RECOMMENDATION ITU-R S.1589

Continuous curves of epfd↓ versus geostationary fixed-satellite service earth station antenna diameter and epfd↑ versus geostationary fixed-satellite service space station antenna beamwidth to indicate the protection afforded by systems complying with the limits to antennas with diameters other than those in Article 22 of the Radio Regulations

(Question ITU-R 231/4)

(2002)

The ITU Radiocommunication Assembly,

considering

a) that the frequency bands 11-14 GHz and 20-30 GHz are available to systems in the fixed-satellite service (FSS) employing satellites in both geostationary (GSO) and non-GSO orbits;

b) that earth stations in the FSS employing satellites in GSO orbits need to be protected from unacceptable interference by satellites in non-GSO orbits transmitting in the shared frequency bands;

c) that in order to provide the requisite protection from such interference, the World Radiocommunication Conference (Istanbul, 2000) (WRC-2000) adopted validation single-entry limits on the maximum permissible equivalent power flux-densities (epfd) which satellites in non-GSO orbits may radiate in some frequency bands, for certain specified earth station antenna diameters;

d) that the Radiocommunication Bureau (BR) will certify compliance with the maximum permissible downlink epfd (epfd↓) validation limits only for those earth station antenna diameters specified in Article 22 of the Radio Regulations (RR);

e) that as indicated in *resolves* 3 of Resolution 137 (WRC-2000) there is a need for GSO FSS network designers to be able to assess the level of interference generated by a non-GSO system meeting the epfd↓ limits for earth station antennas with diameters other than those specified in RR Article 22;

f) that the BR will certify compliance with the maximum permissible uplink epfd (epfd↑) validation limits only for those reference radiation patterns specified in RR Article 22;

g) that as indicated in *resolves* 3 of Resolution 137 (WRC-2000) there is a need for GSO FSS network designers to be able to assess the level of interference generated by a non-GSO system meeting the epfd↑ limits for space station antenna beamwidths other than those specified in RR Article 22,

recommends

1 that the methodologies in Annexes 1 and 2 be used within their specified contexts, for the guidance of designers of GSO FSS links on the maximum expected epfd levels for earth station antenna diameters other than those specified in RR Article 22 (see Notes 1 and 2);

2 that the methodology in Annex 3 be used, within its specified context, for the guidance of designers of GSO FSS links on the maximum expected epfd levels for space station antenna beamwidths other than those specified in RR Article 22.

NOTE 1 – The guidance to the GSO FSS designers is to be taken in this context: the continuous curves provide an approximation of how the regulatory limits of RR Article 22 could appear if they were defined for an arbitrary antenna diameter. In this respect these continuous curves are intended to provide guidelines on the upper bound of interference that GSO FSS earth stations might receive.

NOTE 2 – The epfd levels in this Recommendation are referenced to a bandwidth of 40 kHz. To convert to other bandwidths, a correction factor of 10 log(B/40) may be added to the value of epfd, where B is the required bandwidth (kHz).

ANNEX 1

Methodology to derive continuous curves of epfd↓ versus GSO FSS earth station antenna diameter in the frequency range 10.7-12.75 GHz

(Validation limits in RR Table 22-1A;
additional operational limits in RR Table 22-4A1)

1 Introduction

RR Article 22 contains limits to the epfd, which may be radiated by non-GSO FSS systems transmitting in the shared frequency bands, in order to protect FSS systems operating in the GSO from unacceptable interference. The epfd limits are defined for a small number of GSO FSS earth station antenna diameters, and it is recognized that designers of GSO FSS networks would need some guidance on the expected levels of interference into antennas with other diameters. This Annex provides such guidance, in the form of continuous curves of epfd, derived from the single-entry values for the validation limits and for the additional operational limits in RR Article 22 which apply in the 10.7-12.75 GHz frequency bands.

This Annex covers a subset of the limits defined in RR Article 22. The frequency bands considered are:

10.7-11.7 GHz in all Regions;

11.7-12.2 GHz in Region 2;

12.2-12.5 GHz in Region 3;

12.5-12.75 GHz in Regions 1 and 3.

The values of $epfd_{\downarrow}$ derived are:

– referenced to a bandwidth of 40 kHz;

– applicable to GSO systems with inclination angles less than 2.5º;

– applicable to latitudes below 60º;

– where relevant, applicable after 31 December 2005;

– applicable to antenna diameters in the range 0.6-18 m for the validation limits;

– applicable to antenna diameters in the range 3-18 m for the additional operational limits.

The curves for $epfd_{\downarrow}$ are derived from curve-fitting to the values tabulated in RR Article 22, and are only intended as best approximations.

2 RR Article 22 validation limits

The validation limits for the frequency band 10.7-12.75 GHz are given in Table 1, based on RR Table 22-1A, in terms of the percentage of time during which the $epfd_{\downarrow}$ level may be exceeded.

TABLE 1

Limits to the epfd↓ radiated by non-GSO FSS systems in certain frequency bands

Frequency band (GHz)	epfd↓ (dB(W/m^2))	Percentage of time during which epfd↓ level may be exceeded	Reference bandwidth (kHz)	Reference antenna diameter and reference radiation pattern
10.7-11.7 in all Regions; 11.7-12.2 in Region 2; 12.2-12.5 in Region 3 and 12.5-12.75 in Regions 1 and 3	–175.4 –174 –170.8 –165.3 –160.4 –160 –160	100 10 1 0.07 0.009 0.003 0	40	60 cm Recommendation ITU-R S.1428
	–181.9 –178.4 –173.4 –173 –164 –161.6 –161.4 –160.8 –160.5 –160 –160	100 0.5 0.26 0.143 0.046 0.016 0.009 0.003 0.003 0.0007 0	40	1.2 m Recommendation ITU-R S.1428
	–190.45 –189.45 –187.45 –182.4 –182 –168 –164 –162 –160 –160	100 10 0.5 0.3 0.145 0.029 0.012 0.005 0.001 0	40	3 m Recommendation ITU-R S.1428
	–195.45 –195.45 –190 –190 –172.5 –160 –160	100 1 0.35 0.29 0.01 0.002 0	40	10 m Recommendation ITU-R S.1428

The validation limit reference curves are constructed by linear interpolation between values of epfd↓ (dB) and by logarithmic interpolation between values of percentage of time for which the epfd↓ may be exceeded.

