International Telecommunication Union

ITU-R
Radiocommunication Sector of ITU

Recommendation ITU-R SF.1602
(02/2003)

Methodology for determining power flux-density statistics for use in sharing studies between fixed wireless systems and multiple fixed-satellite service satellites

SF Series

Frequency sharing and coordination between fixed-satellite and fixed service systems

Foreword

The role of the Radiocommunication Sector is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including satellite services, and carry out studies without limit of frequency range on the basis of which Recommendations are adopted.

The regulatory and policy functions of the Radiocommunication Sector are performed by World and Regional Radiocommunication Conferences and Radiocommunication Assemblies supported by Study Groups.

Policy on Intellectual Property Right (IPR)

ITU-R policy on IPR is described in the Common Patent Policy for ITU-T/ITU-R/ISO/IEC referenced in Annex 1 of Resolution ITU-R 1. Forms to be used for the submission of patent statements and licensing declarations by patent holders are available from http://www.itu.int/ITU-R/go/patents/en where the Guidelines for Implementation of the Common Patent Policy for ITU-T/ITU-R/ISO/IEC and the ITU-R patent information database can also be found.

<div style="border:1px solid">

Series of ITU-R Recommendations

(Also available online at **http://www.itu.int/publ/R-REC/en**)

Series	Title
BO	Satellite delivery
BR	Recording for production, archival and play-out; film for television
BS	Broadcasting service (sound)
BT	Broadcasting service (television)
F	Fixed service
M	Mobile, radiodetermination, amateur and related satellite services
P	Radiowave propagation
RA	Radio astronomy
RS	Remote sensing systems
S	Fixed-satellite service
SA	Space applications and meteorology
SF	**Frequency sharing and coordination between fixed-satellite and fixed service systems**
SM	Spectrum management
SNG	Satellite news gathering
TF	Time signals and frequency standards emissions
V	Vocabulary and related subjects

</div>

Note: *This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

Electronic Publication
Geneva, 2011

© ITU 2011

RECOMMENDATION ITU-R SF.1602*

Methodology for determining power flux-density statistics for use in sharing studies between fixed wireless systems and multiple fixed-satellite service satellites

(2003)

Scope

At some elevation angles on the surface of the Earth, the power flux-density produced by a satellite may be smaller than the limiting values required by conformance to a given pfd mask because of the limitations of real antenna gain patterns and the need to avoid self interference. This Recommendation provides a methodology for determining the statistics of the power flux-density produced at the surface of the Earth by satellites in GSO or non-GSO orbits.

The ITU Radiocommunication Assembly,

considering

a)   that it is necessary to ensure that emissions from satellites do not exceed permissible interference to fixed wireless systems (FWS) in the bands shared between FS and FSS;

b)   that FWS can be adequately protected from the aggregate emissions from multiple satellites (non-GSO constellations or fully populated GSO arc) by placing suitable limits on the power flux-density (pfd) in a reference bandwidth produced by individual satellites at the surface of the Earth;

c)   that any limitations of the pfd produced at the surface of the Earth should not place undue restrictions on the design of GSO and non-GSO FSS;

d)   that Recommendations ITU-R SF.1482 and ITU-R SF.1483 provide maximum allowable values of pfd at the surface of the Earth produced by non-GSO satellites in the FSS to protect the FS in, respectively, the 10.7-12.75 GHz and the 17.7-19.3 GHz bands;

e)   that the pfd levels specified in the Recommendations mentioned in *considering* d) were developed from a pfd mask analysis used to calculate the statistics of aggregate power levels received at an FS station by applying pfd levels under consideration to each visible satellite of the non-GSO FSS constellation;

f)   that, when considering a multi-satellite environment, such as non-GSO constellation or fully populated GSO arc, all the visible satellites may not simultaneously radiate the maximum pfd limit in the direction of the FS system under consideration,

recommends

1   that the methodology described in Annex 1 may be used for determining pfd statistics for use in sharing studies between FWS and multiple FSS satellites, taking into account satellite systems characteristics.

