a value z_i, $P(z \geq z_i)$, must be less that the specified performance criteria, $p_i^{C/N}$, i.e.:

$$P(z \geq z_i) = \int_{z_i}^{\infty} p_z(z) \mathrm{d}z \leq p_i^{C/N} \tag{29}$$

with:

$$p_z(z) = p_x(x) * p_y(y) \tag{30}$$

where * represents the convolution of the two probabilities. The convolution is expressed mathematically by:

$$p_z(z) = \int_{-\infty}^{\infty} p_x(w) \cdot p_y(z - w) \mathrm{d}w \tag{31}$$

Since the pdf of fading, $p_x(x)$, and several points on the curve of the probability distribution that the *C*/*N* performance must be achieved, which depends on $p_z(z)$, are predetermined, the levels of interference which can be allowed for various percentages of time, while still maintaining the link performance objectives, can be determined by finding a curve for the probability density $p_y(y)$ which satisfies the above equation. In practice, the maximum allowable interference levels are specified when this equation is expressed as an equality. In essence, the problem reduces to finding a set of interference levels, y_j, which are not exceeded for P_y (= 100 p_y) per cent of the year, which satisfy this equation.

Methodology A' provides a first-order solution to equation (29) in which the pdfs are parameterized by two points, corresponding to:

– the percentage of time when a given level of rain fading or interference is exceeded

– the percentage of time beyond which there is little or no likelihood of rain fading or interference,

together with the linear slope of the distribution between these two points. This single-rectangle model yields an analytical solution to the integral in equation (29), which can readily be implemented in a spreadsheet.

2 Proposed procedure

The application of the following procedure will differ according to the nature of the satellite transponder. For a transparent transponder it is usual to refer the interference limits to the output terminals of the receiving earth-station antenna. In this case, since fading and interference on both uplinks and downlinks will degrade the wanted carrier, and for multi-carrier transponders the reductions in carrier level due to uplink fades will result in equal reductions in the downlink carrier level, strictly speaking it would be necessary to convolve both the uplink and downlink propagation statistics to determine the distribution $p_x(x)$. However, if no uplink power control is applied, the uplink fades may tend to dominate the short-term propagation statistics because rain attenuation for a given percentage of time is much greater at the higher uplink frequency than at the lower downlink frequency. Hence, for the present purposes, the simplification of using the predicted rain-attenuation statistics for the uplink frequency may be made. For carriers which are subject to up-path power control, further study is needed, but in the interim, estimates of the right order of magnitude may be obtained in this case by assuming that the net uplink fades are no more severe than the downlink fades, and thus using the predicted rain attenuation for the downlink frequency. There may be cases, however, even with power control, where the uplink fades dominate.

In the case of a re-modulating transponder, since the uplink *C*/*N* and *C*/*I* ratios are decoupled from the downlink *C*/*N* and *C*/*I* ratios, the interference criteria can be derived separately for the two segments of the connection, allocating the full short-term degradation to fading plus interference on each path.

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

2.1 *Step 1*: characterization of permitted degradation in *C*/*N*

First, determine the values z_j of the total degradation z, as defined in Methodology A, equation (32), which can be exceeded by no more than p_j% of the year:

$$z_j = \left(\frac{C}{N}\right)_{cs} - \left(\frac{C}{N}\right)_j \qquad j = 1, ..., J \tag{32}$$

According to *recommends* 3.1, the interference should be responsible for at most 10% of the time allowance associated with the degradation values. Therefore, the degradation due to fading is allowed no more than 90% of the total degradation time. The probability of excessive degradation due to fading can be expressed as:

$$P_x(x \geq z_j) = \int_{z_j}^{\infty} p_x(x) \mathrm{d}x \leq 0.9 p_j \tag{33}$$

2.2 *Step 2*: characterization of degradation due to fading and other short-term variations in link characteristics

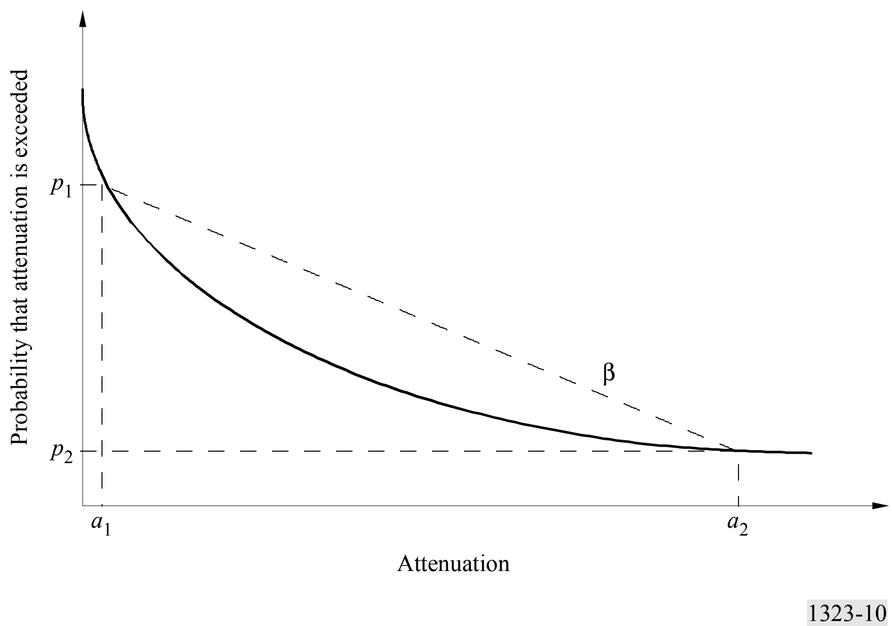
This section currently addresses only degradations due to rain fading. The inclusion of the effects of other time variations in the characteristics of the link requires further study.

For each interfered network, a parametric representation is chosen for the pdf corresponding to the degradation in link performance due to rain fading, $p_x(x)$. In order to facilitate the calculations, it is necessary to simplify the form of these pdfs, reducing them to a set of rain attenuations A_p which can be exceeded for no more than $p_x(x)$ percentage of time.

The parametric representation chosen for present purposes is to simplify the pdf to a set of gradients and an end-point, with the condition that the integral of this function be unity. The fading due to rain attenuation can be represented by the following cumulative distribution function in Fig. 10.

FIGURE 10

Representative cumulative distribution of rain attenuations



This distribution curve can be divided into a single segment which is characterized by the gradient (or slope) of the line between two points, i.e., the gradient $\beta = (p_2 - p_1)/(a_2 - a_1)$ while the upper bound can be established by the probability that the attenuation exceeds a_1 dB, $p = p_1$. The lower bound is then constrained by the requirement that the total probability, i.e., the integral of the pdf, is unity. The purpose of this parametric representation is to transform the probability distributions of the factors affecting the link performance, i.e., the fading, the interference and the link performance requirements themselves, into pdfs in the form of a single rectangle plus two point probabilities, which can be readily convolved in order to derive the allowable distribution of interference levels.

The cumulative distribution of fading due to rainfall attenuation, can be found from the procedure in Recommendation ITU-R P.618, using the rain attenuation coefficients in Recommendation ITU-R P.838. The cumulative distribution is obtained from the basic input parameter, $R_{0.01}$, which is the rainfall rate for the earth station location for 0.01% of an average year. This parameter may be obtained from locally-measured meteorological data, or, in the absence of local data, of Recommendation ITU-R P.837 for the appropriate rain zone. Recommendation ITU-R P.618 then yields the rain attenuations $A_{0.01}$ which will be exceeded for 0.01% of the year, and the cumulative distribution of rain attenuations between 0.001 and 1% of the year, A_p, are obtained at different time percentages p from:

$$\frac{A_p}{A_{0.01}} = 0.12\, p^{-(0.546 \; + \; 0.043 \log p)} \tag{34}$$

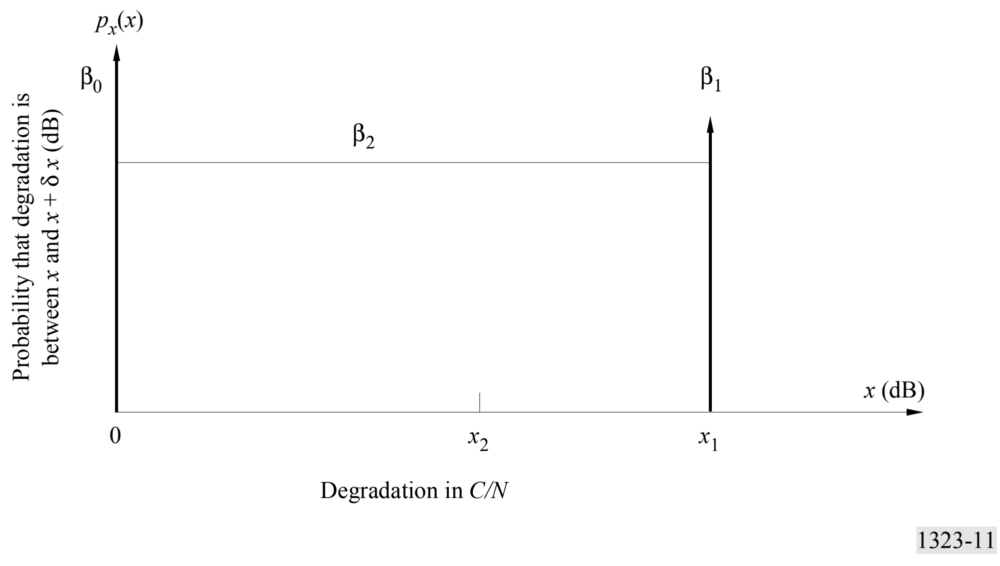
while the percentage of time for which an attenuation will be exceeded can be determined from the inverted form of Equation (34).

$$p_A = 10^{11.628\left(-0.546 \; + \; \sqrt{0.298 \; + \; 0.172 \log\left(0.12 \frac{A_{0.01}}{A_p}\right)}\right)} \tag{35}$$

In the single-rectangle model, rain fading is parameterized by two points on the curve, corresponding to the percentage of time when a given level of attenuation is exceeded, the percentage of time beyond which there is little or no likelihood of rain, and the linear slope of the distribution between these two points. The cumulative distribution is thus approximated to a trapezoid, as shown in Fig. 10, and the probability density function to a single rectangle plus two point values, as shown in Fig. 11.

FIGURE 11

Single-rectangle parameterization of fading pdf



2.2.1 Determination of β_i

β_1 represents the probability that the degradation in *C/N* ratio, x_1 dB, will be exceeded. This degradation can be determined from the $(C/N)_{cs}$ and the $(C/N)_i$ ratios required to achieve a given level of performance at p_i% of time. The permitted degradations are thus given by:

$$x_i = \left(\frac{C}{N}\right)_{cs} - \left(\frac{C}{N}\right)_i \qquad x_1 > x_2 \tag{36}$$

For a re-modulating satellite system, the maximum permitted degradation x_1 can be associated with the fade level on the uplink and separately on the downlink, determined by the rain attenuations.

The fraction of time β_1 for which the maximum degradation must not be exceeded can then be determined from equation (35), i.e., $\beta_1 = p_A$ at a fade of $A_p \equiv x_1$. Note that this fraction of time must comply with the requirement in *recommends* 3.1, that the degradations due to fading account for no more than 90% of the time allowances associated with each BER or *C/N* objective.

For a transparent satellite transponder, a fraction of the total system noise in the earth station receiver will arise from the uplink, and this noise will be reduced by the downlink fade. To take account of this, additional parameters for the system are required, and a procedure for calculating the resultant fade to use in equation (35) is given in Annex 3.

The parameter β_2 represents the slope of the cumulative distribution of attenuation between the point at which β_1 is determined (i.e. at a degradation of x_1 dB), and another point on the distribution where the degradation $x \approx 0$ dB. This point is the lower bound of the distribution and is essentially the fraction of time for which there is no attenuation due to rain. It can be identified with the fraction of time for which rain occurs (i.e. the raining time). Typically, this fraction p_0 will be between 1% and 3% of the time. This number must satisfy certain conditions for use in this methodology (see below). The parameter β_2 can then be determined from:

$$\beta_2 = \frac{p_0 - \beta_1}{x_1} \tag{37}$$

From the requirements of *recommends* 3.1, the time percentage for fading larger than x_2 dB should be no more than 90% of p_2. Therefore:

$$\beta_1 + (x_1 - x_2)\beta_2 \leq 0.9 p_2 \tag{38}$$

From equations (37) and (38), p_0 must satisfy:

$$p_0 \leq \frac{0.9\, p_2\, x_1 - \beta_1\, x_2}{x_1 - x_2} \tag{39}$$

Since the integral of the pdf must equal unity, β_0 can readily be determined from:

$$\beta_0 = 1 - x_1 \beta_2 - \beta_1 \tag{40}$$

The parameters β_0, β_1 and β_2 are thus determined from the details of the fading due to rain, together with the maximum permitted degradation in *C/N*.

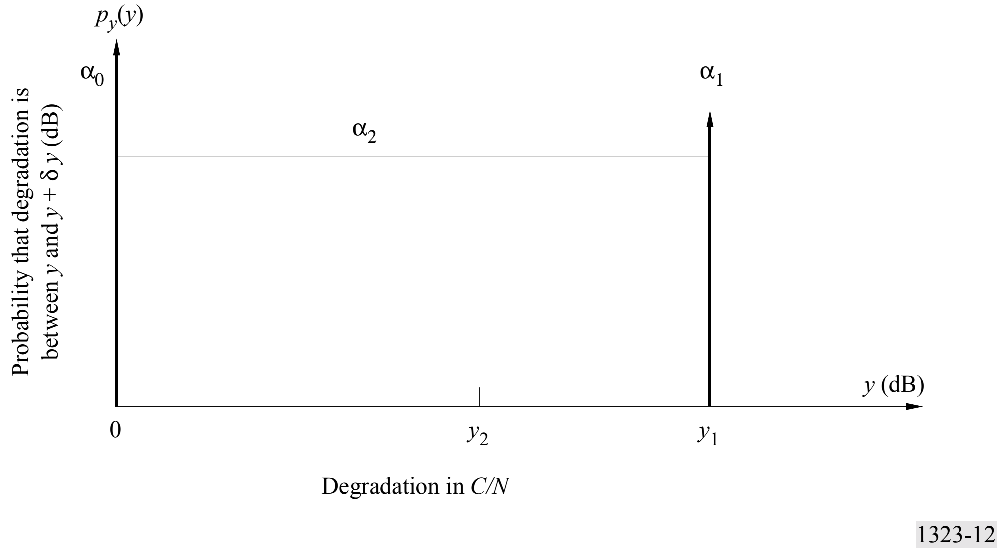
2.3 *Step 3*: characterization of the permitted interference

In theory, there are an infinite number of pdfs $p_y(y)$ which would satisfy equation (30), but for convenience the degradation due to interference is parameterized here in an analogous way to that due to fading, as shown in Fig. 12, with the condition that:

$$\alpha_0 + y_1 \alpha_2 + \alpha_1 = 1 \tag{41}$$

FIGURE 12

Single-rectangle parameterization of interference pdf



2.4 *Step 4*: Convolution of pdfs

The total degradation z can then be represented in parametric form as the convolution of the pdf of the performance criteria, including the characteristics of fading, $p_x(x)$, and the pdf of the interference, $p_y(y)$:

$$p_z(z) = p_x(x) * p_y(y) \tag{42}$$

where $p_x(x)$ is the pdf for rain fading, and $p_y(y)$ is the pdf for the interference.

The two rectangular pdfs are readily convolved with each other to yield the pdf shown in Fig. 13, i.e. a triangle, two rectangles and three point values.

Now, from the input data, and equation (36), the maximum permitted degradations at fractions of time $p_i(p_1 < p_2)$ are:

$$z_i = \left(\frac{C}{N}\right)_{cs} - \left(\frac{C}{N}\right)_i \qquad z_1 > z_2 \tag{43}$$

The degradation z_1 cannot be exceeded for a fraction of time of more than p_1, thus:

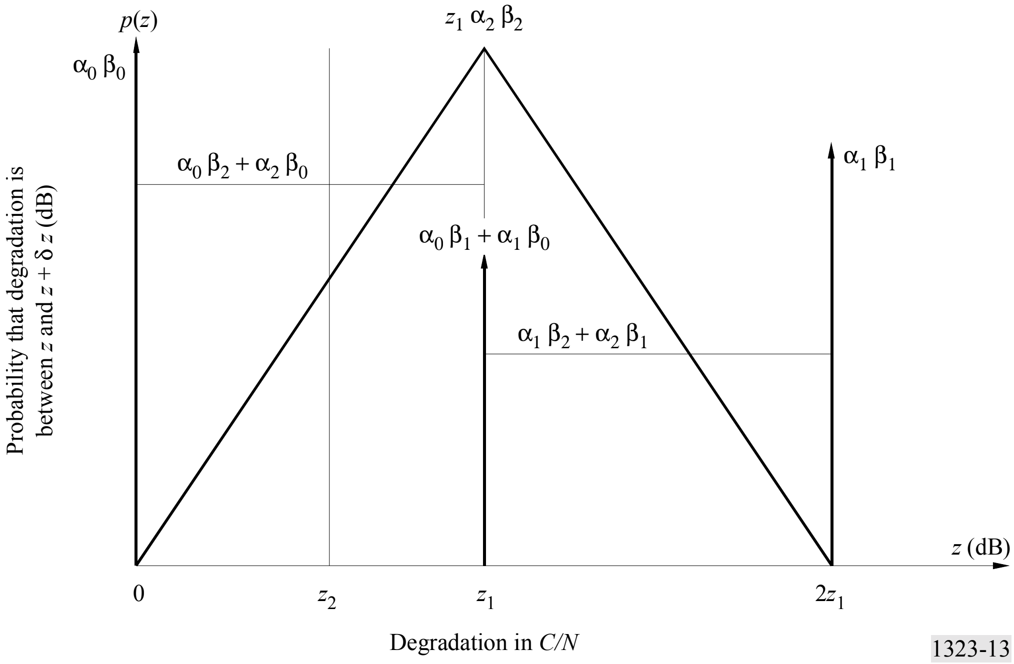
$$P_z\ (z \geq z_1) \leq p_1 \tag{44}$$

Treating this equation as an equality (which, as noted in the Introduction, will lead to the maximum allowable interference levels), the probability $P_z(z \geq z_1)$ can be found from Fig. 13 by integration from $z = z_1$ to $z = \infty$:

$$\alpha_0 \beta_1 + \alpha_1 \beta_0 + \alpha_1 \beta_1 + z_1 \left(\alpha_1 \beta_2 + \alpha_2 \beta_1\right) + \frac{1}{2} z_1^2 \alpha_2 \beta_2 = p_1 \tag{45}$$

FIGURE 13

Convolved pdf for total degradation in *C/N*



Similarly, the degradation z_2 cannot be exceeded for a fraction of time of more than p_2, and, with the assumption of equality in equation (44), the probability that the degradation lies between z_2 and z_1 is given by:

$$P_z(z_1 \geq z \geq z_2) \leq p_2 - p_1 \tag{46}$$

This expression can be expressed as an equality with the introduction of an additional parameter F, thus:

$$P_z(z_1 \geq z \geq z_2) = F(p_2 - p_1) \tag{47}$$

where $F \leq 1$ is a fraction of the time allowance for the degradation $z_1 - z_2$.

This probability can similarly be obtained from Fig. 4, by integrating from $z = z_2$ to $z = z_1$:

$$(z_1 - z_2)\left[\alpha_0 \beta_2 + \alpha_2 \beta_0 + \frac{1}{2}(z_1 + z_2)\alpha_2 \beta_2\right] = F(p_2 - p_1) \tag{48}$$

NOTE 1 – The point value $(\alpha_0 \beta_1 + \alpha_1 \beta_0)$ cannot be included in the derivation of equation (48), since it has been included in the derivation of equation (45).

Now, from equation (41):

$$\alpha_0 = 1 - \alpha_1 - z_1 \alpha_2 \tag{49}$$

and equations (45) and (48) can be rewritten in the form:

$$\begin{aligned} a\alpha_1 + b\alpha_2 &= c \\ d\alpha_1 + e\alpha_2 &= f \end{aligned} \tag{50}$$

and solutions to these simultaneous equations can readily be found:

$$\alpha_1 = \frac{bf - ce}{bd - ae} \qquad \alpha_2 = \frac{cd - af}{bd - ae} \tag{51}$$

where the coefficients are given by:

$$\begin{aligned} a &= \beta_0 + z_1 \beta_2 \\ b &= \frac{1}{2} z_1^2 \beta_2 \\ c &= p_1 - \beta_1 \\ d &= (z_2 - z_1) \beta_2 \\ e &= \frac{1}{2} (z_1 - z_2) [2 \beta_0 - (z_1 - z_2) \beta_2] \\ f &= F (p_2 - p_1) - (z_1 - z_2) \beta_2 \end{aligned} \tag{52}$$

From equations (50) and (51), it can be found that positive values for α_1 can be obtained if the requirement in *recommends* 3.1 is satisfied, i.e. $\beta_1 \le 0.9 p_1$. Equations (37), (39), (50) and (51) further show that, for positive values of α_2, the value of p_0 must satisfy the following condition:

$$p_0 < \frac{(p_2 - p_1)(1 - \beta_1) z_1}{(z_1 - z_2)(1 - p_1)} + \beta_1 \tag{53}$$

This constraint must be combined with that defined in equation (39), i.e. the value of p_0 must satisfy both the constraints in equations (39) and (53). In most cases the constraint defined in equation (39) is more stringent than that of equation (53). When p_0 is chosen using equality in equation (39), 10% of the degraded time allowance is assigned to interference. If, on the other hand, the constraint defined in equation (53) is more stringent and the resulting value of p_0 is lower than the actual value found for the practical application, then the system has no tolerance to interference or the system objectives cannot be met even without interference. In this case the system parameters should be reviewed.