The additional operational limits for the frequency band 10.7-12.75 GHz are given in Table 2, based on RR Table 22-4A1, in terms of the percentage of time during which the epfd↓ level may be exceeded.

TABLE 2

Additional operational limits on the epfd↓ radiated by non-GSO FSS systems into 3 m and 10 m GSO FSS earth station antennas

epfd↓ (dB(W/(m^2 · 40 kHz)))	**Percentage of time during which epfd↓ level may be exceeded**	**Receive GSO earth station antenna diameter (m)**
–182 –179 –176 –171 –168 –165 –163 –161.25 –161.25	0.1 0.06 0.03 0.02 0.016 0.007 0.001 0.00025 0	3
–185 –183 –179 –175 –171 –168 –166 –166	0.03 0.02 0.01 0.004 0.002 0.001 0.0002 0	10

3 Continuous curves for validation limits (RR Table 22-1A)

3.1 Antenna diameters between 0.6 and 10 m

Two limits are defined for the values of epfd↓ (dB(W/(m^2 · 40 kHz))) which may be exceeded for 0% and 100% of time:

$$epfd_0 = -160.0 \text{ dB(W/(m}^2 \cdot \text{ 40 kHz))} \tag{1}$$

$$epfd_{100} = \begin{cases} -180.18 - 21.53 \log D & \text{for } D < 3 \\ -185.89 - 9.562 \log D & \text{for } D \geq 3 \end{cases} \tag{2}$$

where D is the antenna diameter (m).

Two intermediate functions, Φ_1 and Φ_2 are first defined, which are combined by taking their mean value to yield the final curve.

The function Φ_1, derived from curve-fitting to the validation limits, is defined as:

$$\Phi_1(p,D) = -179.77 + \frac{15.114 + 4.794\,D}{1 + \exp\left(\dfrac{0.7042 + 0.159\,D + \log p}{1.948 - \dfrac{1}{0.5976 + (\log D - 0.263)^2}}\right)} - 19.16 \log D \qquad (3)$$

where:

p: percentage of time that the level of epfd may be exceeded

D: antenna diameter (m).

The value of Φ_1 is subject to the following three boundary conditions:

$$\Phi_1(p, D) = \begin{cases} epfd_0 & \text{if} \quad p \le 0.001 \\ epfd_0 & \text{if} \quad \Phi_1 > epfd_0 \\ epfd_{100} & \text{if} \quad \Phi_1 < epfd_{100} \end{cases} \qquad (4)$$

The function Φ_2, derived from an interpolation between the reference curves, is given by:

$$\Phi_2(p, D) = \begin{cases} epfd_{v0.6}(p) + 3.3219\left[epfd_{v1.2}(p) - epfd_{v0.6}(p)\right]\log\left(\dfrac{D}{0.6}\right) & \text{for} \quad 0.6 \le D \le 1.2 \\ epfd_{v1.2}(p) + 2.5130\left[epfd_{v3}(p) - epfd_{v1.2}(p)\right]\log\left(\dfrac{D}{1.2}\right) & \text{for} \quad 1.2 < D \le 3 \\ epfd_{v3}(p) + 1.9125\left[epfd_{v10}(p) - epfd_{v3}(p)\right]\log\left(\dfrac{D}{3}\right) & \text{for} \quad 3 < D \le 10 \end{cases} \qquad (5)$$

where $epfd_{v0.6}(p)$, $epfd_{v1.2}(p)$, $epfd_{v3}(p)$ and $epfd_{v10}(p)$ are the validation limits in RR Table 22-1A for the respective antenna diameters, interpolated to the appropriate percentage of time.

The resulting value of epfd$\downarrow$ (dB(W/(m^2 · 40 kHz))) for antenna diameters between 0.6 m and 10 m is given by:

$$epfd_{22\text{-}1A}(p, D) = -\sqrt{\Phi_1(p, D) \cdot \Phi_2(p, D)} \qquad \text{for} \quad 0.6 \le D \le 10 \qquad (6)$$

3.2 Antenna diameters between 10 m and 18 m

The curves are extrapolated up to an antenna diameter of 18 m by treating the short-term and long-term components separately. The short-term part of the curve is derived through time-shifting by scaling p by $(D_{ref}/D)^2$, while the long-term part is derived through power-addition of the epfd by adding 20 log(D_{ref}/D). Two intermediate functions, Φ_3 and Φ_4, are defined, corresponding to the long-term and short-term parts, respectively:

$$\Phi_3(p, D) = epfd_{v10}(p) + 20 \log\left(\frac{10}{D}\right) \qquad (7)$$

$$\Phi_4(p, D) = epfd_{v10}\left(p \cdot \frac{D^2}{100}\right) \qquad (8)$$

The resulting value for epfd is derived from the short-term curve for increasing time percentages up to the first point at which the curves intersect, and from the long-term curve for higher time percentages. This intersection point is defined in terms of the antenna diameter by:

$$p_{c1} = 0.000179 + \frac{0.0182}{D} \tag{9}$$

The value of epfd↓ (dB(W/(m^2 · 40 kHz))) for antenna diameters between 10 m and 18 m is then given by:

$$epfd_{22\text{-}1A}(p, D) = \begin{cases} \Phi_3(p, D) & \text{for} \quad 0 \le p \le p_{c1} \quad \text{and} \quad 10 < D \le 18 \\ \Phi_4(p, D) & \text{for} \quad p_{c1} < p \le 100 \quad \text{and} \quad 10 < D \le 18 \end{cases} \tag{10}$$

Figure 1 shows the RR Table 22-1A limits together with derived values for antenna diameters of 7 m and 16 m, while Fig. 2 illustrates the variation with antenna diameter for the levels of epfd↓ which may be exceeded for some example percentages of time.

