RECOMMENDATION ITU-R F.1669*

Interference criteria of fixed wireless systems operating in the 37-40 GHz and 40.5-42.5 GHz bands with respect to satellites in the geostationary orbit

(Question ITU-R 127/9)

(2004)

The ITU Radiocommunication Assembly,

considering

a) that it is desirable to determine the protection criteria of fixed wireless systems (FWS) operating in the 38 GHz (37-40 GHz) and 40 GHz (40.5-42.5 GHz) bands with respect to interference from geostationary-satellite (GSO) systems operating on a co-primary basis;

b) that in interference situations involving GSO space stations, fixed service (FS) systems are potentially exposed to high levels of interference for some geometric cases which could affect the performance or availability of these systems;

c) that the FS link design in the 38 and 40 GHz bands is controlled by rain attenuation, which can be modelled using Recommendation ITU-R P.530;

d) that in the 38 and 40 GHz bands, some administrations employ automatic transmit power control (ATPC) on some FS links and that such use will increase the susceptibility of these links, especially with regard to short-term interference;

e) that some FS links employing small net fade margins may not be fully protected from interference from GSO satellite systems without unduly constraining those services;

f) that typical FS links using ATPC will require tighter protection criteria than those needed for FS links with large fade margin that do not use ATPC;

g) that no pointing restrictions apply to FS systems in the 38 and 40 GHz bands, and that such restrictions are not practicable in view of the large-scale, cost-sensitive deployment,

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* This Recommendation should be brought to the attention of Radiocommunication Study Groups 3, 4 and 7.

recognizing

a) that the bands 37.5-40 GHz and 40.5-42.5 GHz are shared on a co-primary basis with the FSS, and that ITU-R established Recommendation ITU-R SF.1573, on pfd levels that are required to protect the FS in these bands;

b) that the application of the criteria in this Recommendation is not intended to lead to a revision of Recommendation ITU-R SF.1573,

noting

a) that the representation of the interference produced by GSO satellites on an FS receiver versus the whole azimuth of this FS receiver presents, as shown in Fig. 2, two interference peaks for two particular FS azimuth for which, depending on the geometry of the FS link, the pointing direction of this link passes through the GSO arc,

recommends

1 that the following interference criteria, defining an interference mask such as described in Fig. 1, should be used to protect the FS systems from interference produced by GSO satellites from various services in the 37-40 GHz and the 40.5-42.5 GHz bands on a co-primary basis:

1.1 for FWSs in general:

1.1.1 the I/N at the input of the FS receiver should not exceed −10 dB except within ±15° separation from the azimuth where the FS antenna main beam intersects with the GSO arc (see Notes 1 and 2);

1.1.2 for the FS azimuth within this ±15° range, I/N at the input of the FS receiver can be accepted up to +5 dB for the azimuth corresponding to the peaks (see Notes 1 and 2);

1.2 for some links in certain broadband wireless access (BWA) applications:

1.2.1 the I/N at the input of the FS receiver should not exceed −10 dB except within ±5° separation from the azimuth where the FS antenna main beam intersects with the GSO arc (see Notes 1 and 2);

1.2.2 for the FS azimuth within this ±5° range, I/N at the input of the FS receiver can be accepted up to +1 dB for the azimuth corresponding to the peaks (see Notes 1 and 2);

2 that the information contained in Annex 1 should be used as guidance for the use of this Recommendation.

NOTE 1 – These I/N levels are referenced to the total noise at the receiver input including system noise level, $k\ T\ B\ F$, and intra-service interference (see § 5 in Annex 1).

NOTE 2 – The ±15° or ±5° azimuth range specified in *recommends* 1.1 and 1.2, respectively, are based on the application of a temporal approach methodology and elements of a specific rain cell model. Further refinement of this rain cell model or a new model may have some impact on these azimuth ranges and may lead to further development of this Recommendation.

Annex 1

Derivation of FS protection criteria in the 38 GHz and 40 GHz bands to be applied in the GSO sharing scenarios

1 Introduction

The methodology presented in this Annex is based on the assumptions that the bit error performance in the 38 GHz and 40 GHz bands is dominated by rain fading. Therefore, in the situations where the interference from GSO satellites arrives at azimuths close to the azimuth of the main-beam axis of the FS receiving antenna, both the desired and the interfering signal will be subjected to fading. As a consequence, the unfaded interference power may be higher than that which would be permissible if the interference power was constant. This unfaded interference power is determined by requiring that the controlling bit error performance criterion be met for the same percentage of time regardless of whether any correlation exists between the fading of the desired and interfering power.

2 FS fade margins

In the 38 GHz and 40 GHz bands, and since link lengths are likely to be shorter than 2 km, an FS fade margin of 14 dB was considered representative of conventional links since it was assumed that a majority of such links have a fade margin (or net fade margin[1]) higher than this value. It has to be noted that this 14 dB fade margin, when considering systems using ATPC, corresponds to a link with a higher margin (e.g. = 14 dB net fade margin +10 dB ATPC range).