An alternative approach is to define a minimization problem which can be solved with linear programming techniques. The optimization problem becomes:

Minimize:

$$\alpha_0 = 1 - z_1 \alpha_2 - \alpha_1$$

with the following constraints:

$$\left.\begin{aligned} &\alpha_0 \beta_1 + \alpha_1 \beta_0 + \alpha_1 \beta_1 + z_1 (\alpha_1 \beta_2 + \alpha_2 \beta_1) + \frac{1}{2} z_1^2 \alpha_2 \beta_2 \le p_1 \\ &(z_1 - z_2) \left[\alpha_0 \beta_2 + \alpha_2 \beta_0 + \frac{1}{2} (z_1 + z_2) \alpha_2 \beta_2 \right] \le p_2 - p_1 \\ &\alpha_0 = 1 - z_1 \alpha_2 - \alpha_1 \\ &\alpha_k \ge 0, \qquad k = 0, 1, 2 \end{aligned}\right\} \tag{54}$$

If a third degradation z_3 (where $0 < z_3 < z_2 < z_1$) is specified, a constraint must be added to the minimization problem defined in equation (54). Given that the degradation z_3 cannot be exceeded for a fraction of time $> p_3$, the probability that the degradation lies between z_3 and z_2 is given by:

$$P_z (z_2 \ge z \ge z_3) \le p_3 - p_2 \tag{55}$$

This probability can be obtained from Fig. 4, by integrating from $z = z_3$ to $z = z_2$:

$$(z_2 - z_3)(\alpha_0 \beta_2 + \alpha_2 \beta_0 + \frac{1}{2}(z_2 + z_3) \alpha_2 \beta_2) \le p_3 - p_2 \tag{56}$$

This constraint, associated with the third degradation z_3, should be added to those in equation (54).

With the values for α_0, α_1 and α_2 thus determined, the permitted levels of interference can be deduced as follows.

2.5 *Step 5*: determination of the interference mask

From Fig. 3, the short-term interference producing a degradation of z_1 dB can be exceeded for no more than 100 α_1% of the time, and the short-term interference producing a degradation of z_2 dB can be exceeded for no more than 100 ($\alpha_1 + (z_1 - z_2)\alpha_2$)% of time. In addition, there must be no degradations due to short-term interference for 100 α_0% of time.

The degradations in *C*/*N*, z_i dB, can be related to the permitted interference as a fraction of the system noise:

$$\left(\frac{I}{N}\right)_i = 10^{z_i/10} - 1 \tag{57}$$

and the interference mask can be defined, for this case, in the following terms:

$$P\left(\frac{I}{N} \geq 10^{z_1/10}\right) \leq 100\,\alpha_1 \qquad \%$$

$$P\left(\frac{I}{N} \geq 10^{z_2/10}\right) \leq 100\left[\alpha_1 + (z_1 - z_2)\,\alpha_2\right] \qquad \% \tag{58}$$

$$P\left(\frac{I}{N} \geq 0\right) \leq 100\,(1 - \alpha_0) \qquad \%$$

This determination of the short-term interference allowances is based on there being two criteria to be met regarding the permitted degradation in *C*/*N*s, z_1 and z_2. If a further degradation $z_3 < z_2$ ($< z_1$) is specified, then since the integrated probability distribution function must equal unity, the probability that this third degradation would be exceeded can be determined by integrating the pdf from zero to z_3 (see Fig. 4), i.e.,

$$P\left(\frac{I}{N} \geq 10^{z_3/10}\right) \leq 100\left[1 - \left(\alpha_0\,\beta_0 + z_3(\alpha_0\,\beta_2 + \alpha_2\,\beta_0) + \frac{z_3^2}{2}\alpha_2\,\beta_2\right)\right] \quad \% \tag{59}$$

2.6 *Step 6*: multiple interfering networks

If there is more than one interfering network, then the time percentages for which each network can be allowed to exceed the permitted levels of interference can be assessed, to a first approximation, by dividing the time percentages obtained from equations (58), and (59) where applicable, by the number of interfering networks.

3 Possible refinement to Methodology A'

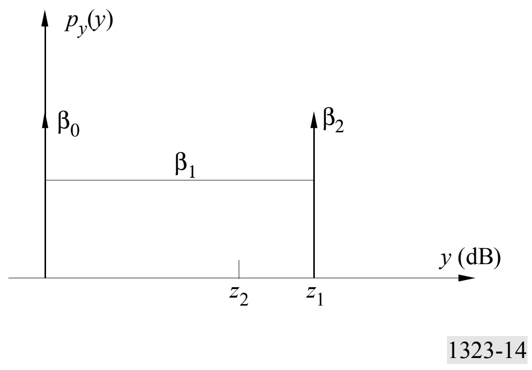
Methodology A' can be further refined by modelling the fading pdf as follows:

$$p_x(x) = p_0\,\delta(x) + 0.01\begin{cases}\exp(a_2 + b_2 x) & \text{for } x < z_3\\ \exp(a_1 + b_1 x) & \text{for } x \geq z_3\end{cases} \tag{60}$$

It is also assumed that the interference pdf can still be represented as shown in Fig. 14.

FIGURE 14

pdf of degradation due to interference



The following formula is obtained for $p_z(z)$:

$$p_z(z)=\begin{cases} \beta_0\ p_0\ \delta(z) & \text{for } z=0 \\ \beta_1\ p_0+0.01\,\beta_0\ \exp(a_2+b_2 z)+\dfrac{0.01}{b_2}\beta_1\ \exp(a_2)\ \left(\exp(b_2\ z)-1\right) & \text{for } 0<z<z_1 \\ \left[\beta_2\ p_0+0.01\,\beta_0\ \exp(a_2+b_2\ z_1)+\dfrac{0.01}{b_2}\beta_1\ \exp(a_2)\ \left(\exp\ (b_2\ z)-1\right)\right]\delta\ (z-z_1) & \text{for } z=z_1 \\ 0.01\,\beta_2\ \exp\left[a_2+b_2(z-z_1)\right] & \\ \quad +\dfrac{0.01}{b_2}\beta_1\ \exp(a_2)\ \left[\exp(b_2\ z)-\exp\left(b_2\ (z-z_1)\right)\right] & \\ \quad +0.01\,\beta_0\ \exp(a_2+b_2\ z) & \text{for } z_1<z\le z_3 \\ 0.01\,\beta_0\ \exp(a_1+b_1\ z)+0.01\,\beta_2\ \exp\left[a_2+b_2\ (z-z_1)\right] & \\ \quad +\dfrac{0.01}{b_1}\beta_1\ \exp(a_1)\ \left[\exp(b_1\ z)-\exp(b_1\ z_3)\right] & \\ \quad +\dfrac{0.01}{b_2}\beta_1\ \exp(a_2)\ \left[\exp\ (b_2\ z_3)-\exp\left(b_2\ (z-z_1)\right)\right] & \text{for } z_3<z<z_1+z_3 \\ 0.01\,\beta_0\ \exp(a_1+b_1\ z)\ +0.01\,\beta_2\ \exp\left[a_1+b_1\ (z-z_1)\right] & \\ \quad +\dfrac{0.01}{b_1}\beta_1\ \exp(a_1)\ \left[\exp(b_1\ z)-\exp\left(b_1\ (z-z_1)\right)\right] & \text{for } z\ge z_1+z_3 \end{cases} \tag{61}$$

The values of a_1, b_1, a_2 and b_2 are obtained by using the minimum mean square error method. By satisfying the conditions on $p_z(z)$, the values of β_0, β_1 and β_2 are obtained.

These conditions are:

$$p(z\ \ge\ z_1)\ \le\ p_1$$

$$p(z_2\ \le\ z\ <\ z_1)\ \le\ p_2\ -\ p_1$$

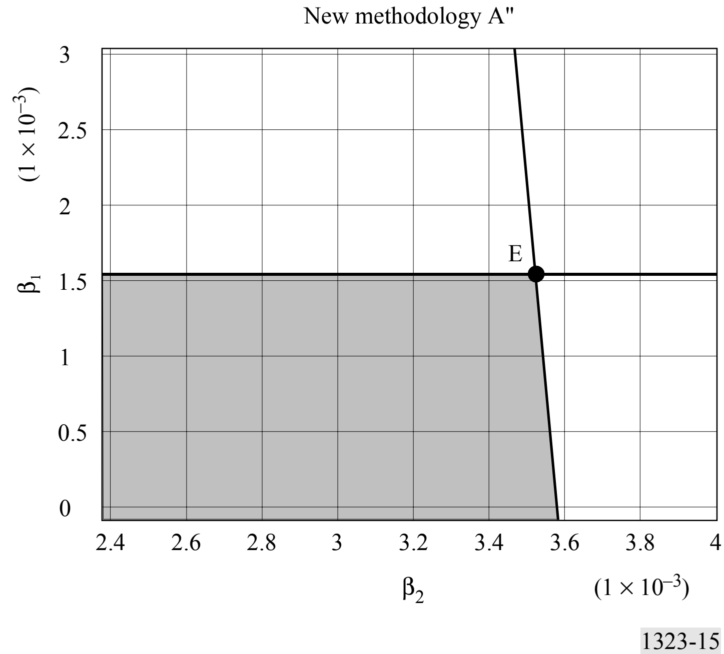
and

$$\int_{-\infty}^{+\infty} p_y(y)\ \mathrm{d}y\ =\ 1 \qquad\qquad \beta_0\ =\ 1\ -\ z_1\beta_1\ -\ \beta_2$$

Figure 15 shows the range of answers for β_1 and β_2. By choosing point E in the figure, the values of β_1 and β_2 are obtained. The point E is chosen in such a way that the value of β_0 is minimized. With the determination of the values of these parameters, the pdf of the degradation due to interference is completely specified.

FIGURE 15

Solutions for β1 and β2 ($A_{0.01}$ = 12.5 dB)



PART 3

Methodology B

In Methodology B, interference effects are considered separately from fading, and performance objectives are summarized by a single short-term 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 (associated with *recommends* 3.1, but see also *recommends* 3.2), Methodology B deems it appropriate to apportion (1/*n*) of the short-term interference time allowance and (1/*n*) of the long-term interfering signal power 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) and GSO/FSS systems 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

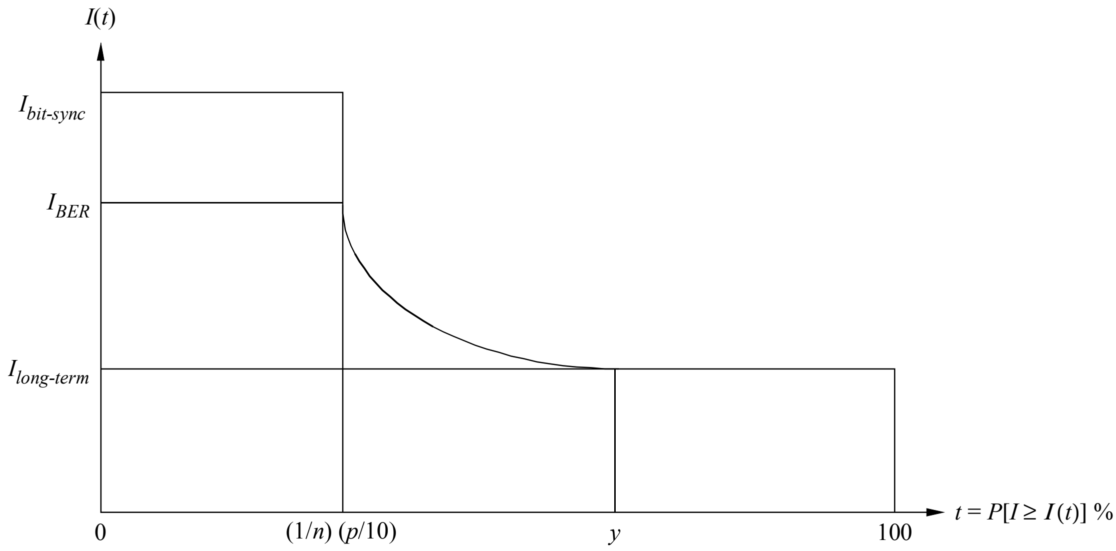
Assumption 1: When the system design relies heavily on power control, it is considered that the joint occurrence of interference and fading not fully compensated by power control, is not statistically significant. Therefore, the interference allowances can be determined by assuming that aggregate interference by itself (no simultaneous fading degradation) can use 10% of the time allowances referred to in *recommends* 3.1. Additionally to satisfy the requirement in *recommends* 3.2 that interference should not lead to loss of synchronization in the desired network more than once per *x* days, interfering signal power should be maintained below a level that would lead to a *C*/*N* value which is z_S dB lower than that required to meet the threshold BER.

Assumption 2a (short-term interference): 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. 16. Consider the interference into LEO A from a GSO network like GSO 13. This GSO employs adaptive power control on the uplink and operates from relatively small earth stations (66 cm antenna). 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. 16, 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.

FIGURE 16

Representation of single-entry interference mask



It should be noted that the actual n would most likely not be equal to the above maximum value. 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 2b (long-term interference): If there are n systems sharing the same spectrum with the desired system that can potentially cause interference, for large percentage of time, the aggregate interference level adds in power. Hence it is appropriate to allocate each system $1/n$ of the aggregate power allowance for long-term interference which is x% of the total system noise power under clear-sky conditions. This value should not be exceeded for more than y% of the time (see Note 1).

NOTE 1 – Values for x% and y% are yet to be determined, values suggested were: ($x = 2$, $y = 4$), ($x = 6$, $y = 10$) and ($x = 6$, $y = 90$).

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:

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

where:

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

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 GSO 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:

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

Step 2: compute interference allowance resulting from threshold BER requirement. From Assumptions 1 and 2:

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

or from equations (62) and (63):

$$P\left[I \geq (10\text{^}(z_t/10) - 1)\,N_T\right] \leq (1/n)\,(p/10) \qquad \% \tag{66}$$

Step 3: compute interference allowance resulting from the synchronization requirement. From z_t compute:

$$z_{bit\text{-}sync} = z_t + z_s \qquad \text{dB} \tag{67}$$

$$P(y_{SE} \geq z_{bit\text{-}sync}) = 0 \qquad \% \tag{68}$$

or

$$P\left[I \geq \left(10\text{^}(z_{bit\text{-}sync}/10) - 1\right)N_T\right] = 0 \qquad \% \tag{69}$$

Step 4: compute interference allowance resulting from the long-term requirement:

$$P\left[y_{SE} \geq 10 \log\left(1 + x/(100\,n)\right)\right] \leq y \qquad \% \tag{70}$$

or

$$P\left[I \geq \left(x/(100\,n)\right)N_T\right] \leq y \qquad \% \tag{71}$$

Step 5: the single entry permissible level of interference mask is therefore (see Fig. 16):

$$I(t) = \begin{cases} I_{bit\text{-}sync} & 0 \leq t < (1/n)\,(p/10) \\ I_{BER} - (I_{BER} - I_{long\text{-}term})\dfrac{\log(t) - \log\left((1/n)\,(p/10)\right)}{\log(y) - \log\left((1/n)\,(p/10)\right)} & (1/n)\,(p/10) \leq t < y \\ I_{long\text{-}term} & y \leq t < 100 \end{cases} \tag{72}$$

where:

$I(t)$ (dBW)

t : time percentage

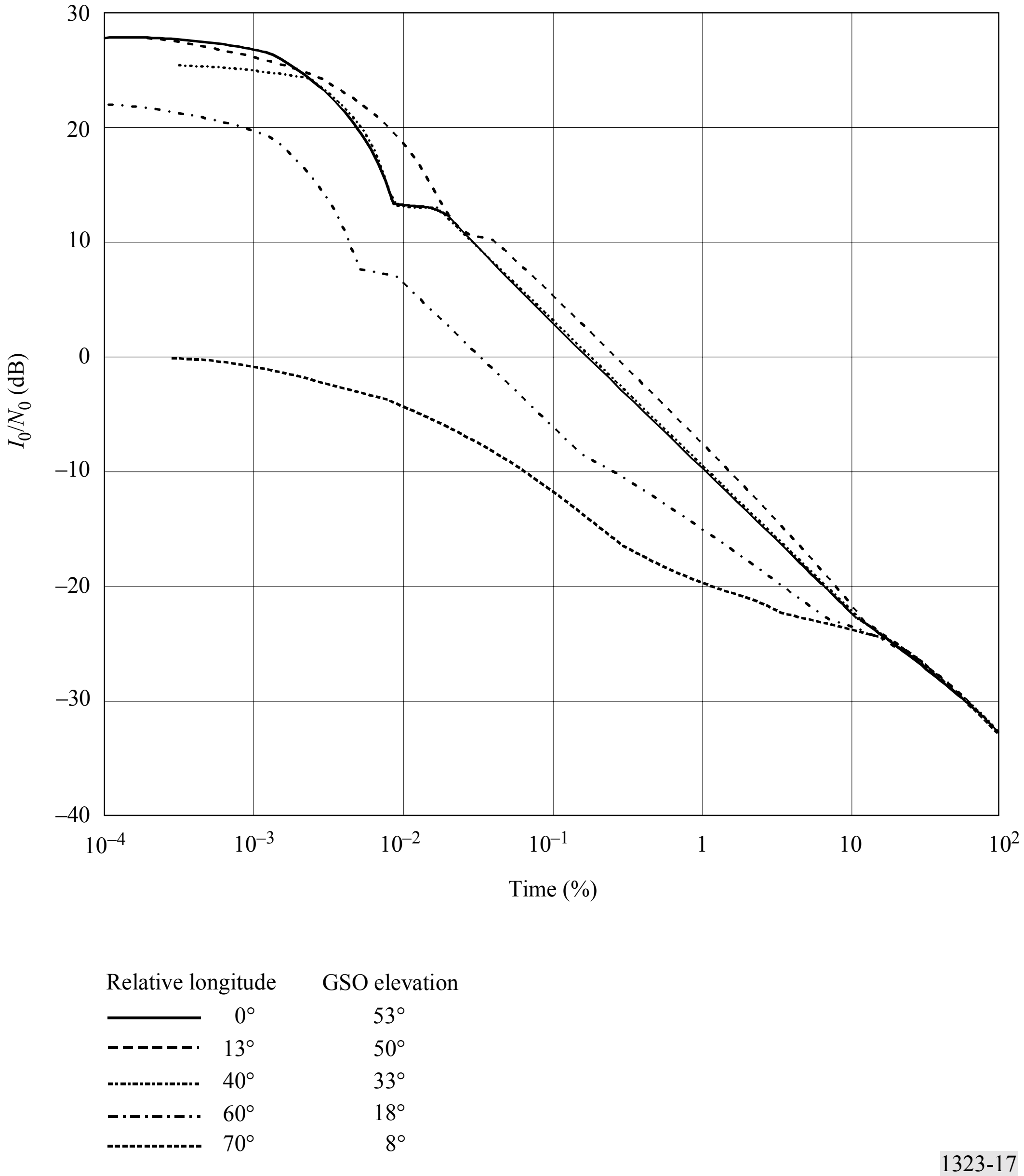
$$I_{bit\text{-}sync} = 10 \log \left[\left(10\char`\^ \left((z_t + z_s) / 10 \right) - 1 \right) N_T \right] \tag{73}$$

$$I_{BER} = 10 \log \left[\left(10\char`\^ (z_t / 10) - 1 \right) N_T \right] \tag{74}$$

$$I_{long\text{-}term} = 10 \log \left[\left(x / (100\, n) \right) N_T \right] \tag{75}$$

FIGURE 17

Uplink interference from GSO 13 to LEO A



4 Example 1 of Methodology B: (LEO A)

LEO A characteristics are given in Recommendation ITU-R S.1328. In this example permissible interference allowances are computed for hypothetical GSO uplinks in the 30 GHz band. Input data for the purpose of computing interference allowances are:

a) $BER_t = 1 \times 10^{-5}$ with a $C/N = 6.4$ dB for both the uplink and downlink.

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

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

c) As a result, the single entry interference allowance becomes (assuming that $z_s = 2$ dB):

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

$$P[I/N_T \ge 3.5\text{ dB}] = 0 \qquad \%$$

$$P[I/N_T \ge 0.2\text{ dB}] \le (1/n)\,0.01 \qquad \%$$

$$P[I/N_T \ge 10\log(x/(100\,n))\,\text{dB}] \le y \qquad \%$$

and

$$I(t)/N_T = \begin{cases} 3.5 & 0 \le t < (1/n)\,0.01 \\ 0.2 - \left[(0.2 - 10\log(x/(100\,n)))\right]\dfrac{\log(t) - \log((1/n)\,0.01)}{\log(y) - \log((1/n)\,0.01)} & (1/n)\,0.01 \le t < y \\ 10\log\left[x/(100\,n)\right] & y \le t < 100 \end{cases}$$

d) n is to be determined. Figure 18 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 less than the aggregate interference allowance ($I/N = 0.2$ dB not to be exceeded for more than 0.01% of the time).