FIGURE 1

RR Table 22-1A epfd↓ levels versus percentage of time

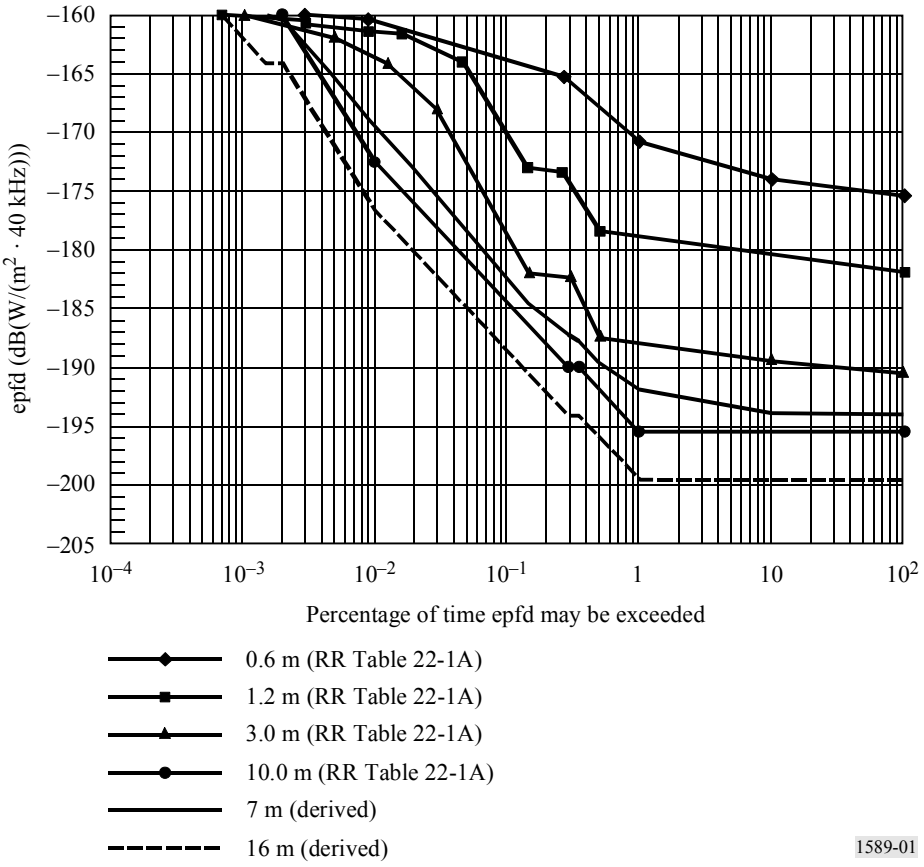
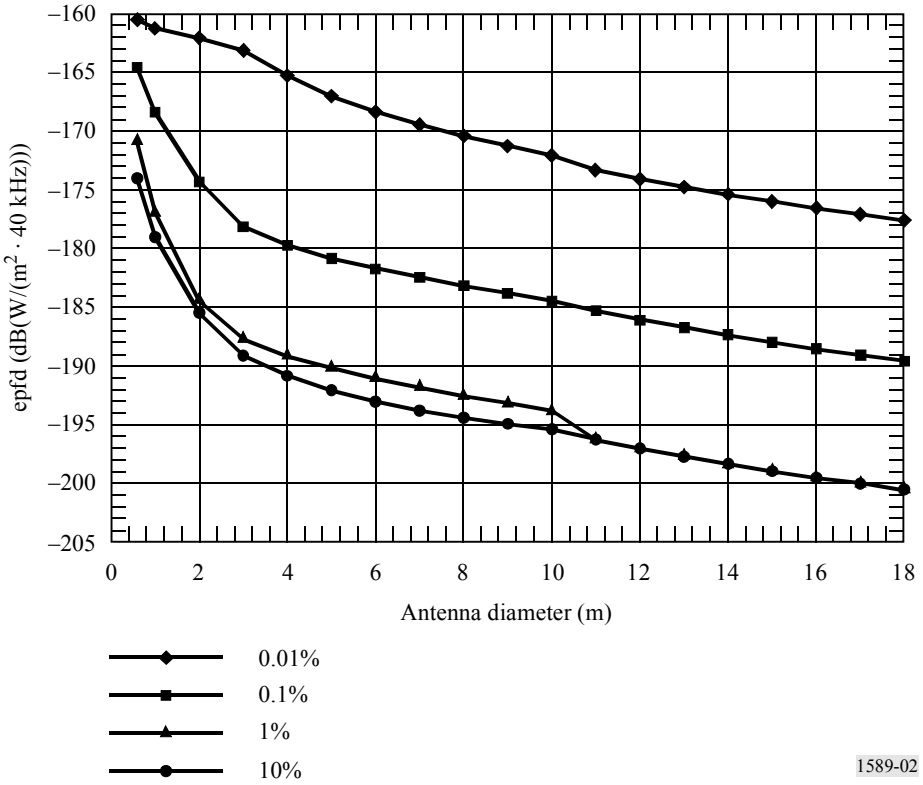


FIGURE 2

RR Table 22-1A epfd↓ levels versus antenna diameter



4 Continuous curves for additional operational limits (RR Table 22-4A1)

4.1 Antenna diameters between 3 m and 10 m

First, a function $\Phi_{max\text{-}op}$ is defined as a linear interpolation between the values of the operational limits to epfd↓ contained in RR Table 22-4A for antenna diameters of 3, 6, 9 and 18 m:

$$\Phi_{max-op}(D) = \begin{cases} -161.25 - 0.91667(D-3) & \text{for } 3 \le D < 6 \\ -164 - 0.5(D-6) & \text{for } 6 \le D < 9 \\ -165.5 - 0.22222(D-9) & \text{for } 9 \le D \le 18 \end{cases} \quad (11)$$

The short-term part of the curve is then given by:

$$\Phi_5(p, D) = \Phi_{max-op}(D) - \frac{7D^2 p}{0.045 + 0.027D} \quad (12)$$

and the long-term part of the curve is obtained from a straightforward interpolation between the two curves for the additional operational limits for 3 m and 10 m diameter antennas:

$$\Phi_6(p, D) = epfd_{AOL3}(p) + 1.9125\left[epfd_{AOL10}(p) - epfd_{AOL3}(p)\right]\log\left(\frac{D}{3}\right) \quad (13)$$

where $epfd_{AOL3}(p)$ and $epfd_{AOL10}(p)$ are values of the additional operational limits interpolated logarithmically to the appropriate percentage of time.