---

* Radiocommunication Study Groups 5 and 4 made editorial amendments to this Recommendation in November 2010 and September 2011, respectively, in accordance with Resolution ITU-R 1.

Annex 1

Methodology for determining pfd statistics for use in sharing studies between fixed wireless systems and multiple FSS satellites

1 Introduction

This Annex presents statistical methodology concerning the impact of non-GSO and GSO satellites on FWS. It takes into account realistic satellite characteristics and is intended for use as guidance in sharing analysis between FS and satellite services.

It should also be noted that Recommendations ITU-R SF.1482 and ITU-R SF.1483 dealing with maximum allowable values of pfd at the surface of the Earth produced by non-GSO satellites in the FSS to protect the FS provides general background to this methodology.

2 Description of the pfd mask analysis

The existing methodology for evaluating the pfd mask used either for GSO or non-GSO satellite systems, such as in the above-mentioned Recommendations ITU-R SF.1482 and ITU-R SF.1483, aggregates the interference from all visible satellites to the FS using a regulatory pfd mask such as defined in Article 21 of the Radio Regulations.

In a typical application of this methodology for the case of GSO satellites, the geostationary arc is filled with a given number of satellites (e.g. 1 every 4°) which produces permanent interference. Representative results produced by the application of this methodology are shown on Fig. 1 for all the FS azimuths.

FIGURE 1

Interference produced by a GSO satellite

1602-01
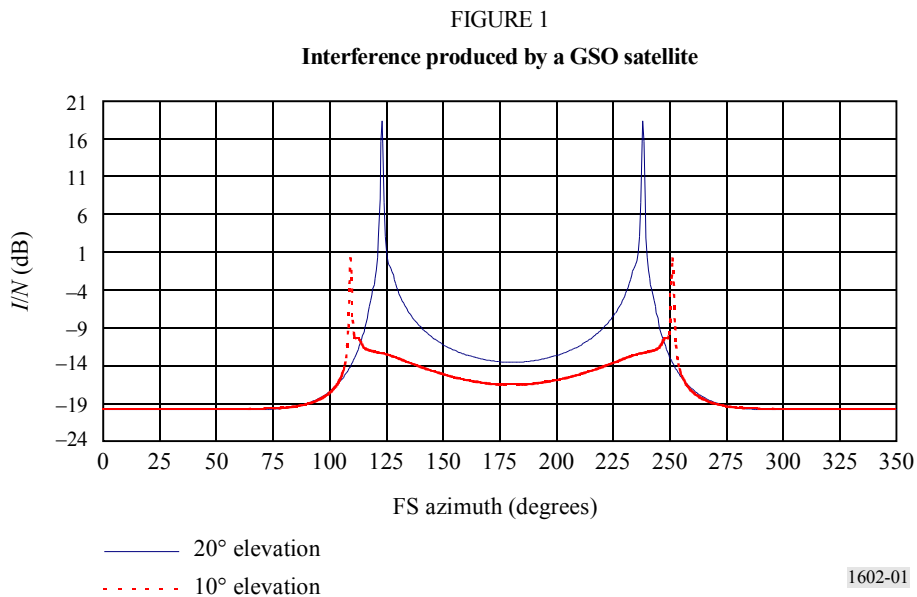
For the case of non-GSO systems, and on the basis of the characteristics of each single constellation (number of satellites, number of planes, inclination(s), altitude, ...), the statistics of the theoretical aggregate power levels received at an FS station are calculated by applying pfd limits under consideration to each visible satellite of the non-GSO FSS constellation (see Recommendation ITU-R F.1108). In a typical application of this methodology, the interference distribution is calculated for the FS azimuth (and for a single elevation angle) that represents the constellation worst-case, which results in distribution of interference level versus percentage of time such as given in Fig. 2.