5 Example 2 of Methodology B: (LEO B)

LEO B characteristics are given in Recommendation ITU-R S.1328. Input data for the purpose of computing interference allowances are:

a) $p = 0.1\%$

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

c) n is to be determined. As a result, the single-entry interference allowance becomes:

$$P\left[I/N_T \ge 3.3\,\text{dB}\right] = 0 \qquad \%$$
$$P\left[I/N_T \ge 0.0\,\text{dB}\right] \le (1/n)\,0.01 \qquad \%$$
$$P\left[I/N_T \ge 10\log(x/(100\,n))\,\text{dB}\right] \le y \qquad \%$$

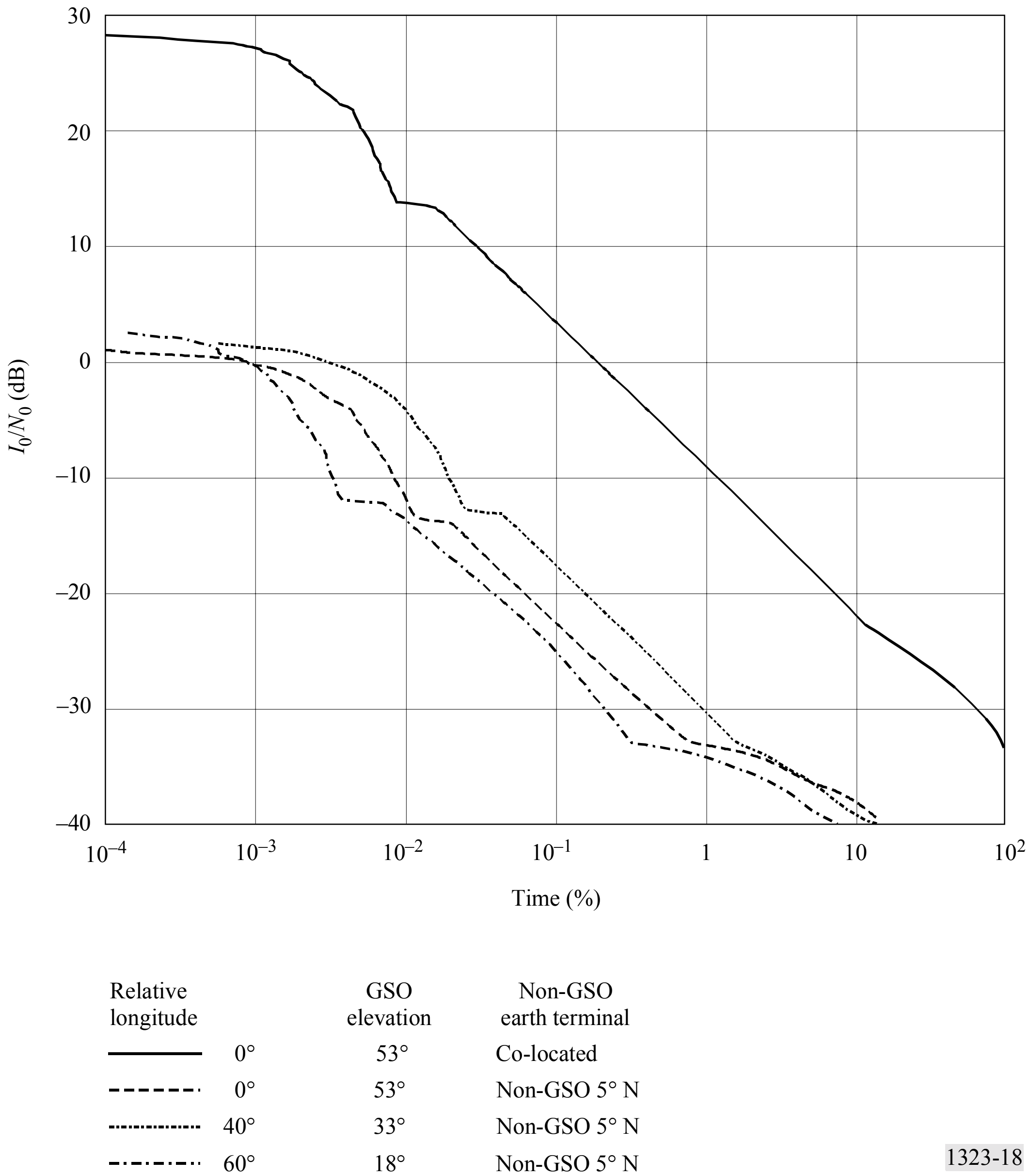
and

$$I(t)/N_T = \begin{cases} 3.3 & 0 \le t < (1/n)\,0.01 \\ 10\log(x/(100\,n))\dfrac{\log(t) - \log((1/n)\,0.01)}{\log(y) - \log((1/n)\,0.01)} & (1/n)\,0.01 \le t < y \\ 10\log(x/(100\,n)) & y \le t < 100 \end{cases}$$

A procedure to apply the principles of Methodology B to the derivation of candidate equivalent power flux-density (epfd) limits is described in Annex 4.

FIGURE 18

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



APPENDIX 1

TO ANNEX 1

A method to take account of uplink thermal noise in transparent-transponder satellite systems

For a transparent satellite transponder, a fraction of the system noise in the earth station receiver will arise from the uplink thermal noise, and this noise will be reduced by the downlink fade. As a result, the permitted margin for rain attenuations will be reduced. To estimate the resultant degradation, the following procedure is proposed.

The downlink carrier power, under clear-sky conditions, into the earth station receiver is determined from:

$$C_{cs} = P_t + G_t^S - L_{BE} - 20\log\left(\frac{4\pi\, d}{\lambda}\right) + G_r^E \qquad \text{dBW} \tag{76}$$

where:

- P_t: satellite transmit power (dBW)
- G_t^S: maximum satellite transmit antenna gain (dB)
- L_{BE}: beam edge loss (dB)
- λ: wavelength (km)
- d: path length for the lowest operating angle (km)
- G_r^E: earth station receive antenna gain (dB).

The earth station system noise power is given by:

$$N = 10\log(k\, T_{sys}\, B) \qquad \text{dBW} \tag{77}$$

where:

- k: Boltzman's constant = 1.3807×10^{-23} J/K
- B: occupied bandwidth of the carrier
- T_{sys}: the system noise temperature and includes both the noise from the earth station receiver, $T_{\downarrow}$, and the contribution from the satellite uplink thermal noise, $T_{\uparrow}$, reduced by the transmission gain, γ (dB):

$$T_{sys} = T_{\downarrow} + 10^{\gamma/10} T_{\uparrow} \tag{78}$$

and

$$\begin{aligned} T_{\downarrow} &= 10^{(G_r^E - (G/T)_E)/10} \\ T_{\uparrow} &= 10^{(G_r^S - (G/T)_S)/10} \end{aligned} \tag{79}$$

From equations (77) and (78), the unfaded clear-sky *C/N* and the *C/N* reduced by a fade ratio *F* can be expressed in linear terms as:

$$\begin{aligned} \left(\frac{C}{N}\right)_{unfaded} &= \frac{10^{C_{cs}/10}}{k\, T_{sys}^{unfaded}\, B} \\ \left(\frac{C}{N}\right)_{faded} &= \frac{10^{C_{cs}/10} / F}{k\, T_{sys}^{faded}\, B} \end{aligned} \tag{80}$$

where:

$$\begin{aligned} T_{sys}^{unfaded} &= T_{\downarrow} + 10^{\gamma/10} T_{\uparrow} \\ T_{sys}^{faded} &= T_{\downarrow} + 10^{\gamma/10} T_{\uparrow} / F \end{aligned} \tag{81}$$

Since the ratio between the unfaded and faded *C/N*s is the degradation Z_1, expressed linearly, the fade (dB) which will produce this degradation ratio Z_1 can be found from

$$f = 10\log\left(\frac{Z_1 T_{\downarrow} + (Z_1 - 1)\, 10^{\gamma/10} T_{\uparrow}}{T_{\downarrow}}\right) \tag{82}$$

The fraction of time for which a *C/N* degradation due to rain of x_1 dB may be exceeded, β_1, can then be found from equation (39) in Methodology A', i.e. $\beta_1 = p_A$ with $A_p \equiv x_1 \equiv f$.

ANNEX 2

Procedure for assessing interference criteria with respect to *recommends* 3.1 of this Recommendation

1 Introduction

A procedure (Procedure D) is developed to assess the impact of a given set of interference criteria on the GSO carrier *C*/*N* performance. Knowing the rain fade degradation statistics and the epfd↑ and epfd↓ statistics (the statistics can be the actual provisional limits or the real epfd generated by a specific non-GSO network) one can assess the impact on the actual *C*/*N* performances and if the interference mask satisfies *recommends* 3.1. The method proposed can then be used for refining the actual interference mask by trial and error in order to exactly meet *recommends* 3.1. (see Note 1). It can also be used to verify that the mask enables the GSO carrier to meet its *C*/*N*-versus-time percentage performance requirements.

It should be noted that the verification process does not produce a unique shape for the epfd↓ or epfd↑ mask. Many different shapes may produce results that are acceptable and meet the requirements specified in *recommends* 3. Thus it is important when developing epfd↓ or epfd↑ masks that this be given consideration.

NOTE 1 – The direct convolution approach of Procedure D can be applied in various ways in addition to the specific application described herein. For example, in order to obtain results for a family of GSO networks using the same uplink parameters, earth station receiver antenna, rain zone and system noise temperature, but varying downlink power margins, the antenna input power level assumed for the GSO satellite could be varied and the associated downlink power margin could be considered in connection with the GSO network unavailability levels that result from application of Procedure D. This would provide insight into the potential impact of frequency sharing criteria on a family of GSO systems (e.g., systems that differ only in the downlink power margin or availability).

2 Assumptions and notations

The sources of interference which have been taken into account in this analysis are:

– internal interference to the considered GSO network (thermal, intermodulation, cross-polarization, isolation, etc.);

– external interference from other GSO networks and from fixed service systems;

– attenuation due to rain on the uplink and downlink and the consequential temperature variations;

– the interference from the non-GSO system under consideration (for which the distributions of the equivalent power flux-density and the aggregate power flux-density have been computed or measured on the most accurate basis).

The following notation is adopted:

– upper case notations refer to variables in a dB format;

– lower case notations refer to variables in linear format;

– b (kHz), is the noise bandwidth of the wanted carrier;

– the characteristics of the link and of the desired transmit earth station of the GSO network are known such that the uplink rain attenuation, $A_\uparrow$, and its cumulative density function (cdf) can be computed;

– $P_\uparrow(X) = P(A_\uparrow \le X)$, is the cdf of the uplink rain attenuation, and the corresponding pdf is $P_\uparrow(X) = \mathrm{d}P_\uparrow(X)/\mathrm{d}X$, i.e. $P(X \le A_\uparrow < X + \mathrm{d}X) = P_\uparrow(X)\mathrm{d}X$;

– the characteristics of the link and of the desired receive earth station of the GSO network are known such that the downlink rain attenuation, $A_\downarrow$, and its cdf can be computed;

– $P_\downarrow(X) = P(A_\downarrow \leq X)$, is the cdf of the downlink rain attenuation, and the corresponding pdf is $p_\downarrow(X) = \mathrm{d}P_\downarrow(X)/\mathrm{d}X$, i.e. $P(X \leq A_\downarrow < X + \mathrm{d}X) = p_\downarrow(X)\mathrm{d}X$;

– the characteristics of the desired GSO network are known such that the wanted power of the desired carrier of the GSO network at the input of the demodulator of the receive earth station, c (W) or C (dBW) = 10 log (c) can be computed as follows (see Methodology A, Annex 1 of this Recommendation):

$$C = F\,(A_\uparrow, A_\downarrow)$$

– the characteristics of the desired GSO network are known such that the noise power in the noise bandwidth of the desired carrier of the GSO network, at the input of the demodulator of the receive earth station, n (W) or N (dBW) = 10 log (n), can be computed as follows (see Methodology A, Annex 1 of this Recommendation):

$$N = G(A_\uparrow, A_\downarrow)$$

– the cdf of the thermal noise generated by the conjunction of the Sun, N_s (dBW), or the Moon can be expressed as follows:

$$P(N_s \leq X) = P_s(X)$$

– the corresponding pdf of the noise power generated by the Sun or the Moon can be expressed as $p_s(X) = \mathrm{d}P_s(X)/\mathrm{d}X$, i.e. $P(X \leq N_s < X + \mathrm{d}X) + p_s(X)\,\mathrm{d}X$;

– the characteristics of the desired GSO network are known such that the link transmission gain, γ or Γ = 10 log (γ) between the output of the GSO space station receive antenna and the output of the wanted receive earth station can be computed as follows:

$$\Gamma = H(A_\uparrow, A_\downarrow)$$

– the non-GSO system is such that the interference power at the GSO space station receive antenna output, $I_\uparrow$ (dBW), or in an equivalent the corresponding aggregate power flux-density, $\mathrm{epfd}_\uparrow$ (dB(W/(m^2 · 4 kHz))), can be considered constant;

– the on-axis antenna gain of the G_r or the wanted receive earth station is known;

– the downlink frequency, f (GHz), of the wanted carrier is known;

– the cumulative distribution function, (CDF) of the equivalent power flux-density, $\mathrm{epfd}_\downarrow$, is known:

$$P(epfd \leq X) = P_{epfd}(X)$$

3 Procedure D

The procedure is based on the computation of the availability of the network without the power levels generated by non-GSO systems, and with these power levels and compute the difference between both availabilities.

It is also based on the fact that the sources of interference are independent, but that a certain level of correlation is introduced due to the fact that rain fades will act on both the wanted path and on the interfering path. Thus the random variables cannot be totally de-correlated. This correlation is not taken into account here and the interfering signal is assumed not to be affected by rain fading.

Step 1: From the characteristics of the desired earth stations and of the space station, and from the method proposed in the various relevant ITU-R Recommendations:

– determine the rain attenuation which is exceeded for 0.01% of an average year on the uplink, $A_{\uparrow,0.01}$ (dB): $P(A_{\uparrow} > A_{\uparrow,0.01}) = 0.01\%$.

– determine the rain attenuation which is exceeded for 0.01% of an average year on the downlink, $A_{\downarrow,0.01}$ (dB): $P(A_{\downarrow} > A_{\downarrow,0.01}) = 0.01\%$;

NOTE 1 – The algorithms for the Crane model (an alternative model for rain attenuation) have also been included in the software developed.

Step 2: From Recommendation ITU-R P.618, determine the cdf of the uplink rain fade and of the downlink rain fade:

$$P_{A_{\uparrow}}(X) = P(A_{\uparrow} \le X) = 1 - \frac{10^{11.628\left(0.546 + \sqrt{0.298 + 0.172 \log (0.12 \times A_{\uparrow,0.01}/X)}\right)}}{100}$$

$$P_{A_{\downarrow}}(X) = P(A_{\downarrow} \le X) = 1 - \frac{10^{11.628\left(0.546 + \sqrt{0.298 + 0.172 \log (0.12 \times A_{\downarrow,0.01}/X)}\right)}}{100}$$

NOTE 1 – The Crane model (an alternative model for rain attenuation) is also available in the computation software.

Step 3: From Step 2, determine the pdf of the uplink and downlink rain attenuation:

$$p_{\uparrow}(X) = \frac{\mathrm{d}P_{A_{\uparrow}}(X)}{\mathrm{d}X} = \frac{1.000008}{100} \times \frac{10^{11.628\left(-0.546 + \sqrt{0.298 + 0.172 \log (0.12 \times A_{\uparrow,0.001}/X)}\right)}}{\sqrt{0.298 + X \times 0.172 \log (0.12 \times A_{\uparrow,0.001}/X)}}$$

and

$$p_{\downarrow}(X) = \frac{\mathrm{d}P_{A_{\downarrow}}(X)}{\mathrm{d}X} = \frac{1.000008}{100} \times \frac{10^{11.628\left(-0.546 + \sqrt{0.298 + 0.172 \log (0.12 \times A_{\downarrow,0.001}/X)}\right)}}{\sqrt{0.298 + X \times 0.172 \log (0.12 \times A_{\downarrow,0.001}/X)}}$$

Step 4: Determine the CDF, P_1, of the wanted C/N (i.e. without the interference level generated by the non-GSO systems), from the characteristics of the GSO network and the existing interference environment:

The total wanted power-to-noise ratio can be expressed as a function of the uplink and the downlink rain attenuation as:

$$(C/N)(A_{\uparrow}, A_{\downarrow}) = F(A_{\uparrow}, A_{\downarrow}) - 10 \log \left[10^{G(A_{\uparrow}, A_{\downarrow})/10} + 10^{(N_s - A_{\downarrow})/10}\right]$$

Therefore:

$$P_1(C/N \le X) = 1 - P_1(C/N > X)$$

thus

$$P_1(C/N \le X) = 1 - \int_0^{A_{\uparrow,1}} p_{\uparrow}(U) \left[\int_0^{A_{\downarrow,1}(U)} p_{\downarrow}(V) \cdot P_S\left(10 \log \left[10^{(F(U,V)-X)/10} - 10^{G(U,V)/10}\right] + V\right) \mathrm{d}V \right] \mathrm{d}U$$

where:

$A_{\uparrow,1}$, such that: $F(A_{\uparrow,1}, 0) - G(A_{\uparrow,1}, 0) = X$ (i.e. $C/N = X$ because of rain fade only on the uplink path, no rain fade on the downlink and no interference due to the extra terrestrial bodies)

$A_{\downarrow,1}(U)$: such that: $F(U, A_{\downarrow,1}) - G(U, A_{\downarrow,1}) = X$ (i.e. $C/N = X$ because of rain fade only on the uplink path and on the down path, and no interference due to the Sun).

Step 5: determine the pdf of the $epfd_\downarrow$ and the $epfd_\uparrow$ generated by the non-GSO system(s):

The interference power *I* (dBW) due to the non-GSO system(s), can then be expressed as:

$$I(A_\uparrow, A_\downarrow) = 10 \log \left[10^{(I_\uparrow + H(A_\uparrow, A_\downarrow))/10} + 10^{(epfd + K_1 - A_\downarrow)/10} \right]$$

where:

$K_1 = 10 \log (b/4) + G_r + 10 \log (\lambda^2/4\pi)$: constant (dBm²)

$\lambda = c/f$: wavelength (m).

Step 6: determine the CDF P_2 of the noise plus interference power ratio, $C/(N + I)$, i.e. including the presence of the non-GSO system:

The total wanted power to noise plus interference ratio can be expressed as a function of the uplink and the downlink rain attenuation as:

$$\left(C/(N+I)\right)(A_\uparrow, A_\downarrow) = F(A_\uparrow, A_\downarrow) - 10 \log \left[10^{G(A_\uparrow, A_\downarrow)/10} + 10^{(N_s - A_\downarrow)/10} + 10^{(I_\uparrow + \Gamma(A_\uparrow, A_\downarrow))/10} + 10^{(epfd + K_1 - A_\downarrow)/10} \right]$$

Therefore:

$$P_2(C/(N + I) \le X) = 1 - P_2\,(C/(N + I) > X)$$

thus:

$$P_2(C/N \le X) = 1 - \int_0^{A_{\uparrow,1}} p_\uparrow(U) \left(\int_0^{A_{\downarrow,1}(U)} p_\downarrow(V) \left[\int_{-\infty}^{N_{s,1}(U,V)} p_s(N) \cdot P_{epfd}\left(epfd(U, V, N)\right) \mathrm{d}N \right] \mathrm{d}V \right) \mathrm{d}U$$

where:

$N_{s,1}(U, V) = 10 \log \left[10^{(F(U,V) - X)/10} - 10^{G(U,V)/10} \right] + V$: extra-terrestrial noise power which, for uplink fade, *U*, and downlink fade, *V*, and with no interference from the non-GSO system(s), would imply $C/(N + I) = X$

$epfd_\downarrow(U, V, N) = 10 \log \left[10^{(F(U,V) - X)/10} - 10^{G(U,V)/10} - 10^{(N - V)/10} - 10^{(I_\uparrow + H(U,V))/10} \right] - K_1 + V$: epfd such that $C/(N + I) = X$, knowing the uplink and downlink rain attenuation (*U* and *V*), and the extraterrestrial bodies interference power (*N*).

Step 7: determine the increase of the unavailability between the situation without the non-GSO system(s), and with the non-GSO system(s):

$$\Delta X = P_2(X) - P_1(X)$$

Step 8: determine the relative reduction of availability due to the introduction of the non-GSO system(s), $R_v(X)$ (%):

$$R_v(X) = 100 \frac{\Delta(X)}{P_2(X)} = 100 \frac{P_2(X) - P_1(X)}{P_2(X)}$$

The algorithm of the software that implements Steps 1 through 8 are presented in Appendix 1.

3.1 Procedure D using direct convolution

The above equations can be simplified under certain assumptions. The applicability of this version using the direct convolution is limited to certain cases because it cannot simultaneously take into account both uplink and downlink rain fades. The methodology can give accurate results for processing satellites where the uplink and downlink degradations can be separated. It can also produce accurate results for transparent satellite links where either the uplink or downlink fade can be ignored. This includes links that have sufficient uplink power control or where the satellite link uses an uplink C-band cross strap. It may also apply to links where either the uplink or downlink earth station is located in a very dry rain zone.

The equation below represents the downlink C/N power ratio when there is rain fading and interference:

$$\frac{C}{N_{\downarrow}} = \frac{C_a}{(T_s + T_r) \cdot k\,B + I\,b} = \frac{C}{\frac{1}{a}\left(T_s + T_r\right)k\,B + I\frac{b}{a}}$$

where:

a: rain attenuation on desired link

b: rain attenuation on undesired link

T_s: total receive system noise temperature (K)

T_r: rain noise temperature (K)

k: Boltzman's constant

B: bandwidth (Hz)

C: desired signal power (W)

I: interfering power (W).

The degradation due to interference and rain, Z, is the ratio of the noise power with interference and rain (denominator in the equation above) and the noise power without rain or interference, T_s. The resulting degradation is shown in the equation below:

$$Z = \frac{\frac{k\,B}{a}\left(T_s + T_r\right) + I\frac{b}{a}}{k\,B\,T_s} = \frac{1}{a}\left(1 + \frac{T_r}{T_s}\right) + \frac{I}{k\,B\,T_s}\frac{b}{a}$$

This degradation can be separated into a component due to rain and a component due to interference as shown below:

$$X = \frac{1}{a}\left(1 + \frac{T_r}{T_s}\right)$$

$$Y = \frac{I\frac{b}{a}}{k\,B\,T_s}$$

where X is the degradation caused by rain and Y is the term due to interference. The analysis assumes that X and Y are independent and therefore their pdfs can be convolved as per Methodology A.

The ratio $b/a = 1$ when the fading on the intefering signal, b, and the desired signal, a, are the same. This is the assumption used for the epfd$_{\downarrow}$ calculation where the significant fading occurs on the downlink. It is also the assumption used for the epdf$_{\uparrow}$ calculation.

When there is no fading of the interfering signal $b = 1$. This is the assumption that should be used in the epfd$_{\downarrow}$ calculation when the significant fading occurs on the uplink.