The function Φ_5 applies only to the short-term part of the curve, at time percentages up to the point at which the two curves intersect, defined by p_{c2}:

$$p_{c2} = \exp\left[0.131823\,(3 - D) - 4.57454\right] \tag{14}$$

The final curve is defined piecewise about p_{c2}, and the additional operational limit (dB(W/(m^2 · 40 kHz))) for antenna diameters in the range 10-18 m is thus given by:

$$epfd_{22\text{-}4A1}(p, D) = \begin{cases} -\sqrt{\Phi_5(p, D) \cdot \Phi_6(p, D)} & \text{for} \quad 0 \le p \le p_{c2} \\ \Phi_6(p, D) & \text{for} \quad p_{c2} < p \le 100 \end{cases} \tag{15}$$

4.2 Antenna diameters between 10 m and 18 m

An intermediate function Φ_7 is defined, which provides the long-term part of the curve, through an extrapolation from the additional operational limits for the 10 m diameter antenna through power addition of the epfd by adding a factor 20 log(D_{ref}/D):

$$\Phi_7(p, D) = epfd_{AOL10}(p) + 20 \log\left(\frac{10}{D}\right) \tag{16}$$

This is combined piecewise with the short-term part of the curve defined above, Φ_5, applied to the antenna diameter range 10 m to 18 m, with the transition between the two curves occurring at the first intersection for p decreasing from 100% (long-term interference) to 0% (short-term interference), p_{c3}, which depends on the antenna diameter:

$$p_{c3} = \frac{0.0523}{D} - 0.000817 \tag{17}$$

The additional operational limit (dB(W/(m^2 · 40 kHz))) for antenna diameters in the range 10-18 m is then given by:

$$epfd_{22\text{-}4A1}(p, D) = \begin{cases} \Phi_5(p, D) & \text{for} \quad 0 \le p \le p_{c3} \quad \text{and} \quad 10 < D \le 18 \\ \Phi_7(p, D) & \text{for} \quad p_{c3} < p \le 100 \quad \text{and} \quad 10 < D \le 18 \end{cases} \tag{18}$$

The additional operational limits are shown in Fig. 3 together with examples of the derived limits for antenna diameters of 6 m and 16 m, and Fig. 4 shows the derived additional operational limits as functions of antenna diameter for some example percentages of time.

FIGURE 3

RR Table 22-4A1 epfd↓ levels versus percentage of time

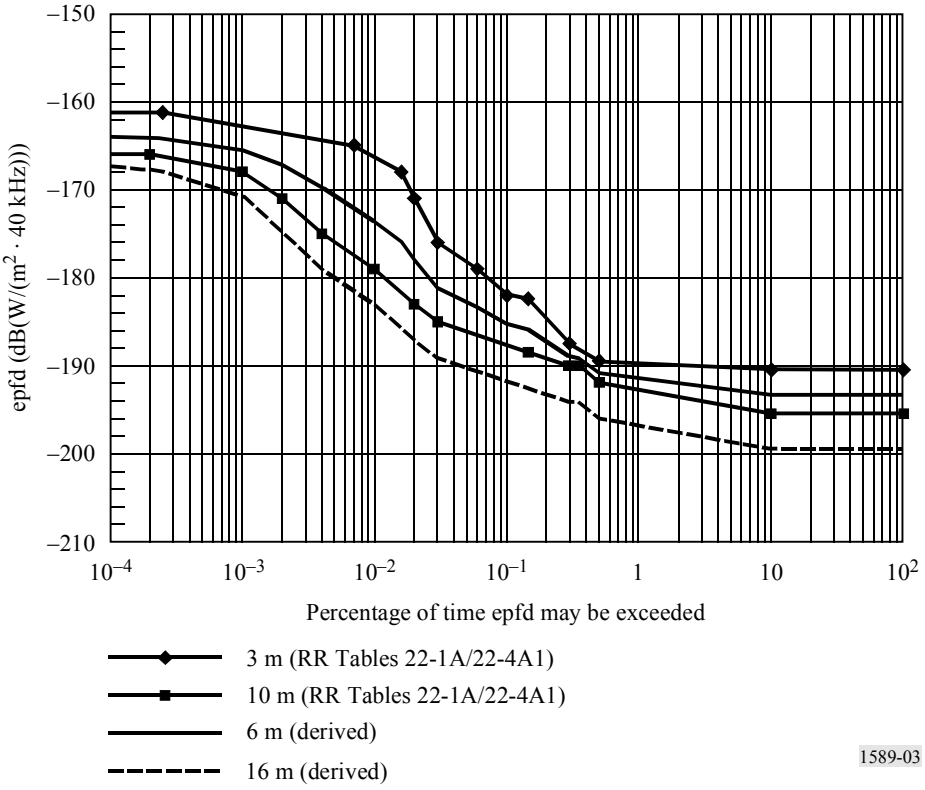
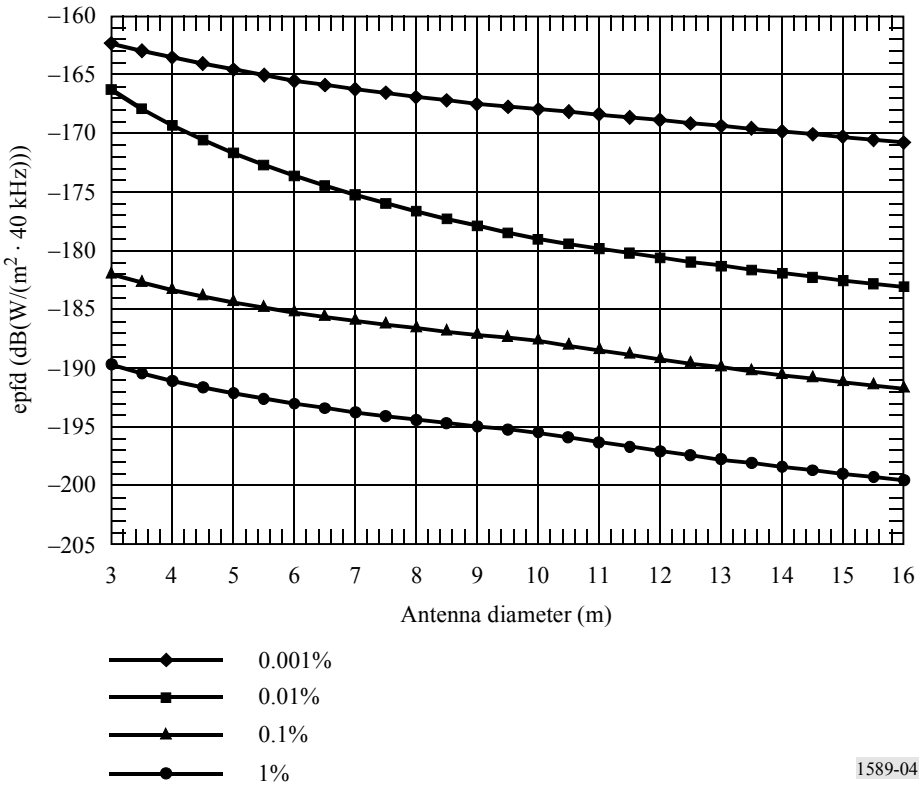