On the other hand, it was also noted that in certain BWA applications, a fade margin of 10 dB is used for some short links and that these links would consequently require a lower *I*/*N* value.

In support of the consideration of these margins, Table 2 which is based on Recommendation ITU-R P.530, gives the required rain margin for link lengths up to 1.6 km at five different rain rates for both vertical and horizontal polarization.

However, it has to be noted that the 14 dB or the 10 dB rain fade margin in these 38 and 40 GHz bands are justified on calculations using Recommendation ITU-R P.530 which does not provide values of fade margin referenced to an error performance measure but gives absolute attenuation values (rain fading) for a given percentage of time.

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[1] For an FS link using ATPC, the net fade margin = total fade margin – ATPC range.

In addition, according to Recommendation ITU-R F.1498, for a link designed for a 99.999% availability and in particular BWA systems which are assumed to compete with fibre, the fade margin may refer to the BER 1×10^{-6} or severely errored seconds (SESs) level. It was also agreed that the design of the FS link should take into account a 1 dB allowance for interference from the FS which hence increases the reference noise power to 1 dB above the system noise power.

In addition, it was also considered that, due to technical reasons (minimum practicable power, available antenna sizes, fixed transmit power for hub stations, …), the FS links in the 38 and 40 GHz bands, and in particular point-to-multipoint systems, are likely to present an "extra design margin" compared to the rain margin. At the minimum, for point-to-point links, the value of this "extra design margin" depends on the level of granularity of the power setting, the possible attenuators as well as the antenna gain that would allow the FS designer to adjust the receiver level as close as possible to the theoretical level. Even though it has not been taken into account in the definition of the reference total margin of the FS link, it was agreed to consider it as an additional confidence factor in the derivation of the protection criteria.

On the basis of the agreed assumptions that the fade margins, M_F, for errored seconds (ES) and SES are respectively 3 dB lower and 1 dB higher than the fade margin referenced to the BER 1×10^{-6} level which is 2 dB lower than the fade margin referenced to the BER 1×10^{-3} level, Table 1 summarizes the different values of fade margins corresponding to a $M_F = 14$ dB and 10 dB referenced to the SES level.

TABLE 1

Correspondence of rain fade margin and error performance objectives

	14 dB rain margin	**10 dB rain margin**
ES (dB)	10	6
BER 1×10^{-6} (dB)	13	9
SES (dB)	14	10
BER 1×10^{-3} (dB)	15	11

3 Derivation of the *I*/*N* mask

The derivation of the *I*/*N* mask to be applied to FSS GSO satellites has been based on the assessment of two different factors:

– the impact on the FS of interference and in particular, in the main beam of the FS antenna in rainy conditions, of the composite interference resulting of faded and unfaded portions of the interference (see Appendix 2);

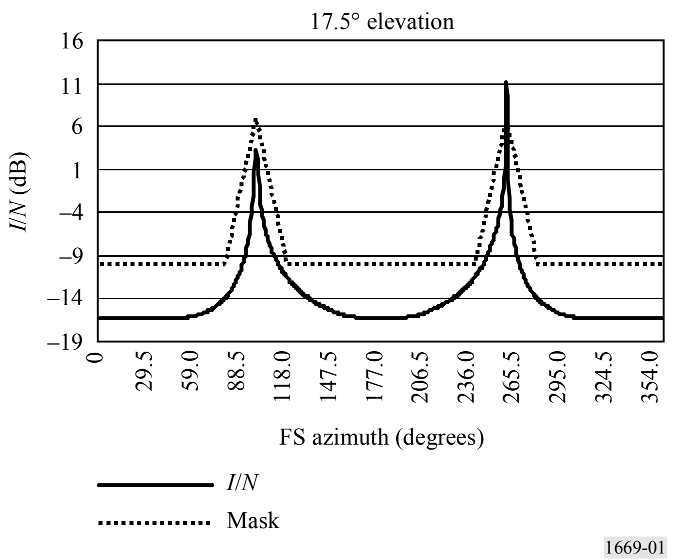
– the correlation between the rain attenuation on the signal and interference in the main beam of the FS antenna in order to determine angle *X*° from the main beam at which this level of correlation can be assumed correlated with a certain level of confidence (see Appendix 3).

4 *I*/*N* criteria mask

Based on the elements in § 3, Fig. 1 describes the *I*/*N* masks that represents the azimuth related protection criteria of the FS presenting a maximum *I*/*N* for the peak interference that relate to the case where the FS receiver is pointing through the GSO arc and an azimuth range for which the *I*/*N* decreases from this maximum down to −10 dB.