The formulation above assumes that the random variables X and Y have units of power. This is different than the formulation of Methodology A where the random variables X and Y are in dB. The reason for doing this formulation in units of power is that it resulted in the variable Y being a function of the ratio b/a.

4 Example of application

In this case, a trial and error method is used to assess the candidate epfd limits. Application of the software to RR Article S22 provisional epfd$_\downarrow$ limits is done. After checking the impact and the resulting *C*/*N* compared with the performance criteria of each GSO carrier, derivation of the epfd$_\downarrow$ limits meeting this Recommendation's criteria is performed. This exercise was performed with two carriers of TELECOM2: a TDMA carrier and a VSAT to Hub carrier.

4.1 VSAT communication inbound – 153.6 kHz

The GSO carrier has the performance criteria given in Table 2 and a 3.5 m antenna for the reception:

TABLE 2

Wanted *C*/*N* (dB)	4.4
Percentage of the time *C*/*N* should be exceeded	98
Wanted *C*/*N* (dB)	3.8
Percentage of the time *C*/*N* should be exceeded	99.92
Wanted *C*/*N* (dB)	1.9
Percentage of the time *C*/*N* should be exceeded	99.96

Several sets of epfd$_\downarrow$ limits were tested. They are summarized in Table 3:

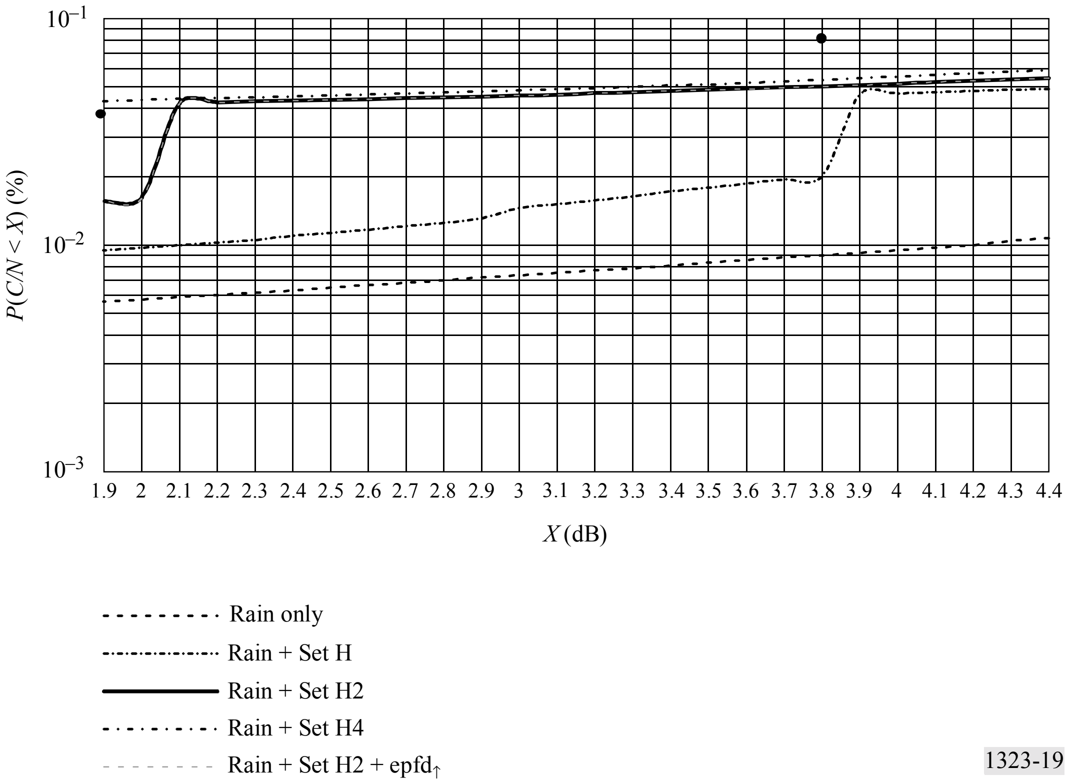
TABLE 3

Set H		Set H2		Set H4	
epfd$_\downarrow$ (dB(W/(m^2 · 4 kHz)))	Percentage of time epfd$_\downarrow$ is not exceeded	epfd$_\downarrow$ (dB(W/(m^2 · 4 kHz)))	Percentage of time epfd$_\downarrow$ is not exceeded	epfd$_\downarrow$ (dB(W/(m^2 · 4 kHz)))	Percentage of time epfd$_\downarrow$ is not exceeded
–175	99.9	–173	99.9	–172	99.9
–171	99.97	–169	99.97	–168	99.97
–161	99.999	–159	99.999	–158	99.999
–160	100	–158	100	–157	100

The results of the application of these sets of limits are shown in Fig. 19.

FIGURE 19

Impact of epfd limits on *C/N* distribution, TELECOM2 - VSAT



For the set of epfd↓ limits meeting this Recommendation's criteria, the results are provided in Table 4.

TABLE 4

C/N	1.9	3.8	4.4
Percentage of time allowed	0.04	0.08	2
Results with rain only	0.00563534	0.00902573	0.01073518
Rain + Set H2 + RR Article S22 epfd↑	0.01558573	0.05011122	0.05456822

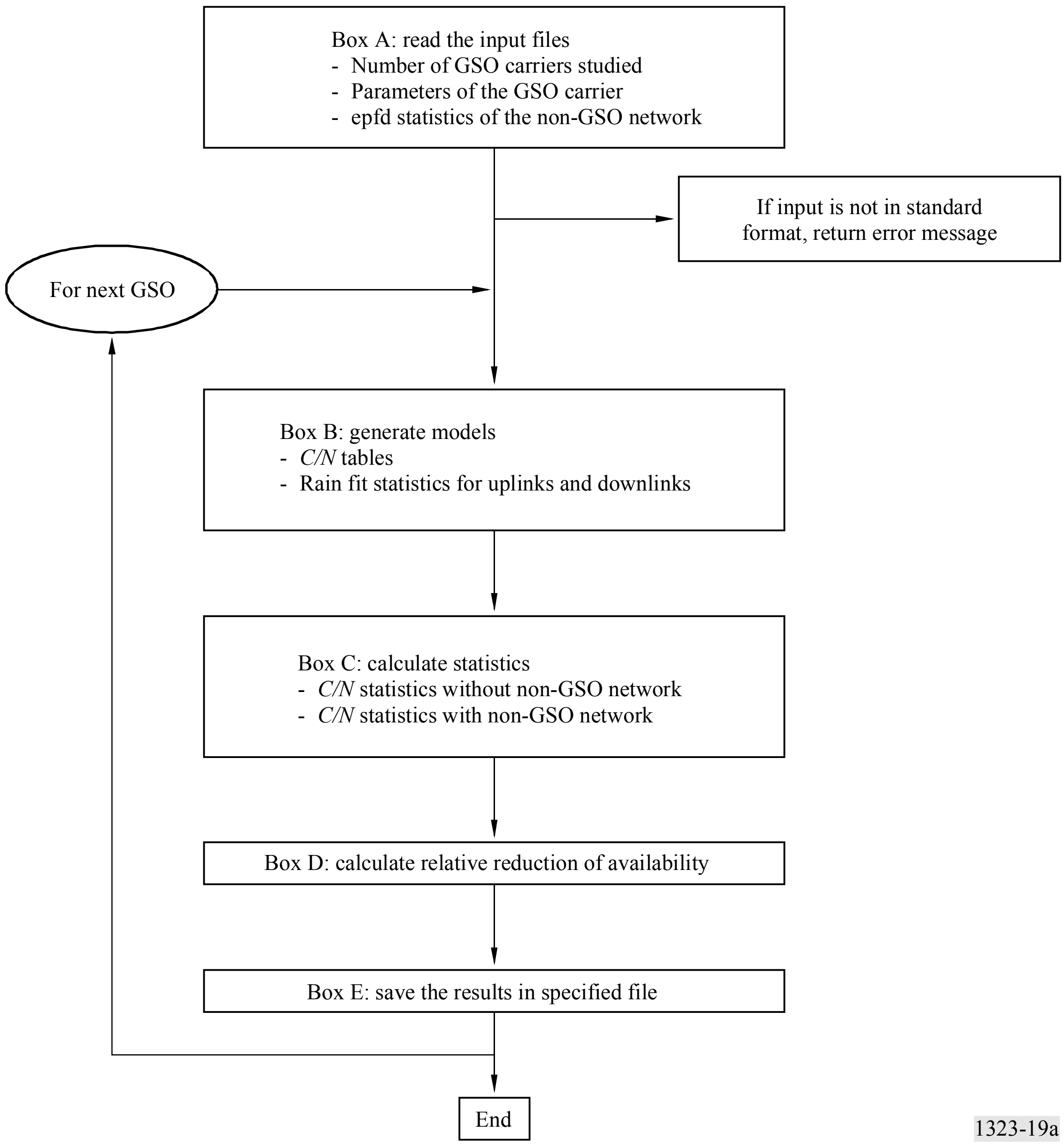
APPENDIX 1

TO ANNEX 2

Algorithm of the software

This Appendix provides a simplified algorithm of the software provided.

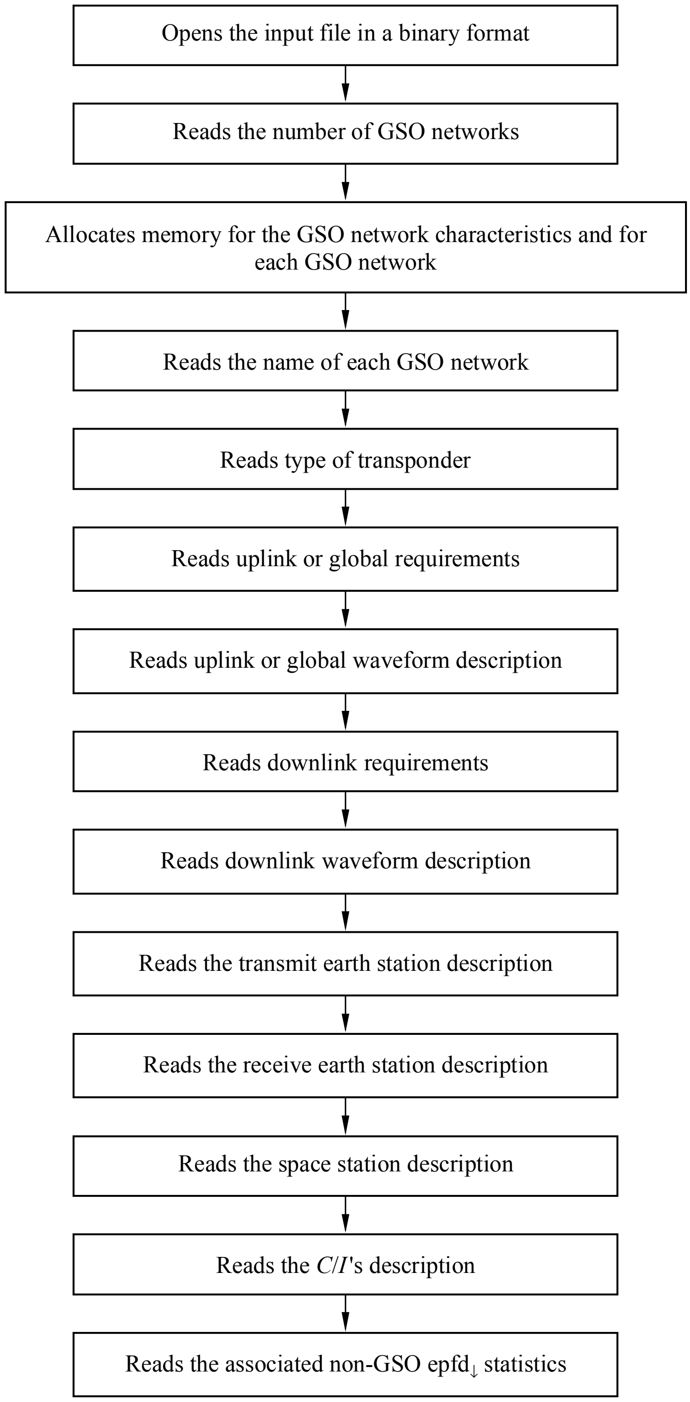
1 General algorithm



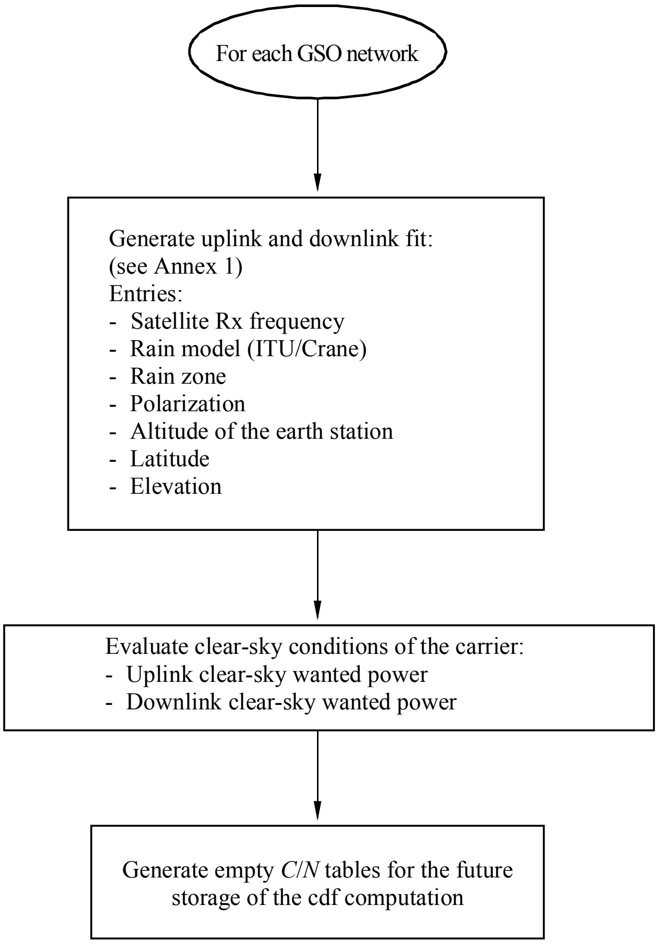
2 Description of the different boxes

2.1 Box A: read input files

This first part of the software reads and stores the different GSO carrier parameters and the different non-GSO epfd$_{\downarrow}$ files. It also checks the standard parameters.



1323-19b

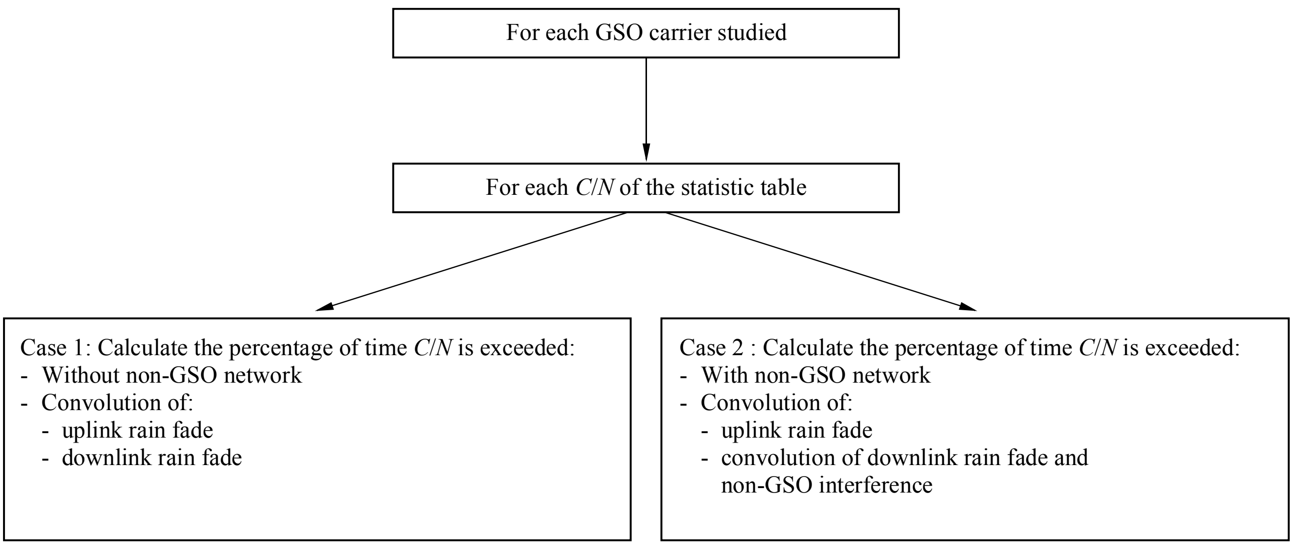


1323-19c

2.2 Box B: generate models

The aim of this subprogram is to generate all the models that will be further used to generate the *C*/*N* statistics. In particular, an approximation is calculated for the rain attenuations. The description of the methodology used to calculate the rain fit is described in Annex 1.

2.3 Box C: calculation of the *C*/(*N* + *I*) statistics



1323-19d

Case 1: cdf of total C/N without non-GSO

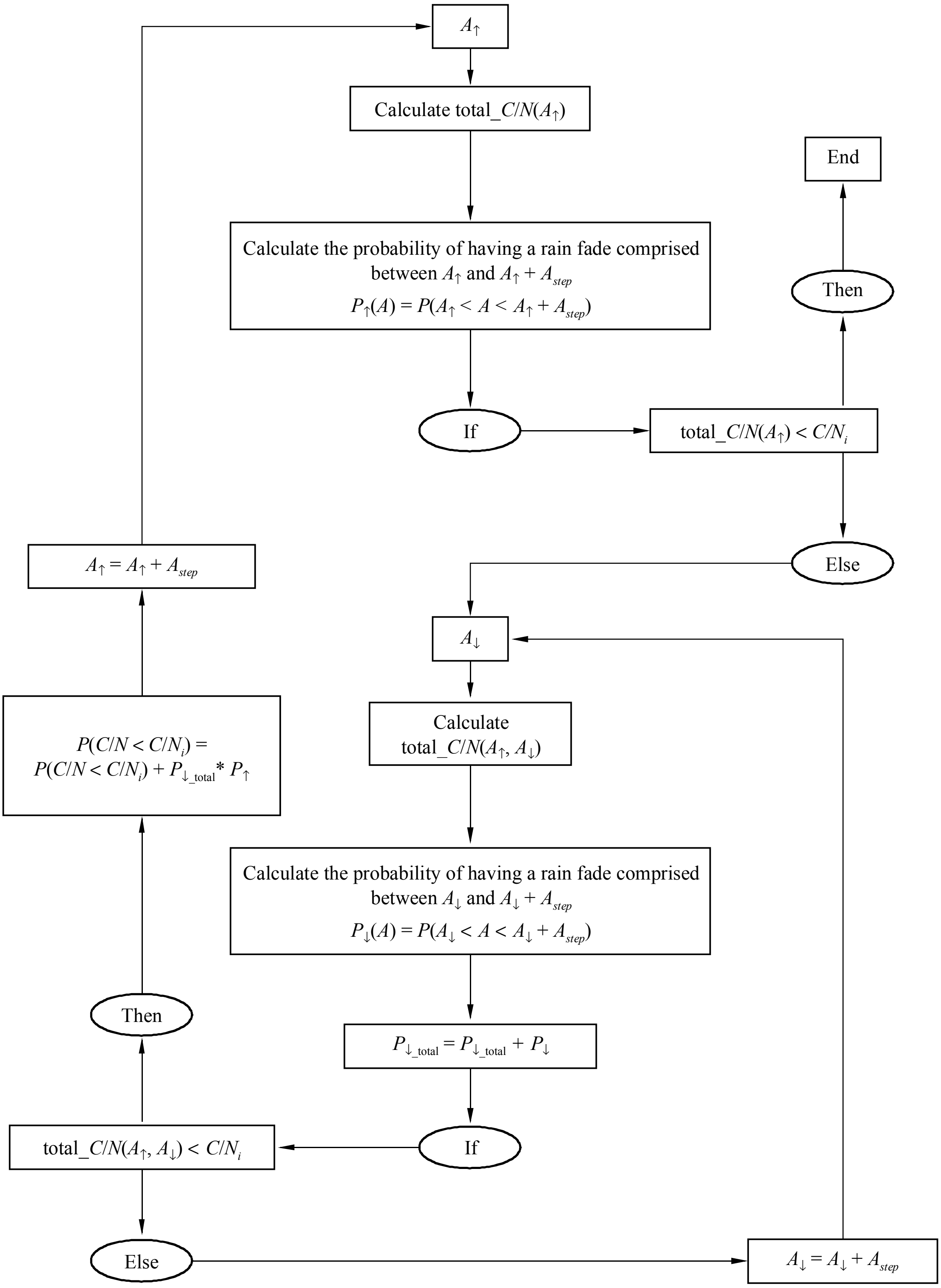
For each tested *C*/*N* of the *C*/*N* statistic table, with the following notations:

total_$C/N(A_\uparrow)$: total *C*/*N* of the carrier with an uplink rain attenuation of $A_\uparrow$ and no downlink attenuation

total_$C/N(A_\uparrow, A_\downarrow)$: total *C*/*N* of the carrier with an uplink rain attenuation of $A_\uparrow$ and a downlink rain attenuation of $A_\downarrow$

C/N_i: *C*/*N* for which the associated percentage of time is being calculated

A_{step}: calculation step for the rain attenuation.