FIGURE 4

RR Table 22-4A1 epfd↓ levels versus antenna diameter



ANNEX 2

Methodology to derive continuous curves of epfd↓ versus GSO FSS earth station antenna diameter in the frequency bands 17.8-18.6 and 19.7-20.2 GHz

(Validation limits in RR Table 22-1B and RR Table 22-1C)

1 Introduction

This Annex covers the subset of the limits defined in RR Article 22 in RR Tables 22-1B and 22-1C. The frequency bands considered are:

– 17.8-18.6 GHz in all Regions

– 19.7-20.2 GHz in all Regions

The values of epfd↓ derived are:

– referenced to a bandwidth of 40 kHz;

– applicable to GSO systems with inclination angles less than 2.5°;

– applicable to latitudes below 60°;

– where relevant, applicable after 31 December 2005;

– applicable to antenna diameters in the range:

  – 1-5 m for the 17.8-18.6 GHz band, and

  – 0.7-5 m for the 19.7-20.2 GHz band.

The curves for epfd↓ are derived from curve-fitting to the values tabulated in RR Article 22, and are only intended as best approximations.

2 RR Article 22 validation limits in the frequency bands 17.8-18.6 GHz and 19.7-20.2 GHz

The validation limits for the frequency band 17.8-18.6 GHz are given from RR Table 22-1B in Table 3, in terms of the percentage of time during which the epfd↓ level may be exceeded:

TABLE 3

Limits to the epfd↓ radiated by non-GSO FSS systems in the 17.8-18.6 GHz frequency band

Frequency band (GHz)	epfd↓ (dB(W/m^2))	Percentage of time during which epfd↓ level may be exceeded	Reference bandwidth (kHz)	Reference antenna diameter and reference radiation pattern
17.8-18.6	–175.4 –175.4 –172.5 –167 –164 –164	100 10 1 0.286 0.029 0	40	1 m Recommendation ITU-R S.1428
	–178.4 –178.4 –171.4 –170.5 –166 –164 –164	100 0.6 0.1 0.087 0.029 0.023 0	40	2 m Recommendation ITU-R S.1428
	–185.4 –185.4 –180 –180 –172 –164 –164	100 0.2 0.2 0.057 0.057 0.002 0	40	5 m Recommendation ITU-R S.1428

The validation limits for the frequency band 19.7-20.2 GHz are given from RR Table 22-1C in Table 4, in terms of the percentage of time during which the epfd↓ level may be exceeded:

TABLE 4

Limits to the epfd↓ radiated by non-GSO FSS systems in the 19.7-20.2 GHz frequency band

Frequency band (GHz)	epfd↓ (dB(W/m^2))	Percentage of time during which epfd↓ level may be exceeded	Reference bandwidth (kHz)	Reference antenna diameter and reference radiation pattern
19.7-20.2	–187.4 –182 –172 –154 –154	100 28.571 2.857 0.017 0	40	70 cm Recommendation ITU-R S.1428
	–190.4 –181.4 –170.4 –168.6 –165 –160 –154 –154	100 9 0.2 0.2 0.057 0.057 0.003 0	40	90 cm Recommendation ITU-R S.1428
	–196.4 –162 –154 –154	100 0.02 0.00057 0	40	2.5 m Recommendation ITU-R S.1428
	–200.4 –189.4 –187.8 –184 –175 –164.2 –154.6 –154 –154	100 10 6 2.857 0.114 0.01 0.001 0.0008 0	40	5 m Recommendation ITU-R S.1428

The validation limit reference curves are constructed by linear interpolation between values of epfd↓ (dB) and by logarithmic interpolation between values of percentage of time for which the epfd↓ may be exceeded.

3 Continuous curves for validation limits in the frequency band 17.8-18.6 GHz (RR Table 22-1B)

The continuous curves for epfd↓ (dB(W/(m^2 · 40 kHz))) in the 17.8-18.6 GHz frequency band are defined by the following sigmoid function, for antenna diameters in the range 1 m to 5 m:

$$epfd_{22\text{-}1B}(p, D) = B(D) + \frac{T(D)}{1 + \exp\left(\frac{V(D) + \log p}{S(D)}\right)} \qquad \text{for} \quad 1 \le D \le 5 \tag{19}$$

where D is the antenna diameter (m).

$$B(D) = -175.4 - 7.15476 \log D - 10.59524 (\log D)^2 \tag{20}$$

$$T(D) = 11.4 + 7.95238 \log D + 9.04762 (\log D)^2 \tag{21}$$

$$V(D) = 0.2783 + 3.09355 \log D - 2.32405 (\log D)^2 \tag{22}$$

$$S(D) = 0.3547 - 0.38349 \log D + 0.52274 (\log D)^2 \tag{23}$$

and with the constraint that

$$epfd_{22\text{-}1B}(p, D) \le -164 \text{ dB(W/(m}^2 \cdot \text{40 kHz))}$$

The error in the resulting curves, when compared with the values of epfd↓ in RR Table 22-1B, is of the order of 1 dB, except for the 5 m diameter antenna, where the error can be up to 3 dB.

Figure 5 shows the epfd↓ limits from RR Table 22-1B together with the resulting curves for the three antenna diameters 1, 2 and 5 m, as a function of percentage of time, while Fig. 6 illustrates the variation of epfd↓ with antenna diameter for some example percentages of time.