FIGURE 1

Description of *I*/*N* mask for GSO satellites in the 38 and 40 GHz bands



For FWSs in general, for which a 14 dB fade margin has been agreed as being representative, the maximum *I*/*N* and azimuth range have been determined to be respectively +5 dB and ±15°.

For some links in certain BWA applications that use a fade margin of 10 dB, these parameters have been determined to be respectively +1 dB and ±5°.

5 Noise level reference

The *I*/*N* masks as described in § 4 refer to the total noise level which includes an agreed 1 dB intra-service interference allowance. It means that $N = k\,T\,B\,F + 1$ dB.

Appendix 1
to Annex 1

TABLE 2

Rain fade margins for 99.999% availability

Link distance (km)	Fade margin at 39.3 GHz, horizontal polarization (dB)					Fade margin at 39.3 GHz, vertical polarization (dB)				
	Rain rate (mm/h) (Zone)					Rain rate (mm/h) (Zone)				
	12 (B)	22 (E)	42 (K)	63 (M)	95 (N)	12 (B)	22 (E)	42 (K)	63 (M)	95[(1)] (N)
0.1	0.8	1.3	2.5	3.6	5.2	0.6	1.1	2.1	3	3.0
0.2	1.5	2.7	4.9	7.1	16.4	1.3	2.3	4.2	6	5.9
0.3	2.2	4	7.3	10.6	15.4	1.9	3.4	6.2	9	8.8
0.4	3	5.3	9.6	14	20.3	2.6	4.5	8.2	11.9	11.6
0.5	3.7	6.5	12	17.4	25.1	3.2	5.6	10.2	14.7	14.3
0.6	4.4	7.8	14.3	20.7	29.8	3.8	6.7	12.2	17.6	17.0
0.7	5.2	9.1	16.6	24	34.3	4.5	7.8	14.2	20.3	19.6
0.8	5.9	10.4	18.9	27.2	38.8	5.1	8.9	16.1	23	22.2
0.9	6.6	11.6	21	30.4	43.2	5.7	10.0	18.0	25.8	24.7
1.0	7.3	12.8	23.3	33.6	47.5	6.3	11.0	19.9	28.5	27.1
1.1	8	14.1	25.5	36.7	51.7	6.9	12.1	21.8	31	29.5
1.2	8.7	15.3	27.7	39.8	55.8	7.5	13.1	23.7	33.7	31.9
1.3	9.4	16.5	29.9	42.8	59.8	8.1	14.2	25.5	36.2	34.1
1.4	10.1	17.7	32	45.8	63.8	8.7	15.2	27.3	38.8	36.4
1.5	10.8	18.9	34.1	48.7	67.6	9.3	16.2	29.1	41.3	38.6
1.6	11.4	20.1	36.2	51.6	71.4	9.9	17.3	30.9	43.7	40.8

[(1)] Fade margins for the case of 95 mm/h rain rate for vertical polarization were calculated under the assumption that the latitude is less than 30° (which impacts the calculation in accordance with Recommendation ITU-R P.530).

Appendix 2
to Annex 1

Impact of interference on FS systems

1 Introduction

In general, a link will be designed to exactly meet only one performance criteria. If this criterion is the controlling criterion, the link will also meet the other criteria. For example, if a link is designed to meet the severely errored second ratio (SESR) criteria of ITU-T Recommendation G.826 or G.828 under the assumption of constant received interference power, the ES criterion must be met at a rain attenuation smaller by 4 dB. Since the percentage of time allowed for ESs may be 10 or 20 times as great as for SES, the ES criterion will be met if the SES criterion is met. For perfectly correlated fading of interfering and desired signals, it can be shown that this 4 dB increase in $C/N + I$ corresponds to a decrease in rain attenuation of about 4.7 dB. Hence, it is likely that the SESR criteria is the controlling criteria and that this is the only criterion that needs to be satisfied.