1323-19e

Case 2: cdf of total C/N with non-GSO

For each tested *C/N* of the *C/N* statistic table, with the following notations:

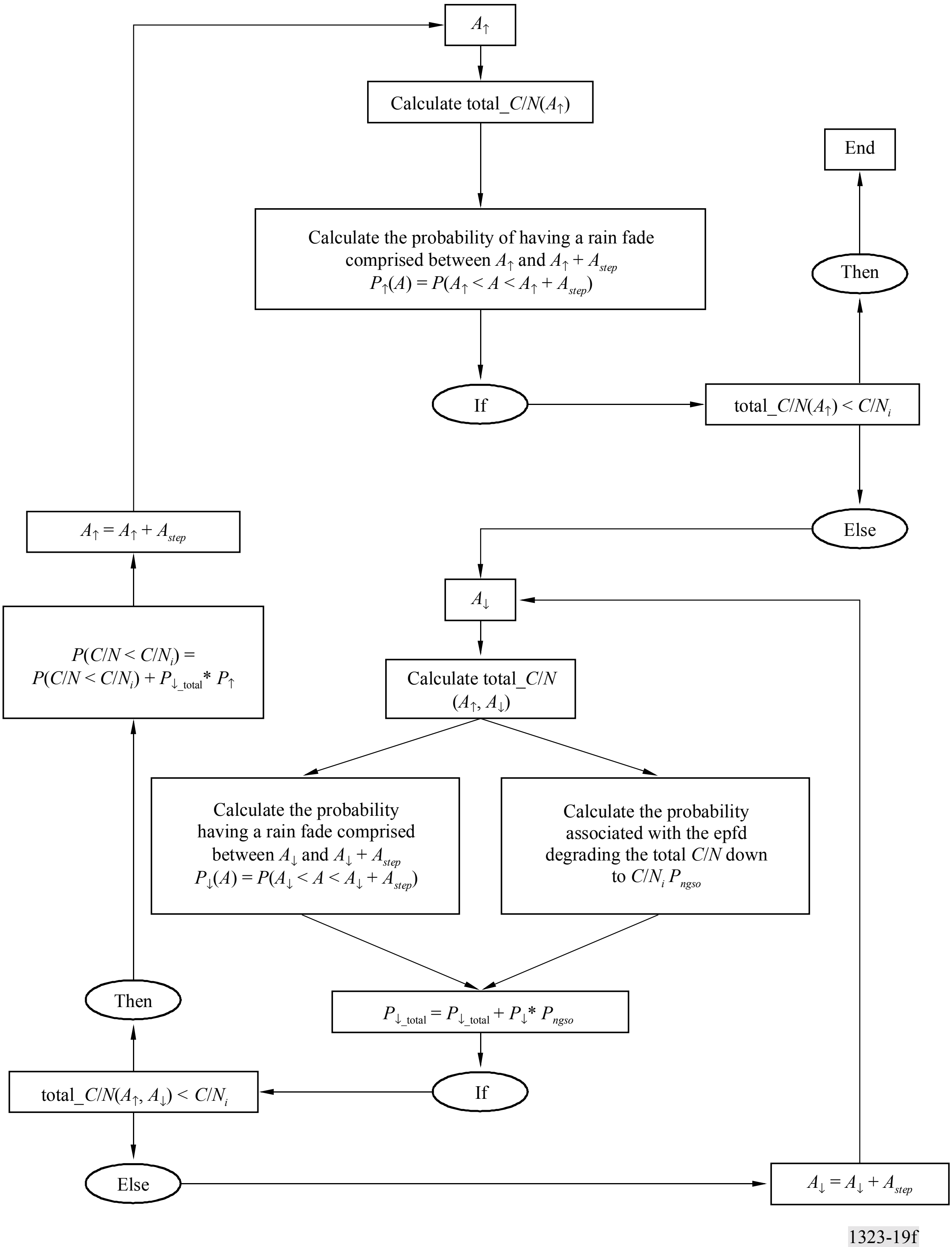
total_$C/N(A_\uparrow)$: total *C/N* of the carrier with an uplink rain attenuation of $A_\uparrow$ and no downlink attenuation

total_$C/N(A_\uparrow, A_\downarrow)$: total *C/N* of the carrier with an uplink rain attenuation of $A_\uparrow$ and a downlink rain attenuation of $A_\downarrow$

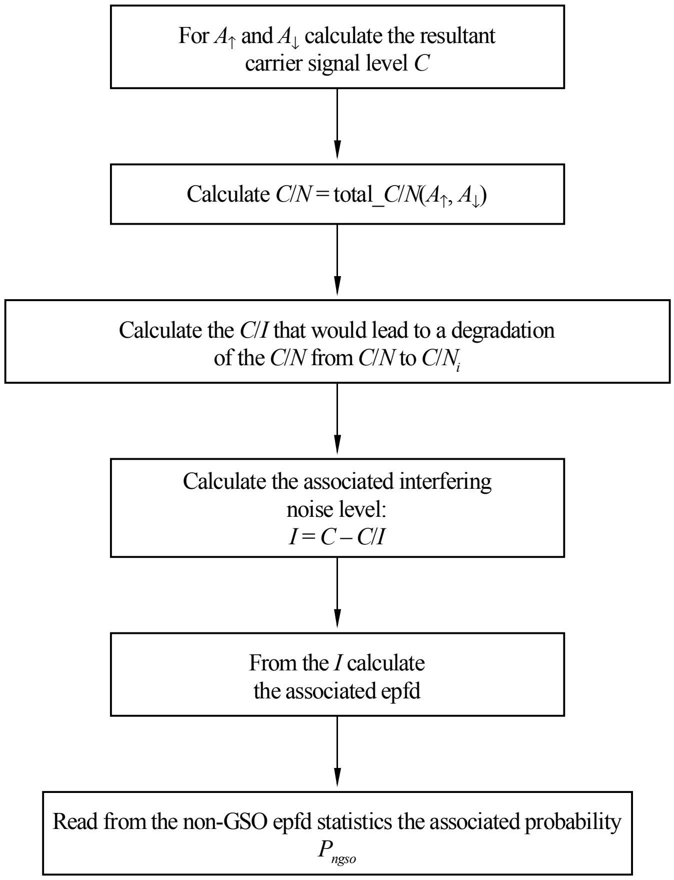
C/N_i: *C/N* for which the associated percentage of time is being calculated

A_{step}: calculation step for the rain attenuation.

The algorithm used is the following:



The following algorithm details the calculation of P_{ngso} with the same notations:



1323-19g

2.4 Box D: calculation of the relative reduction of availability

This part of the software determines the relative increase of unavailability due to the introduction of the non-geostationary system(s), $R_v(X)$ (%):

$$R_v(X) = 100\,\frac{\Delta(X)}{P_2(X)} = 100\,\frac{P_2(X) - P_1(X)}{P_2(X)}$$

where P_1 is the probability of being below a certain level of C/N without non-GSO and P_2 with non-GSO.

3 Description of the functions implemented

This section provides the description of the functions implemented in the provided software.

3.1 Calculation of the clear sky conditions of the carrier

3.1.1 Calculation of the uplink clear sky wanted power

The uplink clear-sky wanted power can be expressed as:

$$C = e.i.r.p._{\uparrow} - L_{\uparrow} + G_{rx\text{-}sat}$$

where:

$e.i.r.p._{\uparrow}$: uplink e.i.r.p.

$L_{\uparrow}$: uplink total propagation loss

$G_{rx\text{-}sat}$: satellite receive antenna gain in direction of earth station.

The uplink e.i.r.p. is derived from the input parameters:

$e.i.r.p\uparrow$: Transmit earth station on-axis e.i.r.p. – Transmit earth station pointing loss

The total uplink propagation losses are calculated from:

$$L_{\uparrow} = L_{fs\_\uparrow} + L_{ga\_\uparrow}$$

where:

$L_{fs\_\uparrow}$: uplink free space loss:

$$20 \log (4 \pi (D_{\uparrow} 1\,000) \cdot (Rx\ Freq/0.3))$$

$L_{ga\_\uparrow}$: uplink gazeous attenuation, calculated from Recommendation ITU-R P.676

$D_{\uparrow}$: distance to the GSO satellite:

$$6\,378\,(6.61 \sqrt{(1.0 - pow\,(\cos\,(E_{\uparrow})\,/\,6.61, 2.0))} - \sin\,(E_{\uparrow}))$$

$E_{\uparrow}$: elevation of the satellite as seen from the earth station considered.

3.1.2 Calculation of the downlink clear-sky wanted power

The downlink clear-sky wanted power can be expressed as:

$$C = e.i.r.p._{\downarrow} - L_{\downarrow} + G_{rx\text{-}es} - P_{rx}$$

where:

P_{rx}: receive earth station pointing loss

$G_{rx\text{-}es}$: on-axis gain of the receiving earth station

$L_{\downarrow}$: downlink total propagation loss

e.i.r.p.$_{\downarrow}$: downlink e.i.r.p.. The downlink e.i.r.p. is an input parameter.

The downlink total propagation loss can be expressed as in the uplink case.

3.2 Calculation of the rain conditions of the carrier

3.2.1 Generation of the rain fit

The purpose of this function is to generate the fit of the rain fade, CDF, in order to further perform the integration of the pdf of the rain statistics. The model is derived from the ITU-R modelling way:

A_{min}: minimum attenuation exceeded for the maximum authorized percentage of the time;

– 1% for ITU-R,

– 5% for Crane.

X, *Y*, *Z* are used for the model:

$$\log (CDF) = X + \sqrt{Y + Z \log (A)}$$

p: probability in per cent (%) that a given attenuation *A* (dB) be exceeded.

The fit is based on the computation of the different moments of the distribution of *p*. In a matrix notation we can write:

$$[B] = [A]\ [X,Y,Z]T,\ [b] = [a][Y,Z]T$$

The Inputs required for this function are:

Frequency: carrier frequency (GHz)

Model: rain model type

Zone: region

$R_{0.01}$: rain fall rate exceeded for 0.01% of the time

Polar: polarization of the carrier

Height: earth station height above mean sea level (km)

Latitude: latitude of the earth station (degrees)

Elevation: elevation angle of the earth station (degrees)

Fit: pointer on the structure to be updated.

3.2.2 Calculation of the uplink wanted power

The purpose of this function is to compute the uplink wanted power of a given carrier in any rain condition.

Notations used:

$A\uparrow$: attenuation due to rain condition on the uplink (dB)

$L\uparrow$: uplink total propagation loss

C: wanted power at space station

$Ga_{cs\_\uparrow}$: gaseous attenuation on the uplink path under clear-sky conditions

$Ga_{rain\_\uparrow}$: gaseous attenuation on the uplink path in rainy conditions (attenuation $A\uparrow$ (dB))

UPC: uplink power control

$UPCA$: uplink power control accuracy

RPC: uplink power control range.

The first step of this function is to verify if the carrier is using UPC and if so, to compute the level of power control. The value of the power control level is calculated by the following formula:

$$UPC = floor((A\uparrow + Ga_{rain\_\uparrow} - Ga_{cs\_\uparrow}) / UPCA)\ UPCA$$

If the power control required by the uplink rain attenuation is superior to the UPC range of the given carrier, then the UPC will have the maximum possible value and then:

$$UPC = RPC$$

The second step is to compute the total additional losses toward the satellite due to rain conditions.

Here we then have:

$$L\uparrow = A\uparrow + Ga_{rain\_\uparrow}$$

We can then compute the wanted power at the GSO space station by deriving it from the clear sky wanted power calculated in the precedent section. The uplink power of the GSO carrier under rain conditions is then given by the following formula:

$$C\uparrow = C_{cs\_\uparrow} + UPC - L\uparrow$$

3.2.3 Calculation of the uplink noise plus interference power level

The purpose of this function is to compute the uplink $(N + I)$ of the GSO carrier considering the contributions of all the interfering sources and with an uplink rain attenuation of $A\uparrow$ dB.

The following notations are used:

$I_{epfd}\uparrow$: C/I due to the considered epfd↑ limit

$Xpol_{TxES}$: C/I due to the transmit earth station cross polarization isolation

$Intermod_{ES}$: C/I due to the transmit earth station intermodulation

$Xpol_{SS}$: C/I due to cross polarization isolation of the GSO space station

$I_{asi\_\uparrow}$: interference power due to uplink adjacent satellite interference (ASI)

$I_{fs\_\uparrow}$: interference power due to uplink fixed service sharing

I_{reuse}: interference power due to frequency reuse

C_{cs}: clear sky wanted power at GSO earth station

C: uplink wanted power

N_{th}: GSO satellite thermal noise power

I: total noise plus interference power

$W_{\uparrow}$: noise bandwidth

T_{sat}: satellite receive system temperature.

The C/I due to the considered epfd↑ limit is only taken into account if the calculation includes epfd↑.

The UPC should change the back off of the amplifier. It is however assumed here that earth station back-off change due to possible UPC has no impact since no data is available.

It is also assumed that the Transmit GSO earth station transmits on the opposite polarization with the same power control increment, if any. The interference power does not change.

The first step is to compute the level of interference of the variables given as C/I:

The interference power at satellite due to the various C/I is computed as follows:

$$I_{C/I} = C + 10 \log (10^{-Intermod_{ES}/10} + 10^{-Xpol_{TxES}/10} + 10^{-Xpol_{SS}/10})$$

for $I_{asi\_\uparrow}$, $I_{fs\_\uparrow}$, I_{reuse}, the carrier level under clear sky is used to derive the interference power level.

The satellite thermal noise power contribution is then computed:

$$N_{th} = -228.6 + 10 \log (W_{\uparrow}) + 10 \log (T_{sat})$$

The total uplink $N + I$ is then computed:

$$I = 10\hat{}(I_{C/I}/10) + 10\hat{}(I_{asi\_\uparrow}/10) + 10\hat{}(I_{fs\_\uparrow}/10) + 10\hat{}(I_{reuse}/10) + 10\hat{}(I_{epfd\uparrow}/10) + 10\hat{}(N_{th}/10)$$

$$I_{\text{dB}} = 10 \log (I)$$

3.2.4 Calculation of the downlink wanted power in rain conditions

The purpose of this function is to compute the downlink wanted power of a given carrier in any condition assuming both downlink and uplink rain attenuation.

The following notations are used:

$A_{\uparrow}$: uplink rain attenuation (dB)

$A_{\downarrow}$: downlink rain attenuation (dB)

$C_{cs\_\uparrow}$: uplink clear sky wanted power

$C_{cs\_\downarrow}$: downlink clear sky wanted power

$C_{\uparrow}$: uplink wanted power with a rain attenuation of $A_{\uparrow}$ (dB)

var_{ibo}: variation of input back-off (IBO)

var_{obo}: variation of output back-off (OBO)

IBO, *OBO*: clear sky total IBO and OBO

ibo, *obo*: ibo and obo under rain conditions

a: slope of the OBO vs IBO variation

$Ga_{cs\_\downarrow}$: clear sky gaseous attenuation on downlink path

$Ga_{\downarrow}$: actual gaseous attenuation

$L_{\downarrow}$: downlink total propagation loss

C: wanted power at GSO earth station.

ALC: automatic level control.

For transparent GSO satellites, the first step is to calculate the actual OBO. The variation of IBO is given by:

$$var_{ibo} = C_{cs\_\uparrow} - C_{\uparrow}$$

For multi-carrier operation the variation of obo is assumed to be equal to the variation of ibo. In general such variation between ibo and obo is appropriate, but in certain cases this can lead to erroneous results that underestimate the link's performance. For transponders operated in the non-linear region with 2-4 carriers per transponder, where no uplink power control is used in the uplink, and where the carriers are uplinked from the same location, the variation in obo due to increase in ibo due to rain is not equal. A better representation of the satellite amplifier's gain transfer characteristics is required for such cases.

If ALC is implemented then single access from the wanted earth station is assumed. In this case, IBO is modified. If the variation of ibo is smaller than the ALC range, then the variation of ibo is supposed null. If the variation of ibo exceeds the ALC range, then:

$$var_{ibo} = var_{ibo} - ALC_{Range}$$

A 0 dB IBO is assumed for 0 dB OBO, thus the variation of IBO implies a variation of OBO. The e.i.r.p. is adjusted in consequence.

The slope of the OBO versus IBO variation is defined as follows:

$$a = OBO/IBO$$

The ibo is calculated by adding the variation of ibo calculated above to the IBO:

$$ibo = IBO + var_{ibo}$$

Knowing the slope of the obo versus ibo variation provides the obo:

$$obo = a \cdot ibo$$

Finally, the variation of obo for single carrier operation is derived as follows:

$$var_{obo} = obo - OBO$$

The next step is to calculate both downlink gaseous attenuation in clear air conditions and in rainy conditions. The total additional losses toward the earth station are then computed.

$$L_{\downarrow} = A_{\downarrow} + Ga_{\downarrow} - Ga_{cs\_\downarrow} + var_{obo}$$

It is then simple to compute the wanted power at the earth station:

$$C = C_{cs\_\downarrow} - L_{\downarrow}$$

3.2.5 Calculation of the downlink noise plus interference power level

The purpose of this function is to compute the downlink $(N + I)$ taking into consideration the contributions of all interfering sources except non-GSO networks.

The following notations are used:

$A_{\uparrow}$: uplink rain attenuation (dB)

$A_{\downarrow}$: downlink rain attenuation (dB)

I_{xpol}: interference due to cross-polarization

I_{asi}: interference power due to ASI

I_{fs}: interference power due to fixed service sharing

I_{reuse}: interference power due to frequency reuse

I_{adj}: interference due to adjacent transponders

$I_{intermod}$: satellite intermodulation interference noise power

C/I_{im}: satellite intermodulation C/I

C_{cs}: clear sky downlink wanted power at earth station

C: downlink wanted power

N_{th}: earth station thermal noise power

A: gaseous and rain attenuation

I: total noise plus interference power

var_{obo}: obo variation

OBO, C/I, a: clear sky OBO, intermodulation C/I, and slope

T_{es}: earth station receive system noise temperature, inclusive of atmospheric absorption.

The first step is to compute the satellite OBO variation:

$$var_{obo} = C_{cs} - (C + A)$$

An 11 dB satellite intermodulation C/I is assumed for 0 dB OBO. Whenever ALC is implemented, the interference noise power generated by intermodulation is given by:

$$a = (C/I_{im} - 11)/OBO$$

$$I_{intermod} = C - (OBO + var_{obo})\, a + 11$$

Calculation of the different sources of interfering noise power are provided hereafter:

– computation of the interference due to frequency reuse:

$$I_{reuse} = C_{cs} - C/I_{reuse} - A$$

– computation of the interference due to adjacent transponders:

$$I_{adj} = C_{cs} - C/I_{adjacent\_transponder} - \mathrm{A}$$

– computation of the interference power due to cross polarization:

$$I_{Xpol} = C + 10 \log \left(10\text{^}(-C/I_{srp}/10) + 10\text{^}(-C/I_{erp}/10)\right)$$

with:

C/I_{srp}: satellite receive cross-polarization C/I

C/I_{erp}: earth station receive cross-polarization C/I

– computation of the interference power due to ASI:

$$I_{asi} = C - C/I_{asi\_\downarrow}$$

with:

$C/I_{asi\_\downarrow}$: C/I due to ASI on the downlink path

– computation of the interference power due to downlink fixed service sharing:

$$I_{fs} = C - C_{fs\_\downarrow}$$

– computation of the earth station attenuation thermal noise power contribution:

$$N_{th} = -228.6 + 10 \log (W_{\uparrow}) + 10 \log \left(T_{es} + 290\,(1 - 10\text{^}(A/10))\right)$$

The total uplink $N + I$ is then calculated by adding all the contributions.

3.2.6 Calculation of the uplink *C/N*

The purpose of this function is to compute the uplink C/N of the GSO carrier.

The following notations are used:

$A_{\uparrow}$: uplink rain attenuation

$C_{\uparrow}$: uplink wanted power

$I_{\uparrow}$: total uplink interference and thermique power.

Computation of $C_{\uparrow}$ and $I_{\uparrow}$ has been explicited in the precedent sections. The resulting C/N for the uplink path is computed:

$$C/N_{\uparrow} = C_{\uparrow} - I_{\uparrow}$$

3.2.7 Computation of the downlink *C/N*

The purpose of this function is to compute the downlink *C/N*. The following notations are used:

$A_\uparrow$: uplink rain attenuation

$A_\downarrow$: downlink rain attenuation

$C_\downarrow$: downlink wanted power

$I_\downarrow$: total downlink interference and thermique power.

Computation of $C_\downarrow$ and $I_\downarrow$ have been explicated in precedent sections. The computation of the downlink *C/N* is then:

$$C/N_\downarrow = C_\downarrow - I_\downarrow$$

3.2.8 Computation of the total *C/N*

The purpose of this function is to compute the total *C/N*.

If only the uplink for regenerative transponders is studied then:

$$C/N = C/N_\uparrow$$

If only the downlink for regenerative transponders is studied:

$$C/N = C/N_\downarrow$$

If the transponder is transparent, the combination of up and down is done:

$$C/N = -10 \log 10\hat{}(-(C/N_\uparrow)/10) + 10\hat{}(-(C/N_\downarrow)/10))$$

3.2.9 Computation of maximum epfd$_\downarrow$

The purpose of this function is to compute the maximum epfd$_\downarrow$ for a given $A_\uparrow$ and $A_\downarrow$ that will drive the GSO link to a given *C/N*. After computing this epfd$_\downarrow$ level, the percentage of time that this epfd$_\downarrow$ is obtained will be checked.

The following notations are used:

C/N_{wanted}: the wanted *C/N*

$A_\uparrow$: uplink rain attenuation

$A_\downarrow$: downlink rain attenuation

C/N: current *C/N* of the GSO link with the rain attenuation $A_\downarrow$ and $A_\uparrow$

C, *I*, *C/I*

K:

Lambda

Gain

Temp

epfd_max

h

p

The first step is to calculate the actual *C/N* of the GSO carrier given the rain attenuation $A_\downarrow$ and $A_\uparrow$. This computation is given in the precedent sections. If the *C/N* is higher than the C/N_{wanted} then:

$$C/I = -10 \log (10\hat{}(-(C/N)_{wanted}/10) - 10\hat{}(-(C/N)/10))$$

The downlink signal level of the GSO carrier is computed using the precedent sections. Knowing the *C/I* that will drive the actual *C/N* to the studied *C/N* value, and knowing the value of *C*, one can derive the value of the interfering signal needed:

$$I = C - C/I$$

The epfd$_\downarrow$ level associated with the interference power I is then derived from the following formula:

$$epfd\_max = I + 10 \log (4\pi/\lambda^2) - G + 10 \log (W_{ngso}/W_{gso})$$

where:

$$\lambda = 0.3/F \quad \text{and} \quad G = G_{max} - P$$

with:

- F: transmit frequency of the GSO satellite
- P: pointing losses (dB)
- G_{max}: on-axis gain.