4 Continuous curves for validation limits in the frequency band 19.7-20.2 GHz (RR Table 22-1C)

First, a cut-off percentage of time, p_{c4} is defined, below which the epfd↓ remains constant at a value of –154 dB(W/(m^2 · 40 kHz)):

$$p_{c4} = 0.00206 - \frac{0.0117}{D} + \frac{0.0223}{D^2} - \frac{0.0105}{D^3} \tag{24}$$

The continuous curves for epfd↓ (dB(W/(m^2 · 40 kHz))) in the 19.7-20.2 GHz frequency band are defined by the following polynomial function, for antenna diameters in the range 0.7 m to 5 m.

$$epfd_{22\text{-}1C}(p, D) = \sum_{i=0}^{4} A_i(D) [\log p]^i \qquad i = 0,..,4 \tag{25}$$

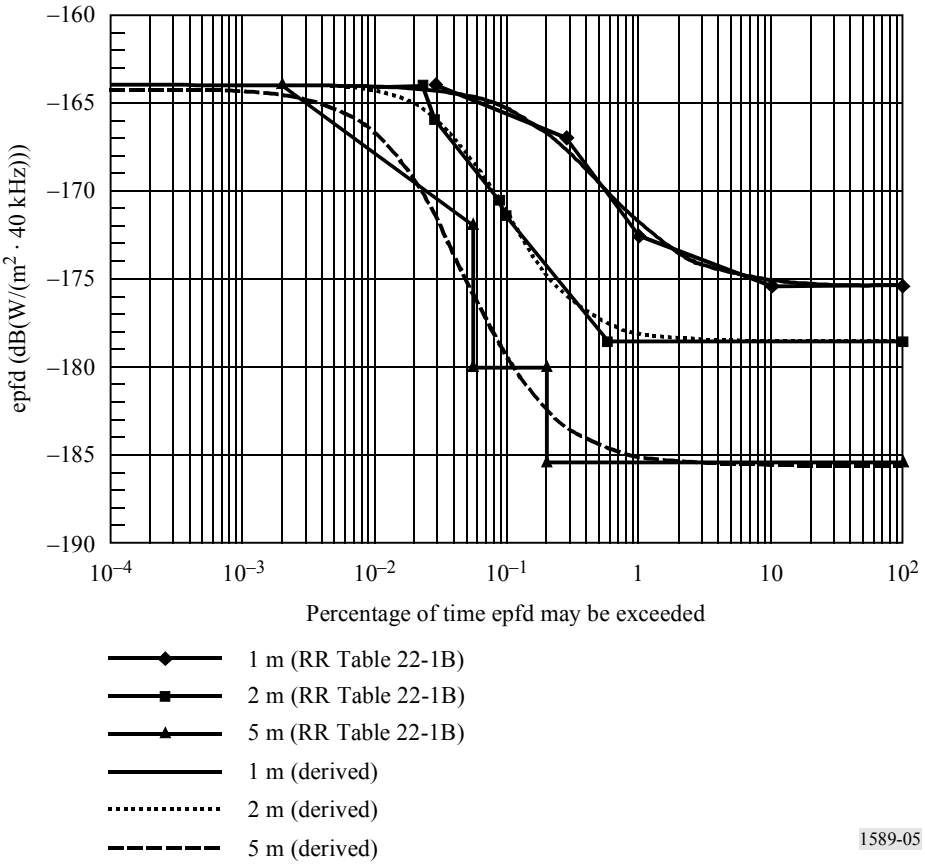
subject to the following two constraints:

$$epfd_{22\text{-}1C}(p, D) \le -154 \text{ dB(W/(m}^2 \cdot \text{40 kHz))}$$

$$epfd_{22\text{-}1C}(p, D) = -154 \qquad \text{if} \quad p < p_{c4}$$

FIGURE 5

RR Table 22-1B epfd↓ levels versus percentage of time



The coefficients A_i are polynomial functions defined by:

$$A_i(D) = \sum_{j=0}^{4} B_{ij} \left[\log D\right]^j \qquad j = 0,..,4 \tag{26}$$

and the coefficients B_{ij} are given in Table 5.

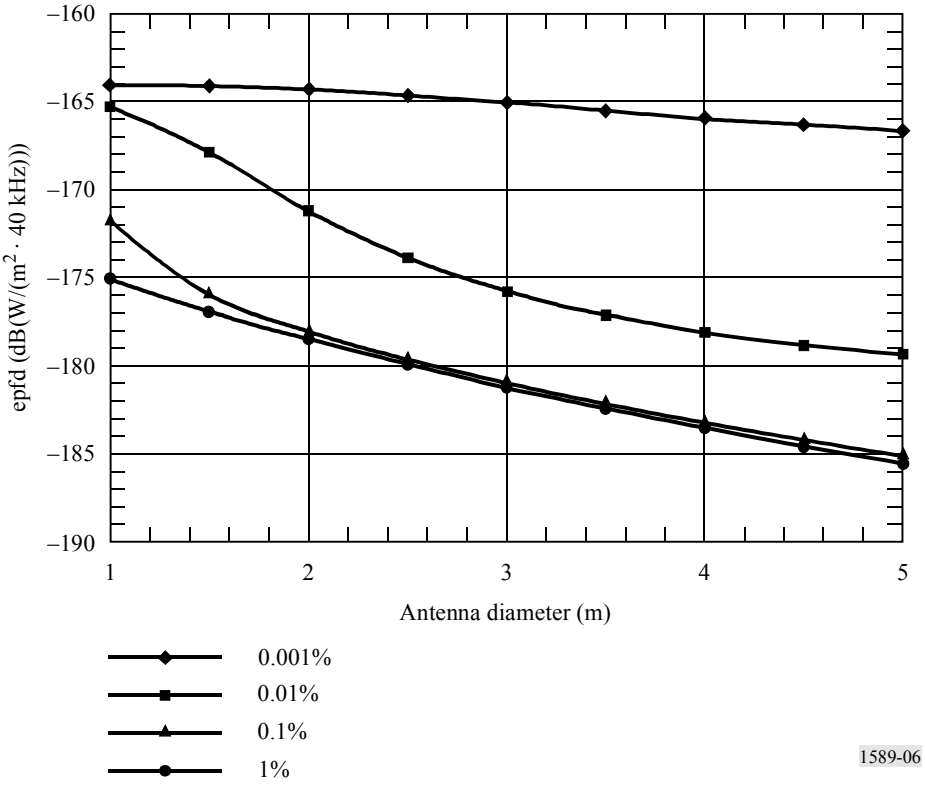
TABLE 5

Values of coefficients B_{ij}

j	B_{0j}	B_{1j}	B_{2j}	B_{3j}	B_{4j}
0	−176.4	−8.942	0.8074	0.2475	−0.04853
1	−30.6	−0.7033	4.567	−0.1355	−0.2177
2	141.2	−19.18	−37.81	3.304	2.495
3	−223.6	55.42	63.48	−11.48	−5.389
4	97.38	−29.66	−28.44	6.375	2.664

FIGURE 6

RR Table 22-1B epfd↓ levels versus antenna diameter



The error in the resulting curves, when compared with the values of epfd↓ in RR Table 22-1C, is less than about 1.5 dB, except for the 90 cm diameter antenna, where a peak deviation of about 3.6 dB occurs.