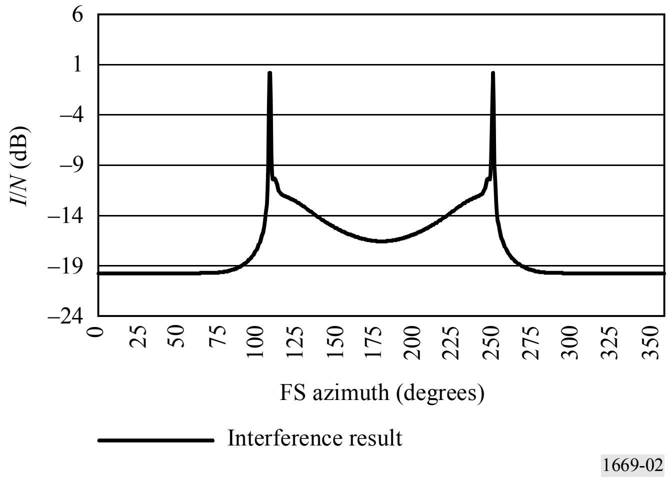
Thus, the case where the interference fading is perfectly correlated with the fading of the desired signal can be handled quite simply. The acceptable level of interference in the absence of fading for this case is merely higher than the permissible interference for the constant (uncorrelated) interference case by the fade margin. In accordance with Recommendation ITU-R F.758, the I/N is –10 dB in these frequency bands for the case of constant (uncorrelated) interference. In accordance with Recommendation ITU-R F.1094, the reference noise should be the total allocated noise consisting of the receiving system noise augmented by an allocated increment due to interference from the FS, an increment for interference from unwanted emissions and the additional increment due to interference from co-primary services. Hence the ratio of interference to total reference noise, I/N_{ref}, is –10 dB, and the ratio of interference to the system noise, I/N_0, is –9 dB. For the case where the fading of the inter-service interference is perfectly correlated with the fading of the desired signal, the same interference power (I/N_0 = –9 dB) must be present when the signal is faded by the fade margin of M_F dB; otherwise the desired performance will not be achieved. Consequently, the ratio of the unfaded interference power to system noise power for the case of perfectly correlated fading is $M_F - 9$ dB.

Figure 2 provides an illustration of the unfaded interference produced by a fully populated GSO arc. The two peaks where the interference level is high correspond to the azimuth at which a single satellite is in the main beam of the antenna of an FS station.

For these two particular azimuths the interference propagation path may be co-linear with the propagation path of the desired signal and the fading would be perfectly correlated at these azimuths. As the azimuth moves from these peak values the fading on the two paths is only partially correlated and the permissible interference reduces from –9 dB to $M_F - 9$ dB. Such a reduction is illustrated by the I/N mask in Fig. 5.

FIGURE 2

Illustration for *I*/*N* produced by GSO satellites



It should be noted that the analysis in this Appendix was performed using the system noise power, ($N_0 = k\,T\,B\,F$), as the reference. However, the analysis includes the additional power contributions due to the interference from the FS transmitters as well as the interference from other co-primary services and interference from unwanted emissions. The margin for each of these interference contributions has been taken at 0.5 dB.

2 *I*/*N* calculations

In order to calculate the maximum acceptable unfaded *I*/*N*, it is necessary to analyse $\frac{C}{N+I}$ under various rainy conditions.

The relative values of *C* and ($N + I$) in rainy conditions are:

$$C = C_0 - A_C \qquad \text{dB} \qquad (1)$$

$$N + I = N_{tot} = N_{ref} + 10\log\left(0.9 + 10^{((I/N_0) + N_0 - N_{ref})/10}\right) \qquad \text{dB} \qquad (2)$$

where A_C is the attenuation (dB) of the signal. The noise power spectral densities are related as described before, so that N_{ref} is the sum at the receiver of the FS system noise, the allocated increment for interference from within the FS, the allocated contribution due to unwanted emissions and the allocated increment due to interference from other services. The quantity N_{tot} represents the sum of noise plus interference. Note that it is equal to N_{ref} when $I/N_{ref} = -10$ dB.

The sum of the FS system noise plus the increment, assumed here to be 0.5 dB, for interference within the FS represents 0.89 of the reference noise power (W). The contribution due to unwanted emissions adds 0.01 of the reference noise power (W). This is in conformance with Recommendation ITU-R F.1094, and it results in the term 0.9 in equation (2). Denoting N_0 as the total system noise, $k\,T\,B\,F$, it is easily shown that $N_{ref} - N_0 = 1.0$.

In the usual case where the interference level is constant, the permissible interference power (W) will be less than or equal to one tenth of the reference noise power. Under these conditions $C/N+I$ may be written as:

$$\frac{C}{N+I} = C_0 - A_C - N_{ref} - 10\log\left(0.9 + 10^{((I/N_0)-1)/10}\right) \quad (3)$$

For the case where the interference power is constant, I/N_0 = –9 dB, which is equivalent to $I/N_{ref} = -10$ dB, the $C/N+I$ reaches the threshold value for SES when the attenuation of the signal, A_C equals the fade margin for SES. Thus:

$$\frac{C}{N+I} = T_{SES} = C_0 - M_F - N_{ref} \quad (4)$$

If the fading of the interference is partly correlated with the fading of the signal, then $I/N_0 = I_0/N_0 - A_I$, where I_0 is the unfaded interference power and A_I is the attenuation (dB) of the interference. In this case $C/N+I$ equals the threshold value under the following condition:

$$\frac{C}{N+I} = T_{SES} = C_0 - A_C - N_{ref} - 10\log\left(0.9 + 10^{((I_0/N_0) - A_I - 1)/10}\right) \quad (5)$$