ANNEX 3

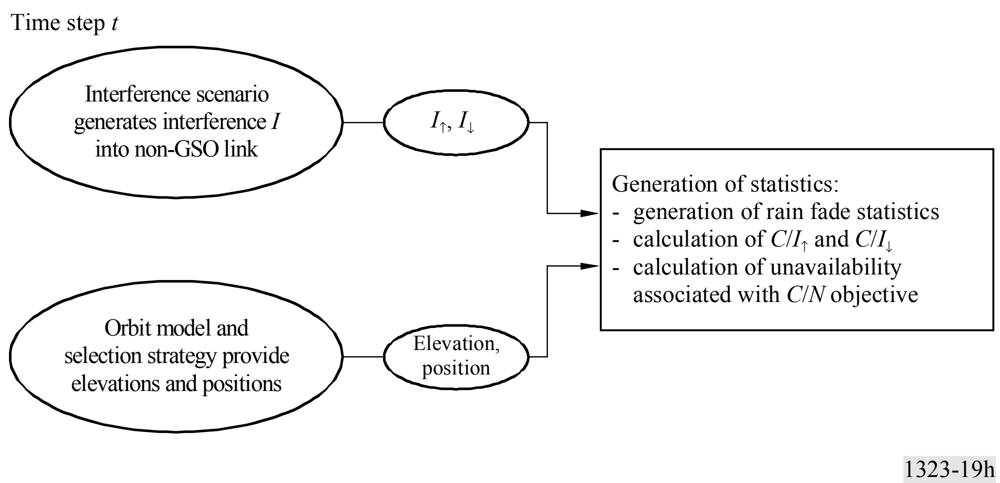
A procedure for assessing interference to links with variable elevation angle

1 Introduction

The approach taken here was to include a dynamic model into Procedure D described in Annex 2. At each time step, the geometrical configuration of the non-GSO system is assessed: position of the serving satellite, elevation of this satellite with both the transmitting and the receiving non-GSO earth stations. For this spatial configuration of the non-GSO constellation, the aggregate interference of a given GSO scenario can be calculated for both the uplink and the downlink path.

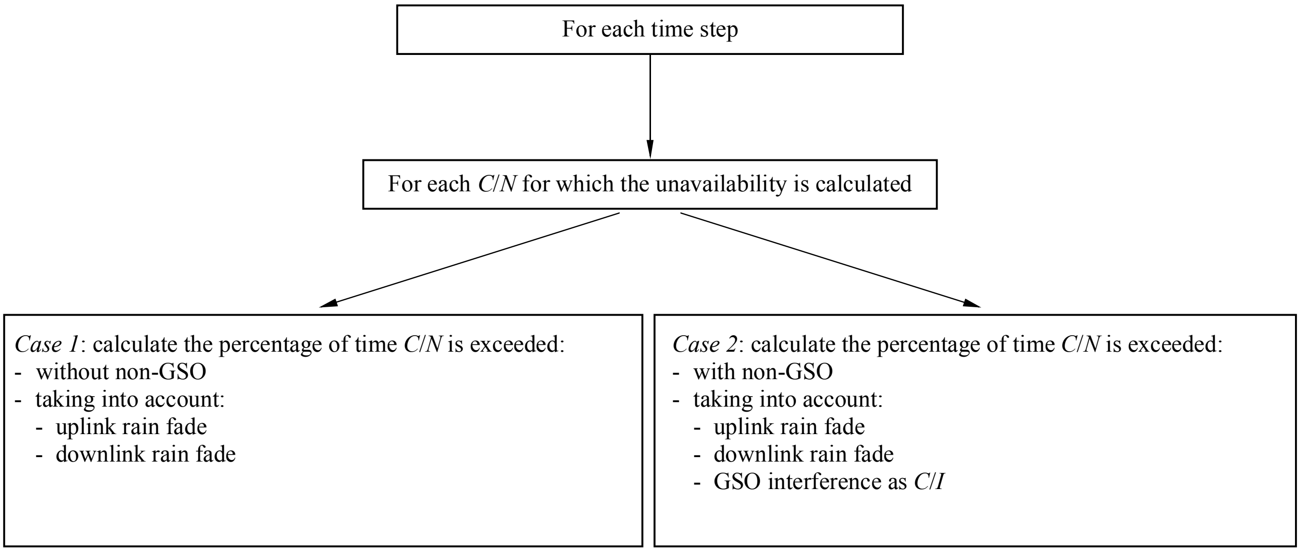
Procedure D can then be applied for the given time step, assessing the impact on the unavailability of the given $I_\uparrow$ and $I_\downarrow$ generated by a GSO network.

The following flow charts describe the different steps in this methodology:



At each time step, the first action is to generate the interference noise power generated by the interference environment and the elevation and position of the non-GSO satellite serving the non-GSO earth station.

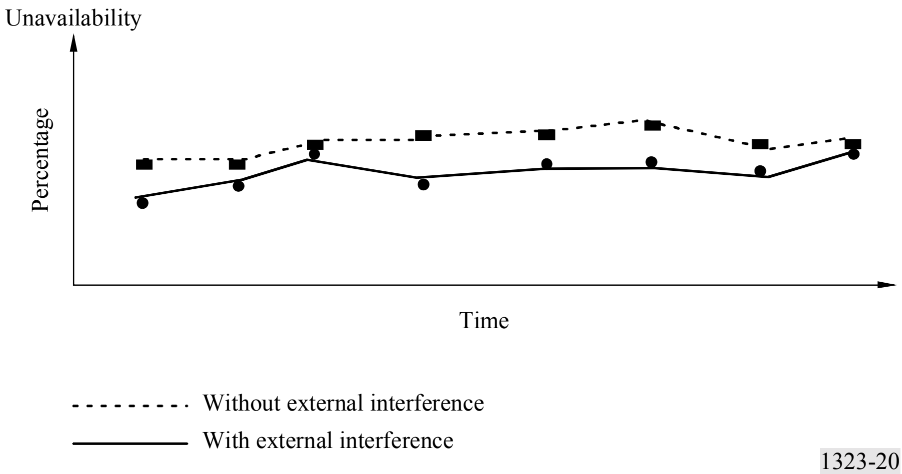
After this first action, for each time step, application of Procedure D is possible, taking into account the interference as a constant C/I (one for uplink and one for downlink).



1323-19i

In the end, a statistic of (C/N, availability associated) and of ($C/(N + I)$, availability associated) is generated for each time step.

FIGURE 20



1323-20

For a given C/N, application of D'.

Case 1: cdf of total C/N without GSO

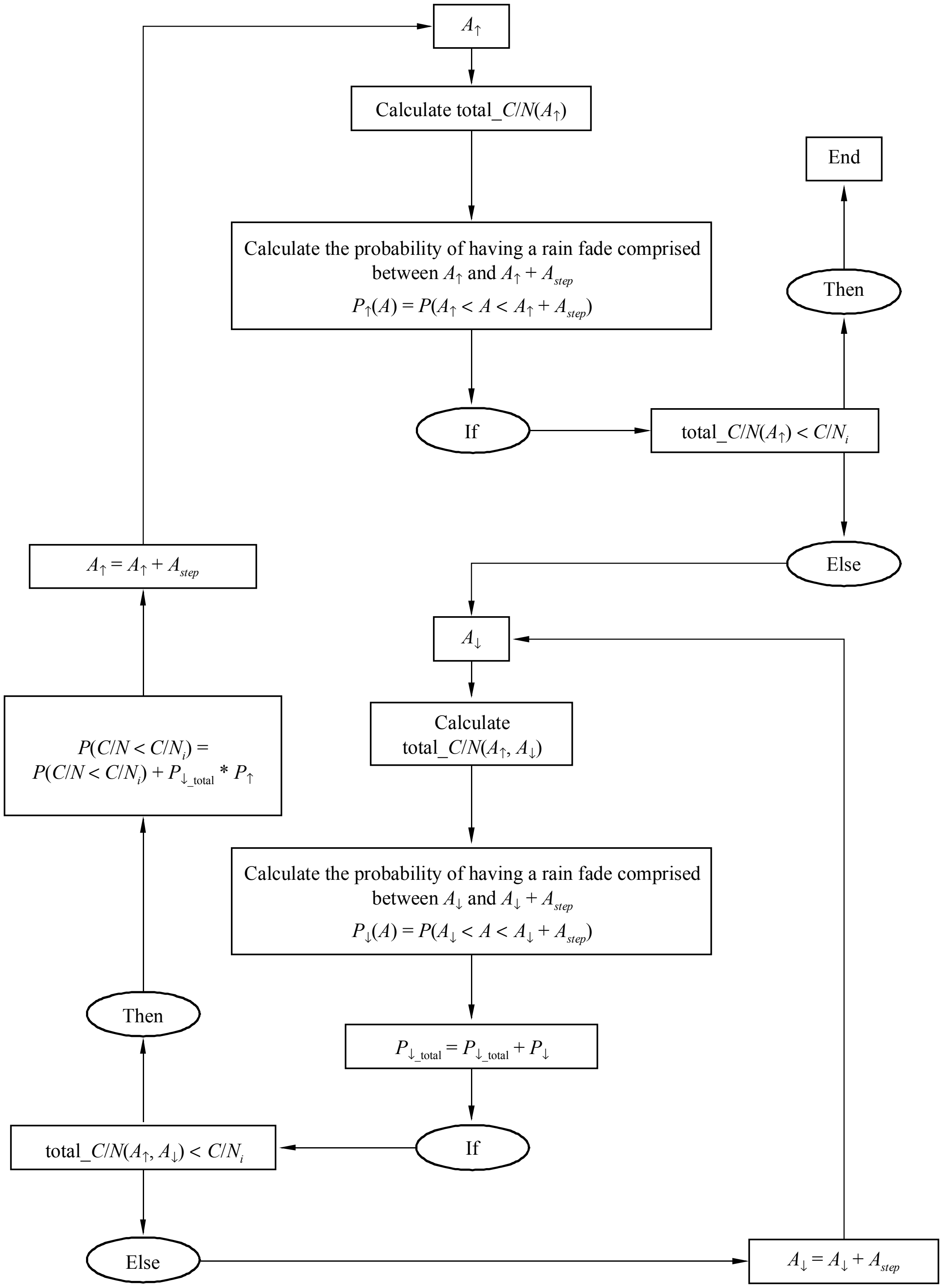
For each tested C/N for which the unavailability is calculated, with the following notations:

total_$C/N(A\uparrow)$: total C/N of the carrier with an uplink rain attenuation of $A\uparrow$ and no downlink attenuation

total_$C/N(A\uparrow, A\downarrow)$: total C/N of the carrier with an uplink rain attenuation of $A\uparrow$ and a downlink rain attenuation of $A\downarrow$

C/N_i: C/N for which the associated percentage of time is being calculated

A_{step}: calculation step for the rain attenuation.



1323-20a

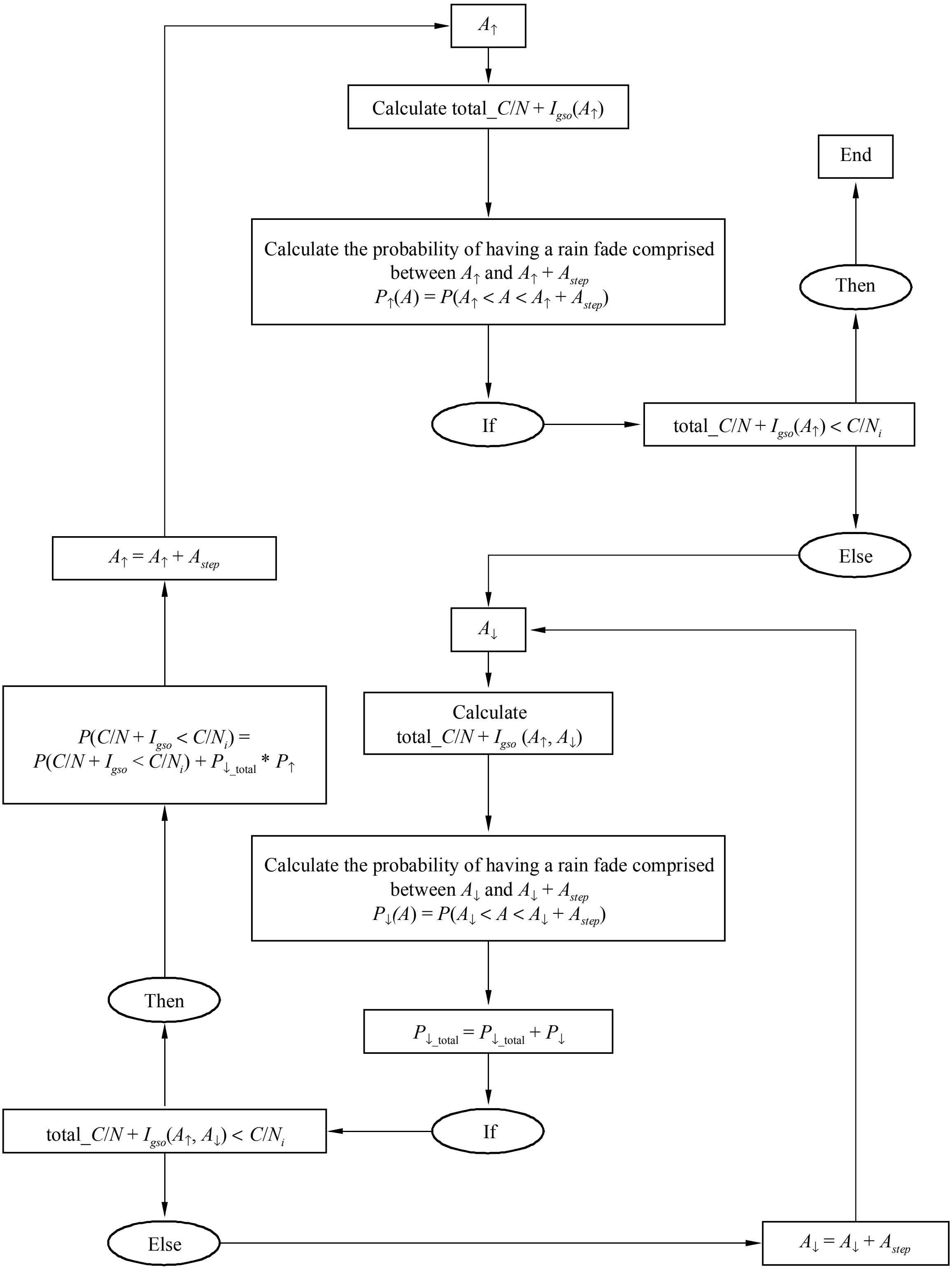
Case 2: cdf of total C/N with GSO

For each tested C/N for which the unavailability is calculated, with the following notations:

total_$C/N + I_{gso}(A↑)$: total $C/(N + I)$ of the carrier with an uplink rain attenuation of $A↑$, with inclusion of $I↑$ and $I↓$ interference noise power generated by the GSO interference scenario and no downlink attenuation total_$C/N + I_{gso}(A\uparrow, A\downarrow)$: total $C/(N + I)$ of the carrier with an uplink rain attenuation of $A\uparrow$ a downlink rain attenuation of $A\downarrow$ and with inclusion of $I\uparrow$ and $I\downarrow$ interference noise power generated by the GSO interference scenario

C/N_i: C/N for which the associated percentage of time is being calculated

A_{step}: calculation step for the rain attenuation.



1323-20b

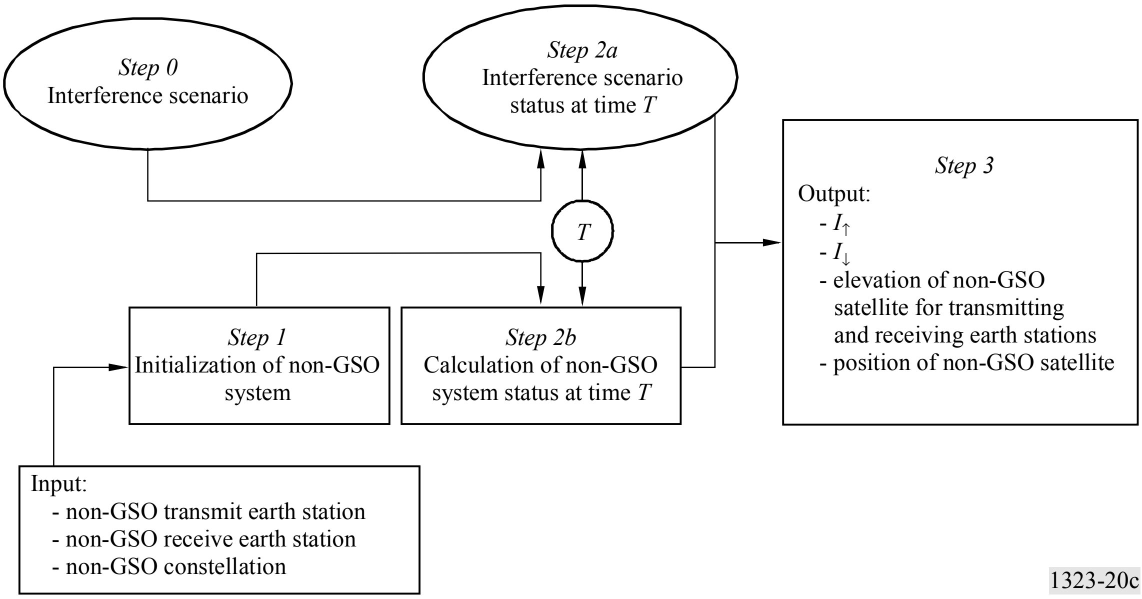
This is done for every time step over a period of the non-GSO constellation. Averaging the different unavailabilities for the *C*/*N* associated with the non-GSO performance objectives, the overall unavailability is obtained.

It is then possible to assess the relative increase of unavailability due to the chosen GSO scenario.

2 Implementation of the methodology

The following section describes an implementation of the described methodology. It provides the flow charts of the software and the various formulae used in deriving the simulations.

2.1 General algorithm



1323-20c

The procedure considers the protection of a given link between the non-GSO transmitting earth station and the receiving non-GSO earth station in the case of a transparent satellite (or only the uplink or downlink cases for regenerative transponder).

2.1.1 *Step 0*: identification of a reference interference scenario

An input to the procedure is the interference environment of the non-GSO system. In the case of impact of GSO systems on a non-GSO FSS network, the establishment of a realistic GSO environment will be the first step.

This database will be in the form of a list of links (GSO space-station/non-GSO earth station). The radio parameters will be the e.i.r.p. radiation pattern of the GSO earth station (on- and off-axis) and the pfd on the ground function of the elevation angle of the GSO satellites. For the e.i.r.p., both on-axis and off-axis e.i.r.p. will be considered.

The format of the pfd and off-axis e.i.r.p. is given hereafter for the 14/11 GHz band:

Downlink: pfd function of the elevation angle

The pfd limits proposed in a contribution are repeated in Table 5.

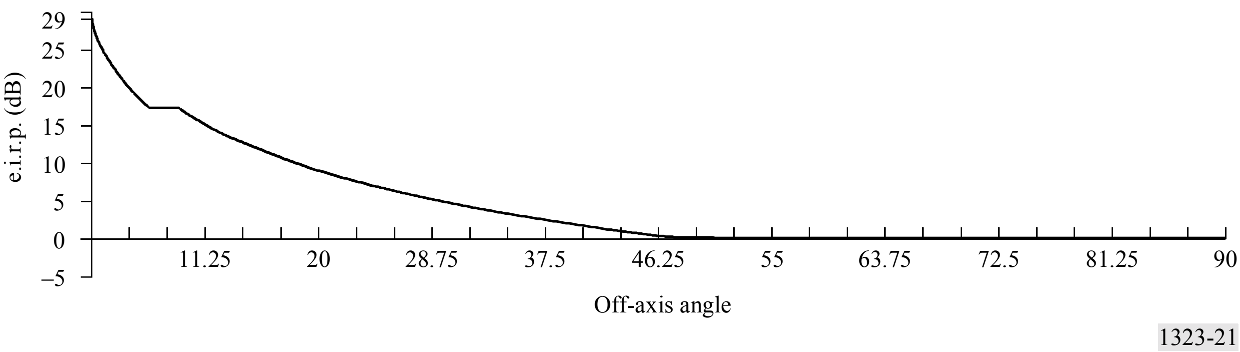
TABLE 5

Frequency band	Service	Limit (dB(W/m²)) for angle of arrival (δ) above the horizontal plane			Reference bandwidth
		0°-5°	5°-25°	25°-90°	
11.7-12.2 GHz (Region 2) and 12.5-12.75 GHz (Region 1)	Fixed-satellite (space-to-Earth)	–114	–114 + 0.5 (δ – 5)	–104	10 MHz

Uplink: off-axis e.i.r.p.

All the GSO earth stations have an e.i.r.p. corresponding to the further described mask. Figure 21 shows the off axis e.i.r.p. mask used for all the GSO earth stations. It corresponds to the off-axis e.i.r.p. mask of Section VI of RR Article S22.

FIGURE 21



or:

Off-axis angle	*Maximum e.i.r.p. per 40 kHz*
2.5° < φ ≤ 7°	(53 – 25 log φ) dB(W/40 kHz)
7° < φ ≤ 9.2°	32 dB(W/40 kHz)
9.2° < φ ≤ 48°	(56 – 25 log φ) dB(W/40 kHz)
48° < φ ≤ 180°	14 dB(W/40 kHz)

2.1.2 *Step 1*: initialization of the non-GSO parameters at time step, *t*

The first step of the procedure is to initialize the different segments of the non-GSO system. The ground segment will be modelled by a receiving earth station (RES) and a transmitting earth station (TES) both identified by their latitude and longitude and their radio parameters. The non-GSO constellation will also be initialized.