Figure 7 shows the epfd↓ limits from RR Table 22-1C together with the resulting curves for the four antenna diameters 0.7, 0.9, 2.5 and 5 m, as a function of percentage of time, while Fig. 8 illustrates the variation of epfd↓ with antenna diameter for some example percentages of time.

FIGURE 7

RR Table 22-1C epfd↓ levels versus percentage of time

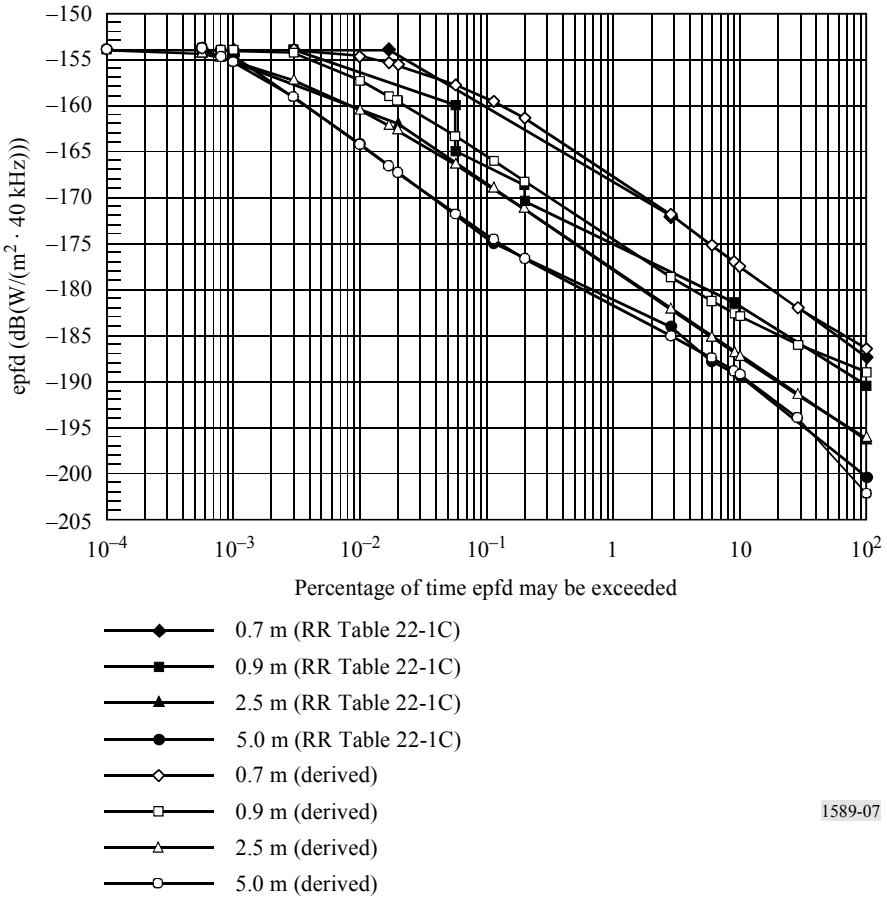
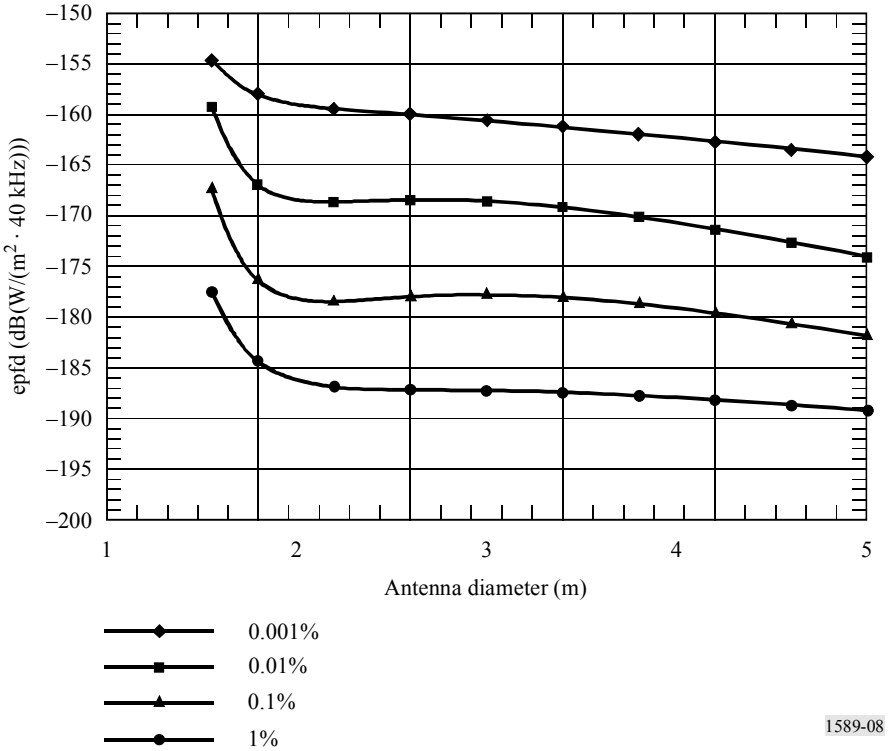


FIGURE 8

RR Table 22-1C epfd↓ levels versus antenna diameter



ANNEX 3

Method for estimating the level of epfd↑ into space station antennas having beamwidths other than those specified in RR Article 22

(Validation limits in RR Table 22-2)

1 Introduction

The epfd↑ limits in RR Table 22-2 are defined for only one specific value of the beamwidth of the affected GSO FSS space station antenna. This Annex provides guidance on the expected level of interference into other antenna beamwidths from non-GSO earth stations radiating at the maximum permitted power levels.