In the case where there is perfect correlation between the fading of the desired signal and the fading of the interference, $A_C = A_I$, This equation is satisfied for $A_C = M_F$ if:

$$I_0/N_0 = M_F - 9 \quad (6)$$

More generally, if the correlation of the fading is less than perfect, the unfaded I/N would need to be lower to avoid an increased number of events where $C/N+I$ is below threshold. By expressing the unfaded I/N as:

$$I_0/N_0 = M_F - 9 - L_{IN} \quad (7)$$

where L_{IN} is the "loss" in I/N due to the departure from perfect correlation. The concern is to avoid additional increases in the controlling error performance defects (SES, for instance) because of the lack of correlation in the fading on the interfering path. Hence, for fading on the signal path that does not exceed the fade margin, the following relations can be obtained by using equations (7) and (4) in (5):

$$L_{IN} = M_F - A_I - 10\log\left(10^{(M_F - A_C + 10)/10} - 9\right) \quad (8)$$

or equivalently:

$$I_0/N_0 = A_I + 1 + 10\log\left(10^{(M_F - A_C)/10} - 0.9\right) \quad (9)$$

Appendix 3
to Annex 1

Correlation of fading on signal interference and determination of *I*/*N* masks

1 Temporal approach methodology

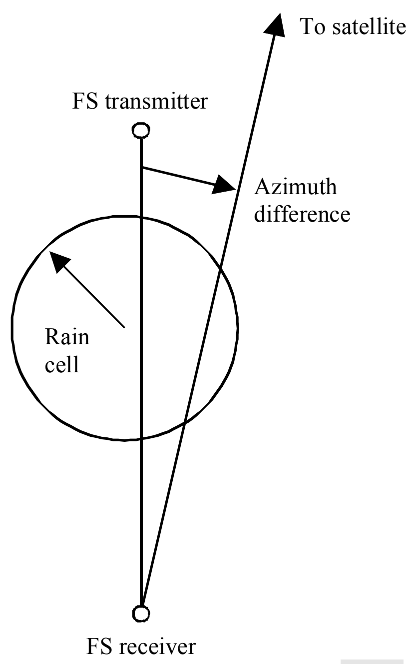
In order to determine the correlation between the rain attenuation on the signal and interference in the main beam of the FS antenna, a temporal approach methodology has been used that takes account of the assumptions that rain cells are not static and that they do present a temporal aspect as they are in constant motion relative to the FS link.

On this basis, a cylindrical rain cell of uniform rain rate has been used on the example of a rain cell of a radius of 0.2 km and a specific attenuation of 50 dB/km. In order to represent the temporal aspect of a rain cell, the cell can be assumed to be located anywhere around the FS receiver. In this analysis the rain cell is assumed to be located anywhere along and across the FS link in increments of 0.5 m.

A calculation has been made for the rain cell located in each grid location. As shown on Fig. 3, this calculation consists of determining, for each rain cell location, the amount of attenuation A_C expected to occur along the desired FS path (at 0° elevation) as well as A_I along the interfering path in the horizontal plane, both referred in equation (9) in Appendix 2, and comparing the magnitude of the difference in attenuation.

FIGURE 3

Signal and interference propagation paths with rain-cell geometry shown for FS path length of 0.7 km, rain cell radius of 0.2 km and off-main-beam-axis azimuth angle of 10°



Where the attenuation on desired and interfering paths is only partly correlated, it is possible to describe the interference as having two components: one constant and one perfectly correlated. Assuming that a fraction p of the unfaded interference power is correlated and $1–p$ is constant, then at threshold and using the elements from Appendix 2:

$$10 \log \left(p 10^{-M_F/10} + 1 - p\right) + I_0 = N_{ref} - 10 \qquad (10)$$

or

$$I_0/N_0 = -10 \log \left(p 10^{-M_F/10} + 1 - p\right) - 9 \qquad (11)$$

Solving for p gives:

$$p = \frac{1 - 10^{-((I_0/N_0 + 9)/10)}}{1 - 10^{-M_F/10}} \qquad (12)$$

where M_F is the FS link fade margin and noting that equation (12) may be used any time that the permissible value of I_0/N_0 is between –9 dB and M_F – 9 dB.

On this basis and for different FS link fade margins (10, 11, 14 and 15 dB), equation (12) and equation (9) allow to determine respectively the fraction p as in Fig. 4 and the resulting I/N mask as in Fig. 5.