A switching strategy is then necessary to identify which of the satellites of the non-GSO constellation will be serving the two non-GSO earth stations (called the active non-GSO satellite) at a given time step.

2.1.3 *Step 2*: calculation of the elevations and active non-GSO satellite position

For a given time step, Step 1 has provided which satellite of the non-GSO constellation is serving the TES and the RES. The next step is to calculate the elevations (E_{TES} and E_{RES}) of the satellite with respect to the RES and TES.

The position of the active non-GSO satellite (Xa, Ya, Za) will also be calculated in this step.

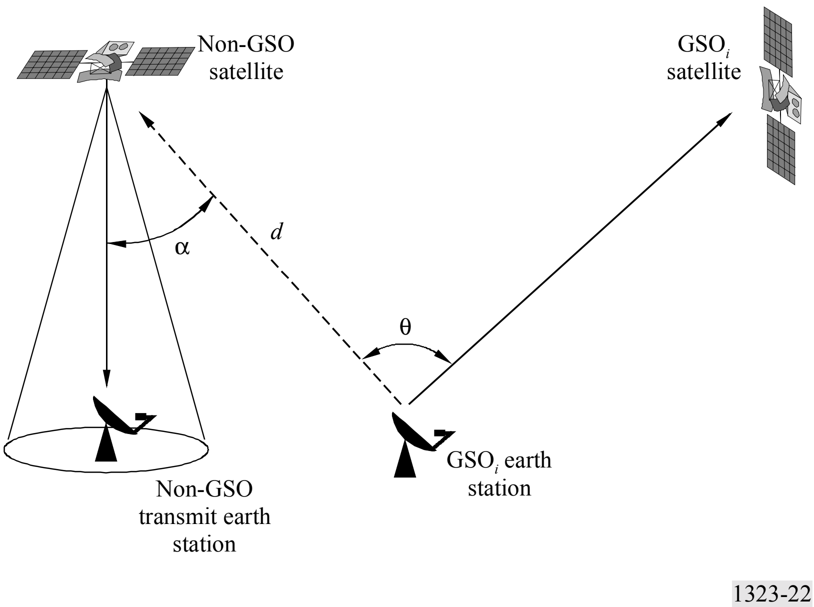
2.1.4 *Step 3*: calculation of the uplink interference, $I_{\uparrow}$, and downlink interference, $I_{\downarrow}$

The next step of the methodology is to calculate the uplink and the downlink noise power due to the GSO interference scenario chosen.

– Uplink noise power calculation:

The interference from one GSO earth station is pictured in Fig. 22:

FIGURE 22



The interference noise power generated by the *i*-th GSO earth station on the uplink path is given by:

$$(I_{\uparrow})_i \;=\; e.i.r.p.(\theta) \;-\; 20 \log (4\pi \, d/\lambda) \;+\; G_{ngso}(\alpha) \;+\; 10 \log (B_{ngso})$$

where:

e.i.r.p.(θ): off-axis e.i.r.p. in the non-GSO satellite direction

d: distance between the non-GSO satellite and the GSO earth station

λ: wavelength

$G_{ngso}(\alpha)$: non-GSO satellite reception gain in the direction of the GSO earth station

B_{ngso}: calculation bandwidth.

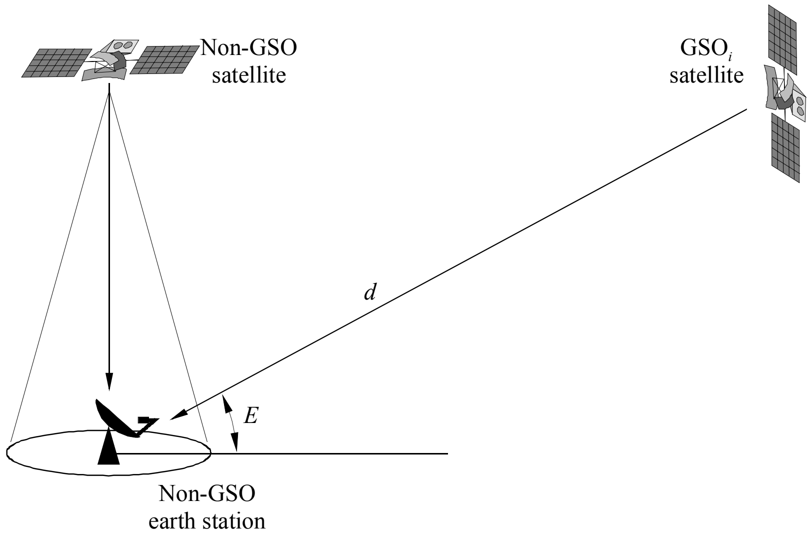
The aggregate uplink interference noise power is given by the sum of each individual contributions:

$$(I_{\uparrow}) = \sum (I_{\uparrow})\, i \;=\; \sum (e.i.r.p.(\theta) \;-\; 20 \log (4\pi \, d/\lambda) \;+\; G_{ngso}(\alpha) \;+\; 10 \log (B_{ngso}))$$

– Downlink noise calculation:

On the downlink path the interference geometry is given by Fig. 23:

FIGURE 23



1323-23

The first step is to calculate the epfd generated by the equivalent GSO constellation. It is given by:

$$epfd_{\downarrow} = 10 \log \left[\sum_{i=1}^{N_s} 10^{pfd_i/10} \cdot \frac{G_r(\theta_i)}{G_{max}} \right]$$

where:

N_s: number of GSO space stations;

pfd_i: pfd generated by the i-th GSO space station

$G_r(\theta)$: gain of the non-GSO earth station in the direction of the interfering GSO

G_{max}: maximum gain of the non-GSO earth station.

The interference noise power is calculated by:

$$I_{\downarrow} = epfd_{\downarrow} + 10 \log (\lambda^2/4\,\pi) + G_{max\_RES} + 10 \log (B_{ngso})$$

where:

$epfd_{\downarrow}$: pfd on the ground of the GSO constellation

λ: wavelength

G_{max_RES}: maximum receive antenna gain of the non-GSO earth station

B_{ngso}: reference bandwidth.

2.1.5 *Step 4*: application of Procedure D at the given time step

The next step is to apply the procedure described in Annex 2 of this Recommendation. Procedure D, with a link budget associated with the non-GSO system, enables to calculate, for the given time step, the unavailability associated to the performance objectives (C/N) and the relative reduction due to the GSO interference scenario.

2.1.6 *Step 5*: derivation of the impact of the GSO scenario

Once Step 4 has been done for the whole non-GSO constellation period, an average of all the time steps provide the system C/N availability performance and the impact of the GSO scenario.

2.2 Example of application

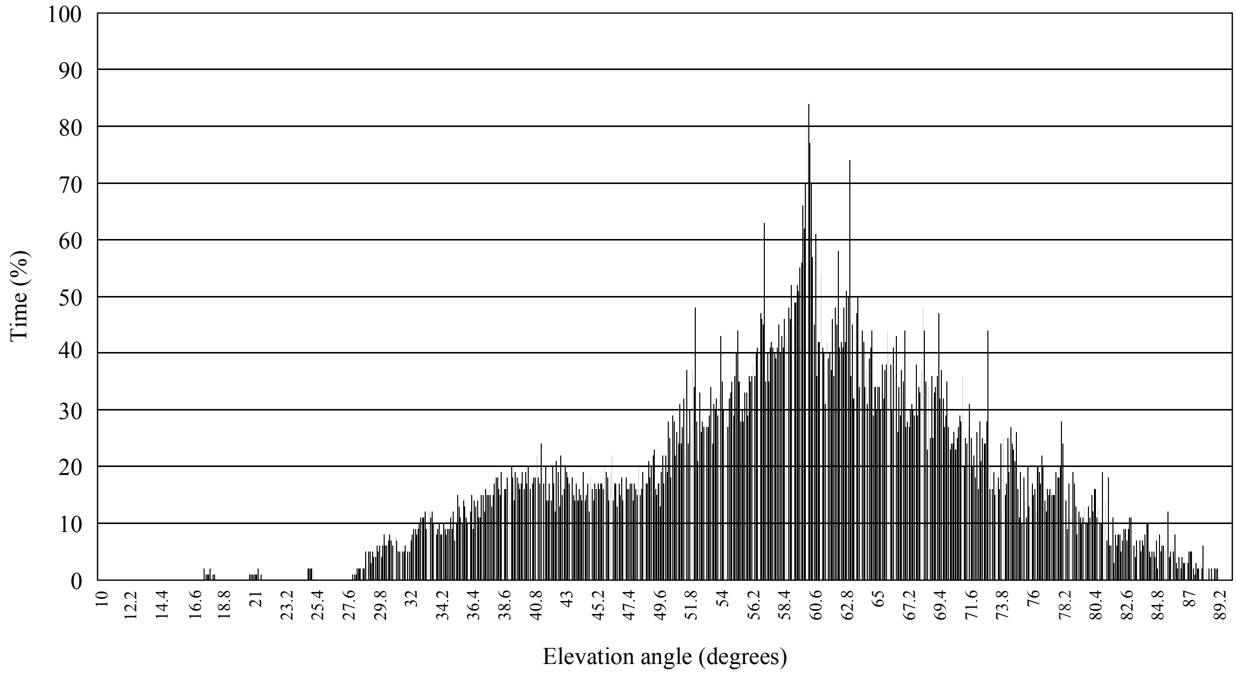
This example is given with the following interference scenario:

Name_GSO	Longitude	Name of earth station	Latitude	Longitude
GSO0	0	ES0	55	–20
GSO1	3	ES1	55	–10
GSO2	6	ES2	55	0
GSO3	9	ES3	55	10
		ES4	55	20
		ES5	45	–20
		ES6	45	–10
		ES7	45	0
		ES8	45	10
		ES9	45	20
		ES10	35	–20
		ES11	35	–10
		ES12	35	0
		ES13	35	10
		ES14	35	20
		ES15	25	–20
		ES16	25	–10
		ES17	25	0
		ES18	25	10
		ES19	25	20
		ES20	15	–20
		ES21	15	–10
		ES22	15	0
		ES23	15	10
		ES24	15	20
		ES25	5	–20
		ES26	5	–10
		ES27	5	0
		ES28	5	10
		ES29	5	20

Each of the GSO space station is pointed at by all the GSO earth stations. The simulation is run over 13 000 s with a 1 s time step. The following results are available:

FIGURE 24

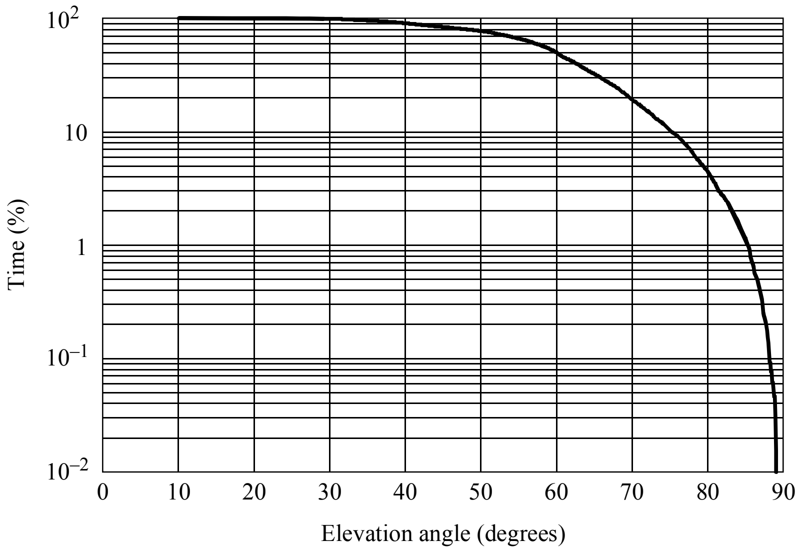
pdf of the elevation of the active non-GSO satellite



1323-24

FIGURE 25

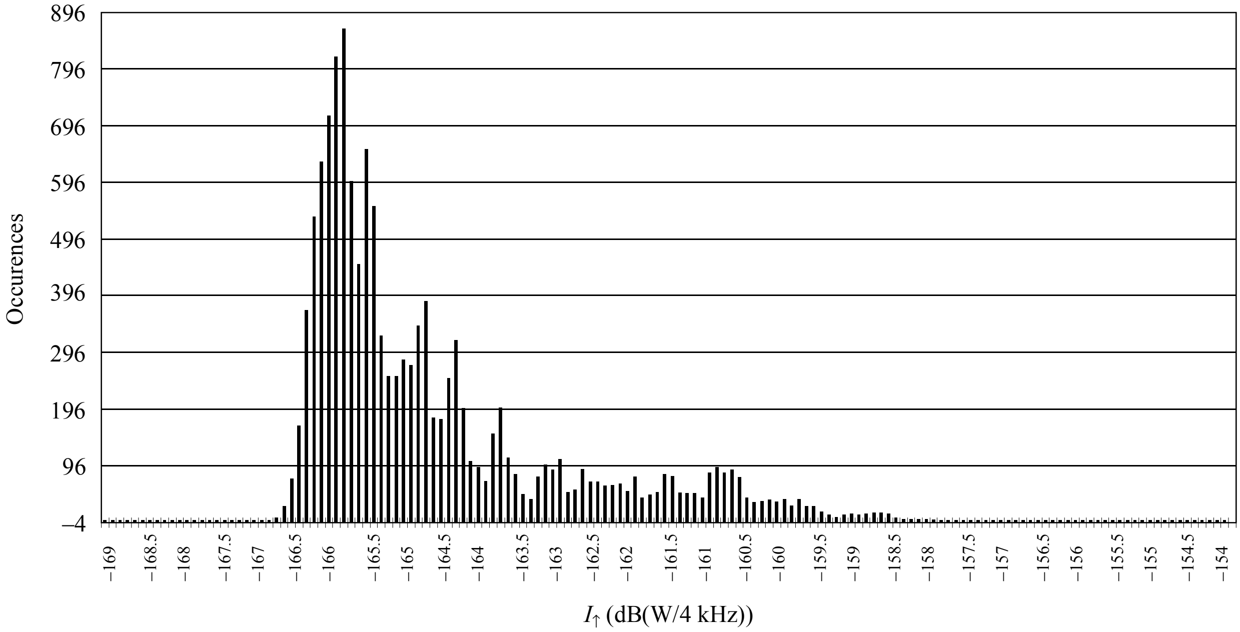
CDF of the elevation of the active non-GSO satellite



1323-25

FIGURE 26

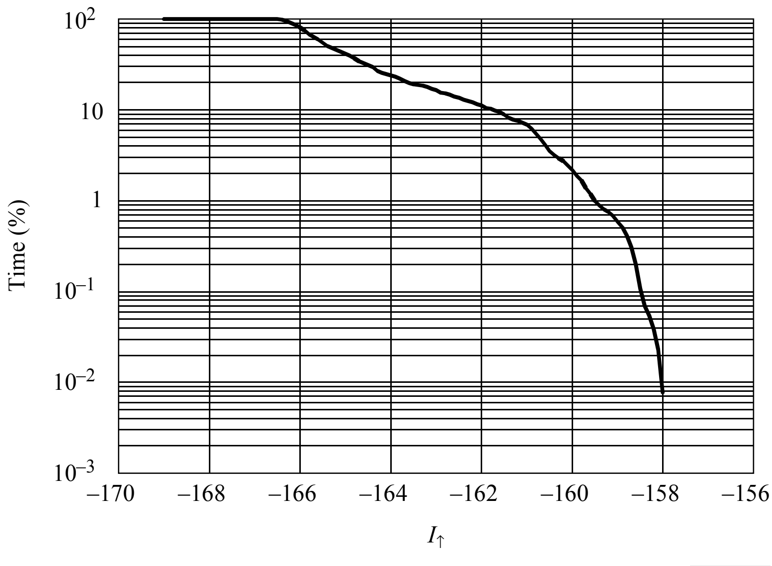
pdf of the uplink interference noise



1323-26

FIGURE 27

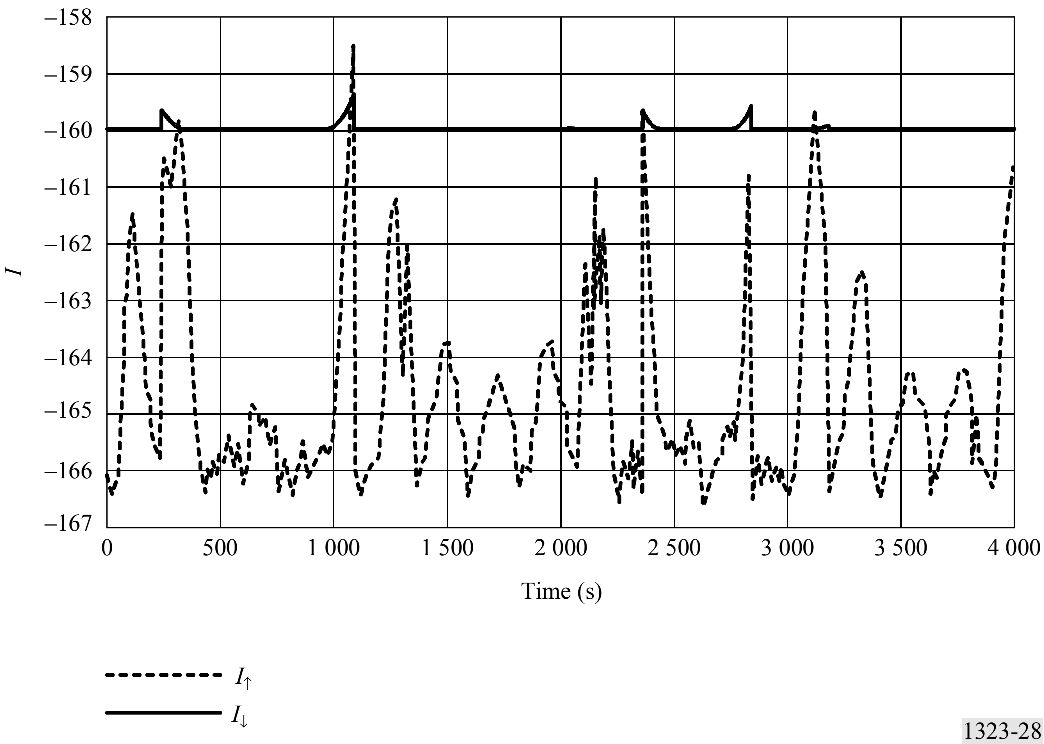
CDF of the uplink interference noise



1323-27

FIGURE 28

Variation of the uplink and downlink interference noise power with time



1323-28

The second step of the methodology is an application of Procedure D.

ANNEX 4

Procedure to determine acceptable epfd$_{\downarrow}$ levels via Methodology B

1 Introduction

This Annex develops a procedure to determine acceptable interfering epfd$_{\downarrow}$ levels into GSO satellite networks in the FSS from non-GSO satellite systems in the FSS from *I*/*N* ratios.

2 Expected interference scenarios

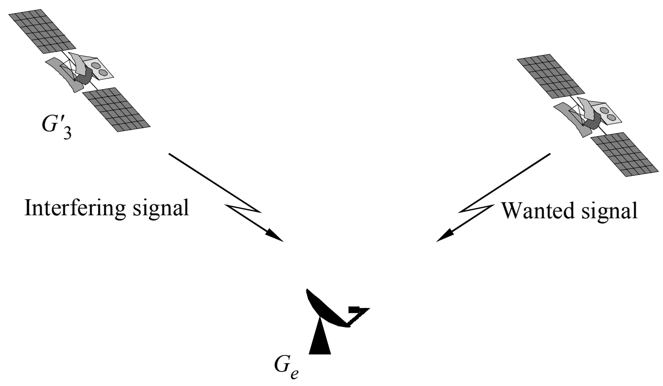
Interference between two satellite networks can occur when there is frequency overlap in one or more transmission links. In the case of interference between satellite networks there are up to five separate scenarios for frequency overlap, for which the system *I*/*N* can be determined. Those cases and the resultant equations for computing the causative pfd interference level are described in the following sections.