Since only single values of epfd↑ are defined for one antenna beamwidth in each frequency band, curve-fitting to different values of beamwidth is not possible. A simulation methodology was thus developed, based on Recommendation ITU-R S.1503, in which a GSO satellite antenna, with the beamwidth specified in RR Article 22 (4° in the 14 GHz band and 1.55° in the 30 GHz band) is directed towards one of the locations of maximum epfd↑. The GSO earth stations located at the northern edge of the half-power beamwidth are assumed to operate with an elevation angle of 10° in the 14 GHz band and 30° in the 30 GHz band. The interfering non-GSO earth stations were assumed to be distributed uniformly over the land area of the Earth.

By holding fixed the northern edge of the half-power beamwidth footprint, the beam centre will move north as the beamwidth decreases and south as the beamwidth increases. For each value of beamwidth, the equivalent isotropically radiated power (e.i.r.p.) of each interfering source is scaled by $1/d^2$, where d is the distance from the source to the satellite. The level of epfd↑ is then determined by summing the contributions from each interfering station, using the standard relationship in RR Article 22, for each value of GSO satellite antenna gain in the direction of the interfering stations. The results are then scaled to equate the value of epfd↑ at the reference beamwidths with the levels specified in RR Table 22-2. From these analyses, a simplified expression was derived from curve-fitting, which may be used to provide an estimate of the levels of epfd↑ expected into GSO satellite antennas with other beamwidths.

The method is based on the reference antenna radiation pattern in Recommendation ITU-R S.672, and uses as one of its input parameters the side-lobe level L_S.

2 Continuous curves of epfd↑ as a function of GSO satellite antenna beamwidth

The approximate level of epfd↑ may be determined as a function of the beamwidth of the satellite antenna, θ (degrees), and the side-lobe level, as defined in Recommendation ITU-R S.672, L_S (dB), from the following expression:

$$epfd_{\uparrow}(\theta, L_S) = \mathrm{k} + 10\log\left(\left(\mathrm{a} + \mathrm{b}10^{\frac{L_S}{10}}\right)\theta^{\mathrm{c}} - \mathrm{d} + \mathrm{e}10^{\frac{L_S}{10}}\right) \quad (27)$$

where:

θ: antenna beamwidth (degrees)

L_S: side-lobe level from Recommendation ITU-R S.672 (dB)

k, a, b, c, d and e: constants, given in Table 6 for the two frequency bands, 14 GHz and 30 GHz.

TABLE 6

Coefficients in equation (27)

Coefficient	12.5-14.5 GHz 17.3-18.1 GHz (Regions 1 and 3) 17.8-18.1 GHz (Region 2)	27.5-28.6 GHz 29.5-30 GHz
k	−172.1	−172.1
a	2.95	3.77
b	1.9	12.1
c	1.26	1.13
d	1.26	2.14
e	35	38

The resulting curves of epfd↑ as a function of antenna beamwidth are shown in Fig. 9 for the 12.5-14.5 GHz and 17.3-18.1 GHz bands and in Fig. 10 for the 27.5-28.6 GHz and 29.5-30 GHz bands.

These algorithms yield values for epfd↑ which differ from the simulation results by at most 0.3 dB.

FIGURE 9

RR Table 22-2 epfd↑ levels as a function of antenna beamwidth, for the 12.5-14.5 GHz and 17.3-18.1 GHz frequency bands; symbols represent results from simulations, lines represent results from the algorithm in equation (27)

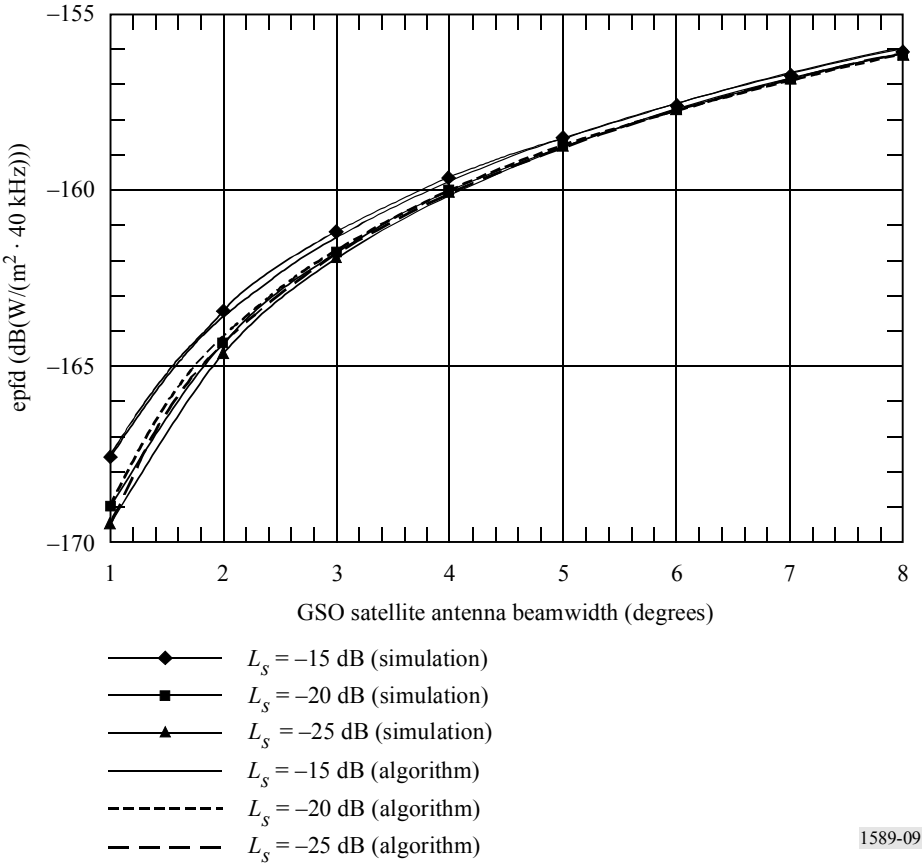


FIGURE 10

RR Table 22-2 epfd↑ levels as a function of antenna beamwidth, for the 27.5-28.6 GHz and 29.5-30.0 GHz frequency bands; symbols represent results from simulations, lines represent results from the algorithm in equation (27)