FIGURE 4

Effective fraction of perfectly correlated interference for entries at angles removed from the main beam axis of the FS antenna

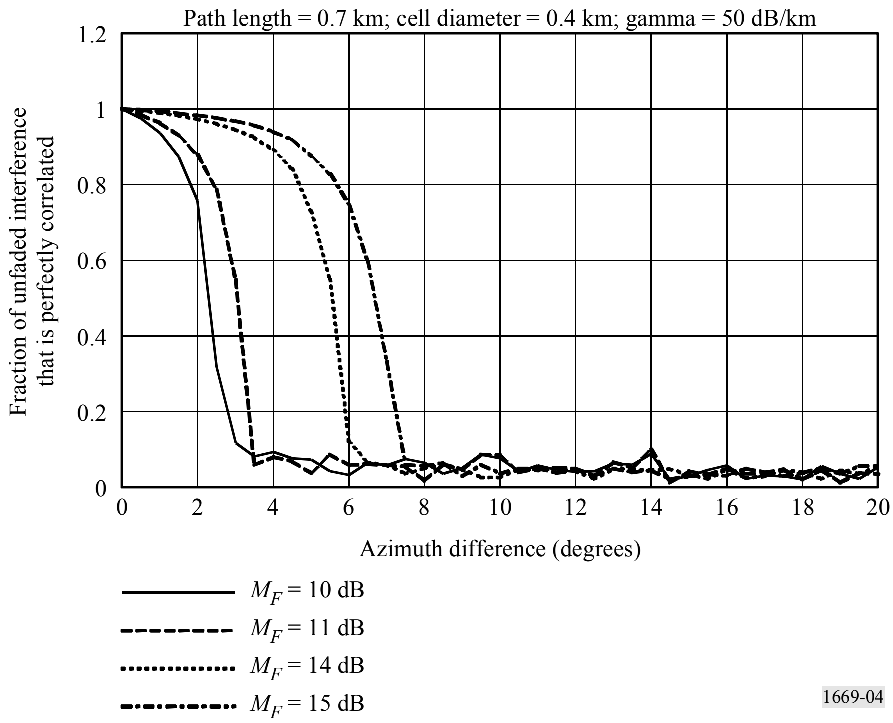


FIGURE 5

***I/N* mask for azimuths removed from the main beam axis of the FS antenna**

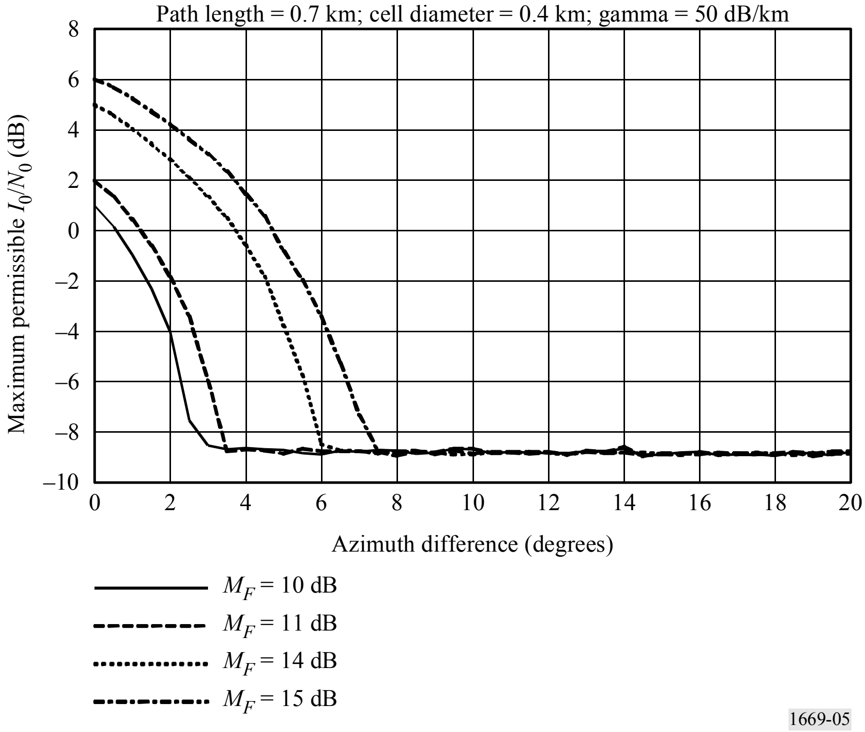


Figure 5, based on an example cylindrical rain cell of 0.2 km and a 50 dB/km specific attenuation, shows that both maximum allowable *I*/*N* and azimuth range, *X*°, depend on the value of the fade margin. For the 14 dB and 10 dB fade margin considered in section 2 of Annex 1, the maximum *I*/*N* is respectively +5 dB and +1 dB while the value of *X* is respectively 2° and 6°.

2 Rain cell size model

The analysis in section 1 above is illustrated with an example cylindrical rain cell of 0.2 km and a 50 dB/km specific attenuation but it is worth noting that the results of the temporal approach methodology, for a given value of fade margin, are obviously dependent on the assumed rain cell parameters, at least with regard to the value of the azimuth range, *X*°, as can be seen from Fig. 6.