2.1 Scenario 1

Overlap in the downlink only, i.e. wanted signal originates from the wanted satellite such as a telemetry signal or downlink transmissions from an onboard processing satellite (see Fig. 29).

$$epfd_{\downarrow} = 10 \log\left(\frac{I_e}{N_e}\right) - G_{e\,max} + 10 \log(T_e) + 10 \log(B) + G(1\,\text{m}^2) - 228.6 \qquad \text{dB(W/m}^2\text{)} \qquad (83)$$

FIGURE 29



1323-29

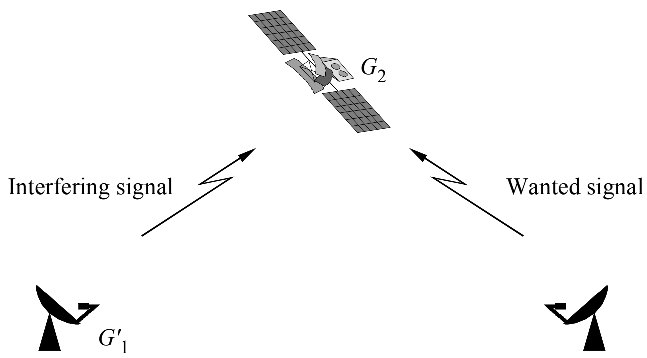
2.2 Scenario 2

Overlap in the uplink only, i.e. wanted signal originates in an earth station and terminates in the wanted satellite. Example is a telemetry signal or on board processing satellite (see Fig. 30).

$$epfd_{\uparrow} = 10 \log\left(\frac{I_s}{N_s}\right) - G_s + 10 \log(T_s) + 10 \log(B) + G(1\,\text{m}^2) - 228.6 \qquad \text{dB(W/m}^2\text{)} \qquad (84)$$

$$G_s = G_{2\,max}$$

FIGURE 30



1323-30

2.3 Scenario 3

Overlap in the uplink only, i.e. wanted signal originates in an Earth terminal and ends in a wanted earth station. A transparent (bent pipe) satellite network is an example (see Fig. 31).

$$epfd_{\uparrow} = 10 \log \left(\frac{\left(\frac{I_s}{N}\right) \times \left(\frac{4\pi}{\lambda^2}\right) k\,(T_e + \gamma T_s)\,B}{G_s \times \gamma} \right) =$$

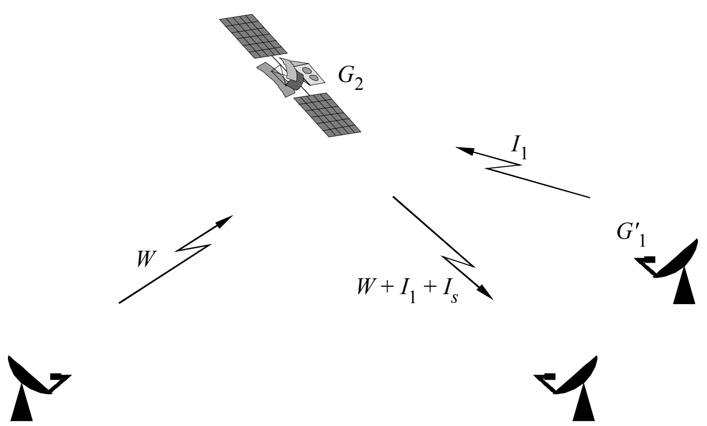
$$= \frac{I_s}{N} - 10 \log (G_s) + 10 \log \left(\frac{T_e}{\gamma} + T_s \right) + 10 \log (B) + G(1\,\text{m}^2) - 228.6 \qquad \text{dB(W/m}^2) \qquad (85)$$

where:

$$G_s = G_{2\,max}$$
$$T = T_e + \gamma T_s \qquad (85a)$$

$$\gamma = \frac{\left(\frac{C}{N}\right)_{\downarrow} T_e}{\left(\frac{C}{N}\right)_{\uparrow} T_s}$$

FIGURE 31



I_1 : interfering signal
I_s : uplink interfering signal retransmitted from the satellite
W : wanted signal

1323-31

2.4 Scenario 4

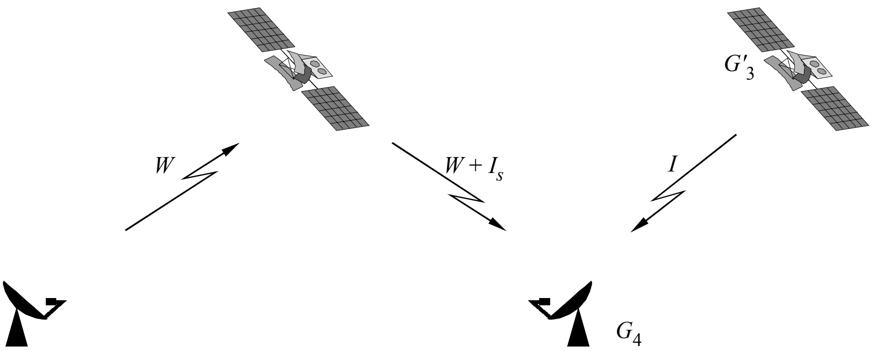
Overlap in the downlink only. The wanted signal originates in an earth station and terminates in a wanted earth station. A transparent (bent pipe) satellite transmission is an example (see Fig. 32).

$$epfd_{\downarrow} = 10 \log \left(\frac{I_e}{N} \right) + 10 \log (T) - G_e + 10 \log (B) + G(1\,\text{m}^2) - 228.6 \qquad \text{dB(W/m}^2) \qquad (86)$$

where:

$$G_e = G_{4\,max}$$
$$T = T_e + \gamma T_s \qquad (86a)$$

FIGURE 32



I : interfering signal
I_s : interfering signal generated in a bent-pipe satellite
W : wanted signal

1323-32

2.5 Scenario 5

Overlap in both links. Wanted signal originates and terminates in an earth terminal, i.e. bent-pipe net (see Fig. 33).

$$\frac{I_\downarrow}{N} = epfd_\downarrow \times \frac{\lambda^2}{4\pi} \times \frac{G_{4\,max}}{k\,T\,B}$$

$$epfd_\downarrow = \frac{\frac{I_\downarrow}{N} \times k\,T\,B\left(\frac{4\pi}{\lambda^2}\right)}{G_e}$$

$$\frac{I_\uparrow}{N} = \gamma\, epfd_\uparrow \times \frac{\lambda^2}{4\pi} \times \frac{G_2}{k\,T\,B}$$

$$epfd_\uparrow = \frac{\frac{I_\uparrow}{N} \times k\,T\,B\left(\frac{4\pi}{\lambda^2}\right)}{G_s\,\lambda}$$

$$epfd_\downarrow = \left(\frac{I_\downarrow}{N}\right) + 10\log\left(T_e + \gamma T_s\right) - G_e + 10\log\left(B\right) + G(1\,\text{m}^2) - 228.6 \qquad \text{dB(W/m}^2\text{)} \qquad (87)$$

$$epfd_\uparrow = \left(\frac{I_\uparrow}{N}\right) + 10\log\left(\frac{T_e}{\gamma} + T_s\right) - G_s + 10\log\left(B\right) + G(1\,\text{m}^2) - 228.6 \qquad \text{dB(W/m}^2\text{)} \qquad (88)$$

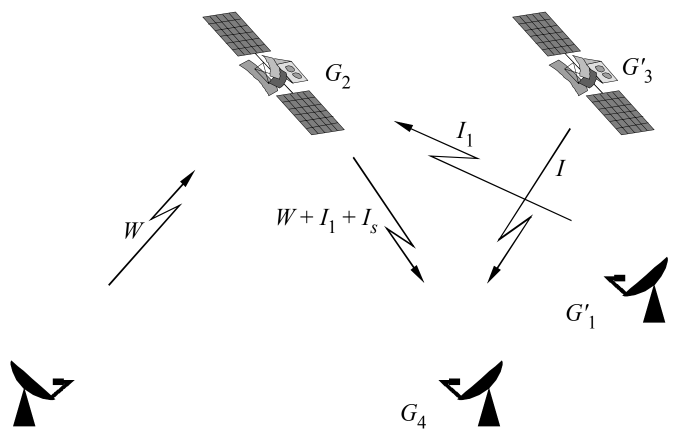
where:

$$\frac{I_\downarrow}{N} = \frac{I_e}{N} = \frac{\Delta T_e}{T}$$

$$\frac{I_\uparrow}{N} = \frac{I_s}{N} = \frac{\Delta T_s}{T} \qquad (88a)$$

$$T = T_e + \gamma T_s$$

FIGURE 33



3 The effect of transmission gain, γ

In equations (85) to (88), although similar to equations (83) and (84), the term for transmission gain, γ, appears. The impact of transmission gain and how best to take it into account is considered in the following discussion.

From Recommendation ITU-R S.738, transmission gain, γ, is defined as:

"γ transmission gain of a specific satellite link subject to interference evaluated from the output of the receiving antenna of the space station S to the output of the receiving antenna of the earth station e_R (numerical power ratio, usually less than 1)."

Transmission gain, γ, can be expressed as:

$$\gamma = \left(\frac{\left(\frac{C}{N_0}\right)_\downarrow}{\left(\frac{C}{N_0}\right)_\uparrow} \right) \left(\frac{T_e}{T_s}\right)$$

$$T = \left(\frac{\left(\frac{C}{N_0}\right)_\downarrow}{\left(\frac{C}{N_0}\right)_\uparrow} \right) T_e \qquad (89)$$

where:

$(C/N_0)_\uparrow$: uplink C/N density ratio including only thermal and other background noises (numerical ratio)

$(C/N_0)_\downarrow$: downlink C/N density ratio including only thermal and other background noises (numerical ratio)

$(C/N_0)_t$: total link equivalent C/N density ratio including intra-satellite impairment (intra-satellite interference, intermodulation), thermal and other background noises (numerical ratio).

Since the pfd protective level is to be derived from a criteria that is defined as a percentage of the system noise temperature, the resultant pfd level will increase or decrease with the value of transmission gain, γ. To be effective the pfd level selected to protect a GSO-FSS network must take into account the network's lowest system noise temperatures as function of transmission gain, γ. Therefore, selecting the smallest γ, $(T_e + \gamma T_s)$ for each specific earth station size (antenna gain) would determine the maximum acceptable pfd value required to protect all GSO/FSS networks when operating in bands shared with non-GSO/FSS networks.

From equation (89) it is seen that the numerical value of transponder gain, γ, is dependent on the *C*/*N* values of both uplinks and downlinks and the values of T_e and T_s. The *C*/*N*s, in turn, are dependent on transponder saturation levels; transponder signal back-off levels; earth station antenna size; specific frequency bands; and, individual carrier performance requirements. It can be shown that different carriers simultaneously using the same transponder may have different transmission gain values. It can also be shown that the transmission gain for similar carrier transmissions using the same transponders will vary depending on, among other things, rain margins needed for the area served and the slant range to the Earth surface to be served. Accordingly, it is difficult to determine standard values for transmission gain, γ. It is, however, reasonable to expect that network links using smaller earth stations will generally exhibit smaller values of transmission gain than large earth stations, which in some cases could exceed 15 dB. However, large earth station networks, especially those utilized for narrow multi-carrier operation can have minimal transmission gain ratios, some approaching minus 20 (–20) dB.

4 Selection of pfd equation

During the period of development (near year 2000) of this Recommendation, contemporary thermal noise temperature values expected to be achieved for earth stations and space stations receivers operating in the 10-14 GHz bands, are about 150 K and 500 K respectively. Since receiver thermal noise temperature for different antenna sizes are approximately constant whereas the minimum value of γ increases with antenna size, it is appropriate to considering the effect of γ on networks that utilize large earth stations using the best expected system noise temperatures. Given the above minimum values i.e. $T_e = 150$ K, $T_s = 500$ K and $\gamma = 0.01$ then from equation (85a), (86a) or (88a) the system noise temperature for a network with those parameters is:

$$T = (150 + 0.01(500)) = 155\ \text{K}$$

It is apparent that the effect of transmission gain, γ, on downlink system noise temperatures of even large earth station networks can be minimal and therefore ignored for even bent-pipe networks. The effect of, γ, is still minimal when T_e and T_s are increased by some factor (say 20%) to account for self and intra-network interference. This value is to be reviewed based on the link parameters supplied as part of the ITU-R studies relating to the review of the provisional pfd limits.

Where the above assumptions are valid, equation (83) and (84) (which are equivalent) may be used to determine candidate pfd (epfd↑ or epfd↓) limits needed to protect GSO/FSS networks from non-GSO/FSS networks.

4.1 Parameter values for calculating epfd↓ and epfd↑

Equations (87) and (88) are reproduced below with parameter revisions that take into account recommended system noise temperature increases (33%) due to internal and intra-system sources of interference.

$$epfd_{\downarrow} = 10 \log \left(\frac{\Delta T_e}{T_e} \right) - G_{e\,max} + 10 \log (1.33\, T_e) + 10 \log (B) + G(1\,\text{m}^2) - 228.6 \qquad \text{dB(W/m}^2) \quad (90)$$

$$epfd_{\uparrow} = 10 \log \left(\frac{\Delta T_s}{T_s} \right) - G_s + 10 \log (1.33\, T_s) + 10 \log (B) + G(1\,\text{m}^2) - 228.6 \qquad \text{dB(W/m}^2) \quad (91)$$

The values 1.33 T_e and 1.33 T_s represent the uplink and downlink system noise temperatures that would exist in an FSS allocated band. Equations (90) and (91) represent the pfd levels that would allow an incremental increase of the (up/down) link noise temperature of 100 · Δ*T*/*T*%. The Δ*T*/*T* ratio increase will cause a degradation of the (up/down) link *C*/*N*s of:

$$Degradation = 10 \log \left(1 + \frac{\Delta T}{T} \right) \tag{92}$$

Table 6 presents a typical summary calculation of epfd↓ levels from non-GSO/FSS into GSO/FSS downlinks for various degradations of system noise temperatures for representative earth station sizes and frequencies in the 11 GHz band. The earth station receiver noise temperature is assumed to be 150 K. It is also assumed that other sources of noise i.e. self and intra-network interference, adds 33% additional noise for all cases. Note that by appropriately using the values in the column allowable degradation values of epfd↓ corresponding to different percentages of time can be derived.

Figure 34 reduces the information required to specify epfd↑ and epfd↓ limits to protect GSO/FSS networks during their availability to several example ranges i.e. 3%, 6% and 15% (single non-GSO/FSS entry, multiple entry to be determined) and presents it in a graphical format, thereby allowing the determination of protective limits for a wide range continuum of antenna sizes. Short-term unavailability requirements require further study.

FIGURE 34

Downlink interfering epfd limits in the 12 GHz band

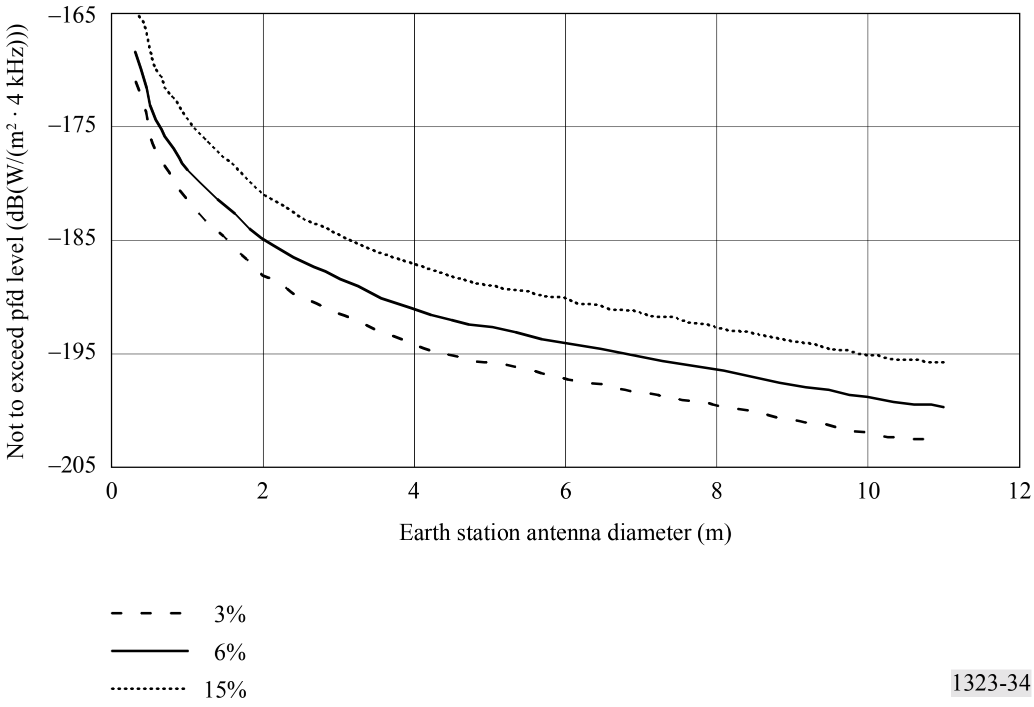


TABLE 6

Example calculations of epfd↓ for various earth station antennas

Downlink frequency:	11.82 GHz		Reference bandwidth:	4 kHz
Receiver noise temperature:	150 K		Reference 1 m antenna gain:	42.9 dB
Noise increase due to intra- and inter-system interference:	25%	$T_{\downarrow\text{-}self} + T_{\downarrow\text{-}other\ GSO} = 25\% \ (T_{Rx\text{-}Earth})$		
Total system noise temperature, T_s:	187.5 K			

		Earth station antenna size (m)			0.3	0.6	0.8	1.0	1.2	1.8	2.4	3.0	4.5	10.0	11.0
		Earth station antenna beamwidth (degrees)			5.91	2.95	2.21	1.77	1.48	0.98	0.74	0.59	0.39	0.18	0.16
		Earth station antenna efficiency (%)			72.00	72.00	72.00	72.00	70.00	68.00	65.00	65.00	63.00	62.00	60.00
		Earth station antenna gain (dBi)			30.0	36.0	38.5	40.4	41.9	45.3	47.6	49.5	52.9	59.8	60.5
		Earth station G/T_e (dB/K)			7.2	13.3	15.8	17.7	19.2	22.6	24.9	26.8	30.2	37.0	37.7
$\Delta T_s/T_s$ (%)	I/N (dB)	Allowable rain fade (dB)	G/T degradation (dB)	Allowable degradation (dB)	Maximum epfd from non-GSO systems (dB(W/(m^2 · 4 kHz)))										
0.9	–20.46	0.02	0.01	0.04	–177.4	–183.4	–185.9	–187.8	–189.3	–192.7	–195.0	–196.9	–200.3	–207.2	–207.9
1	–20.00	0.03	0.01	0.04	–176.9	–182.9	–185.4	–187.4	–188.8	–192.2	–194.5	–196.5	–199.9	–206.7	–207.4
3	–15.23	0.06	0.07	0.13	–172.1	–178.2	–180.7	–182.6	–184.1	–187.5	–189.8	–191.7	–195.1	–202.0	–202.6
6	–12.22	0.11	0.14	0.25	–169.1	–175.2	–177.7	–179.6	–181.1	–184.4	–186.8	–188.7	–192.1	–198.9	–199.6
10	–10.00	0.27	0.14	0.41	–166.9	–172.9	–175.4	–177.4	–178.8	–182.2	–184.5	–186.5	–189.9	–196.7	–197.4
15	–8.24	0.33	0.27	0.61	–165.2	–171.2	–173.7	–175.6	–177.1	–180.5	–182.8	–184.7	–188.1	–195.0	–195.6
25	–6.02	0.45	0.52	0.97	–162.9	–169.0	–171.5	–173.4	–174.9	–178.3	–180.6	–182.5	–185.9	–192.7	–193.4
35	–4.56	0.67	0.63	1.30	–161.5	–167.5	–170.0	–171.9	–173.4	–176.8	–179.1	–181.0	–184.4	–191.3	–192.0
45	–3.47	0.77	0.85	1.61	–160.4	–166.4	–168.9	–170.8	–172.3	–175.7	–178.0	–179.9	–183.3	–190.2	–190.9
50	–3.01	0.82	0.94	1.76	–159.9	–165.9	–168.4	–170.4	–171.8	–175.2	–177.5	–179.5	–182.9	–189.7	–190.4
60	–2.22	1.00	1.04	2.04	–159.1	–165.2	–167.7	–169.6	–171.1	–174.4	–176.8	–178.7	–182.1	–188.9	–189.6
70	–1.55	1.17	1.13	2.30	–158.5	–164.5	–167.0	–168.9	–170.4	–173.8	–176.1	–178.0	–181.4	–188.3	–189.0
80	–0.97	1.25	1.30	2.55	–157.9	–163.9	–166.4	–168.3	–169.8	–173.2	–175.5	–177.4	–180.8	–187.7	–188.4
90	–0.46	1.41	1.38	2.79	–157.4	–163.4	–165.9	–167.8	–169.3	–172.7	–175.0	–176.9	–180.3	–187.2	–187.9
100	0.00	1.56	1.46	3.01	–156.9	–162.9	–165.4	–167.4	–168.8	–172.2	–174.5	–176.5	–179.9	–186.7	–187.4
200	3.01	2.64	2.13	4.77	–153.9	–159.9	–162.4	–164.4	–165.8	–169.2	–171.5	–173.5	–176.8	–183.7	–184.4
300	4.77	3.51	2.51	6.02	–152.1	–158.2	–160.7	–162.6	–164.1	–167.5	–169.8	–171.7	–175.1	–182.0	–182.6
400	6.02	4.21	2.78	6.99	–150.9	–156.9	–159.4	–161.4	–162.8	–166.2	–168.5	–170.5	–173.8	–180.7	–181.4
500	6.99	4.85	2.94	7.78	–149.9	–155.9	–158.4	–160.4	–161.8	–165.2	–167.5	–169.5	–172.9	–179.7	–180.4
600	7.78	5.40	3.05	8.45	–149.1	–155.2	–157.7	–159.6	–161.1	–164.4	–166.8	–168.7	–172.1	–178.9	–179.6
700	8.45	5.88	3.15	9.03	–148.5	–154.5	–157.0	–158.9	–160.4	–163.8	–166.1	–168.0	–171.4	–178.3	–179.0
800	9.03	6.31	3.23	9.54	–147.9	–153.9	–156.4	–158.3	–159.8	–163.2	–165.5	–167.4	–170.8	–177.7	–178.4
900	9.54	6.70	3.30	10.00	–147.4	–153.4	–155.9	–157.8	–159.3	–162.7	–165.0	–166.9	–170.3	–177.2	–177.9
1000	10.00	7.08	3.34	10.41	–146.9	–152.9	–155.4	–157.4	–158.8	–162.2	–164.5	–166.5	–169.9	–176.7	–177.4

5 Overall principles for the establishment of candidate epfd↓ limits via Methodology A'

The selection of candidate pfd limits to protect GSO/FSS networks must take into account a generic range of parameters characterizing the GSO/FSS link, for both existing and planned networks. The limits should also allow evolutionary technological improvement of satellite and earth station receivers, particularly at the higher frequencies where receiver noise temperatures have significant opportunities to improve.

Interference from non-GSO/FSS networks differs from that of GSO/FSS networks in that it is of a time-varying nature and not steady state as from an interfering GSO/FSS network. It is consistent with *recommends* 6 to allow non-GSO/FSS networks to share spectrum with GSO networks provided that the aggregate from all non-GSO network would limit its effect on all GSO network system noise temperatures to a 6% increase or less during at least 90% of the time.

Recommends 3.1 would also indicate that all non-GSO networks sharing the band should contribute no more than 10% to the short-term unavailability period of any GSO network.