Elements for parametric rain cell size are currently only provided in Appendix 4 to Annex 1 of Recommendation ITU-R P.452, but information was provided on the fact that this model is only applicable to rain scatter calculations on trans-horizon paths. However, it has also been proposed to use for this purpose an alternative model, even though it is not specified in any ITU-R Recommendation[2].

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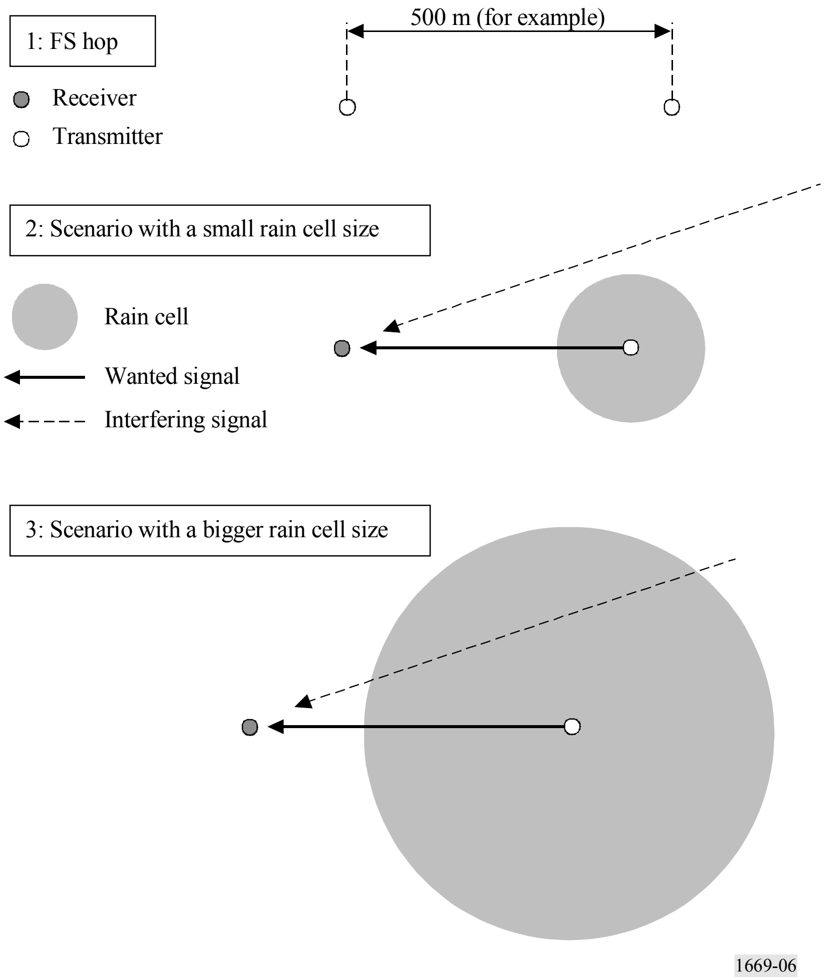
[2] This alternative model was tested by Radiocommunication Study Group 3 in the development of Recommendation ITU-R P.618.

FIGURE 6

Description of scenarios with different rain cell size



This alternative model consists of a population of cells with exponential profile and rotational symmetry, in which the rain fall R at distance ρ from the centre, is given by:

$$R = R_M \exp(-\rho/\rho_0) \tag{13}$$

where R_M is the peak rain intensity and ρ_0 is the distance at which the intensity decays by a factor 1/e, referred as conventional "cell radius".

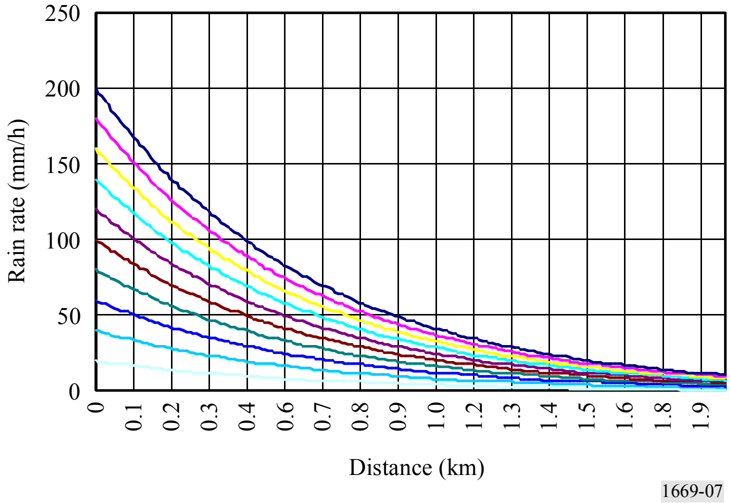
For the monoaxial case, normalized values of ρ_0 depend on the values of R_M and are given by the following double power law form:

$$\rho_0(R_M) = 1.7\left[\left(\frac{R_M}{6}\right)^{-10} + \left(\frac{R_M}{6}\right)^{-0.26}\right] \qquad \text{for} \quad R_M > 5 \tag{14}$$

On this basis, Fig. 7 gives, for maximum rain rate from 20 to 200 mm/h (with an increment of 20), the shape of the corresponding rain cell.

FIGURE 7

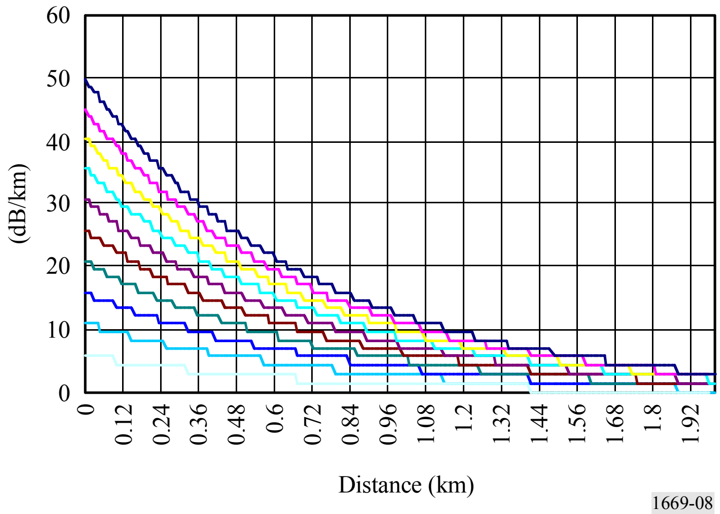
Rain rate from the centre of the rain cell



In addition, using rain rates of Fig. 7, it is hence possible, on the basis of Recommendation ITU-R P.838, to derive the corresponding specific attenuations as in Fig. 8.

FIGURE 8

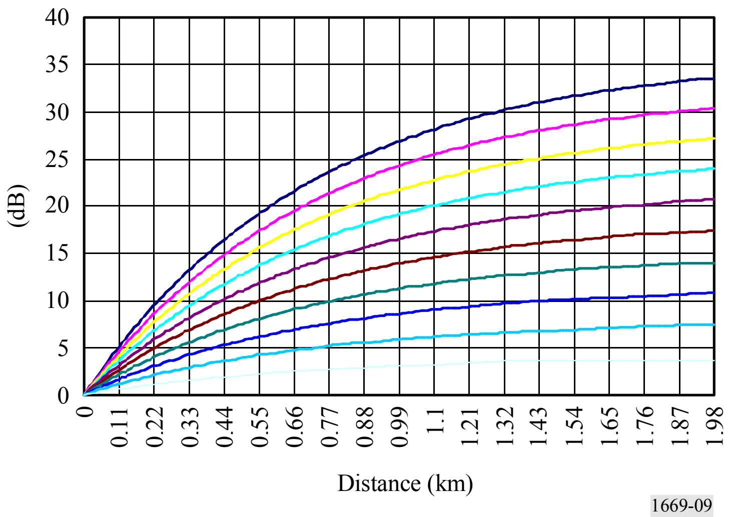
Specific attenuation from the centre of the rain cell



Further, integrating these specific attenuations over the distance from the centre of the cell allows calculation of the cumulative attenuation induced by the corresponding rain cell, as given in Fig. 9.

FIGURE 9

Cumulative attenuation from the centre of the rain cell



Finally, Table 3 gives, for each rain rate, the cell radius ρ_0 (as expressed in equation (14)).

TABLE 3

Radius of the rain cell for different maximum rain rate

Maximum rain rate (mm/h)	**ρ_0, radius of the cell (km)**
200	0.68
180	0.70
160	0.72
140	0.75
120	0.78
100	0.82
80	0.87
60	0.93
40	1.04
20	1.24

Even though the elements in Figs. 7 to 9 and Table 3 demonstrate that rain cells are not cylindrical but present an exponential profile, they however tend to show that the 0.2 km cell radius used in the calculation in the previous section underestimates the impact of rain and hence the value of the azimuth range, $X°$.

Without trying to draw any definitive conclusion on a cylindrical rain cell radius corresponding to the above elements derived from the alternative propagation model, it is likely that applying the temporal approach with this model would lead to a significant increase of the azimuth range.

With a reasonable factor of confidence, it was hence assumed that increasing the azimuth range to 5° and 15° for respectively 10 dB and 14 dB FS link fade margin (compared to 2° and 6° as in Fig. 7 for 0.2 km rain cell radius) would be conservative enough to ensure, associated respectively with the +1 dB and +5 dB maximum I/N, the required protection of the FS from interference produced by GSO satellites.

Further refinement of this rain cell model or a new model may have some impact on these azimuth ranges and may lead to further development of this Recommendation.