FIGURE 2

Interference distribution produced by a non-GSO system
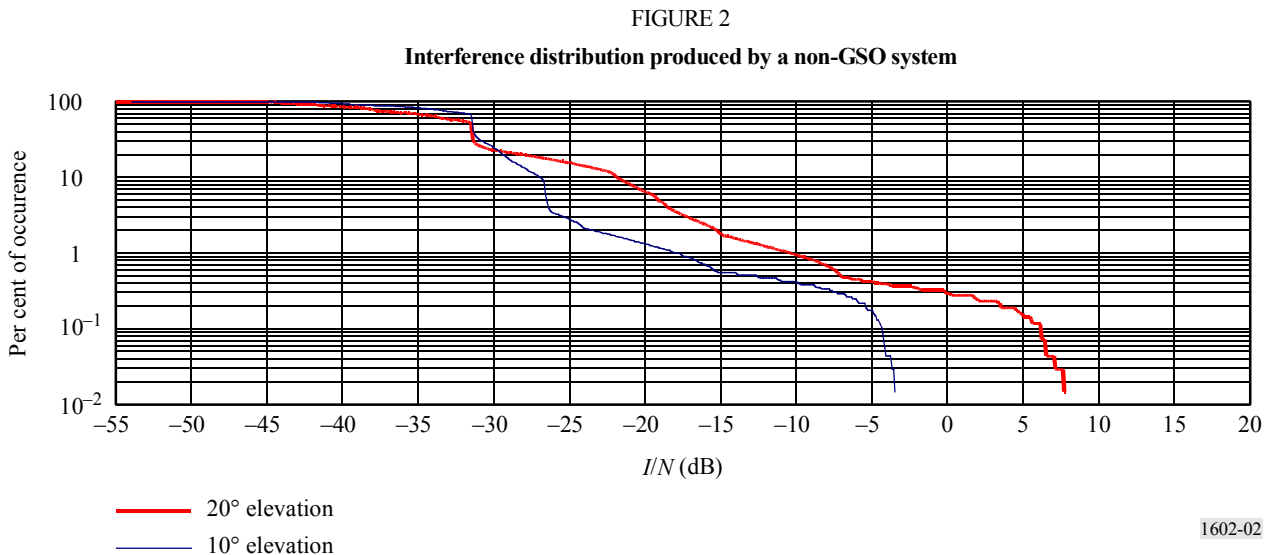
This methodology has typically been used as a basis in inter-service sharing studies. This has the advantage of being a simple calculation but also represents an overestimation of the real interference that could be suffered by FS stations.

With regard to the FSS characteristics, the analysis assumes that all the visible satellites radiate simultaneously at the maximum pfd limits, in the direction of the FS system under consideration. Such an assumption does not take into account the patterns of the real satellite antenna, the power limitations of each satellite or the restrictions that self-interference (as a result of frequency reuse) would impose on an FSS system as well as the fundamental operational constraints of FSS systems.

The methodology described in § 3 provides a statistical approach toward accommodating the FSS operational characteristics.

3 pfd analysis and satellite models

This methodology takes into account realistic satellite antenna patterns, the power limitations of each satellite and the restrictions that self-interference would impose on a non-GSO FSS system, as well as the fundamental operational constraints of non-GSO FSS systems.

This methodology assumes that, in a multi-satellite environment, all the satellites visible from a given point on the Earth do not simultaneously produce the maximum pfd allowed by a mask.

The parameters necessary to accurately model the pfd produced by a given satellite (maximum power, number of beams, antenna gain and antenna pattern) can generally be found in ITU-R documentation. The following is an analytical model of some of the possible parameters of a GSO FSS and a non-GSO FSS system.

The values of such parameters depend on the considered frequency band and the type of satellite (GSO or non-GSO). It is possible to derive a general equation linking them together.

In the main beam, for single beam coverage satellites, which could be implemented in certain frequency bands, the radiated power of the satellite necessary to produce the maximum pfd in the main beam is:

$$P_s = pfd_m - G_s + 10\log(4\pi d^2)$$ (1)

where:

P_s: power density of the satellite (dB(W/MHz))

pfd_m: the maximum value of the pfd mask

G_s: antenna gain of the satellite (dBi)

d: range from the satellite to its sub-satellite point (m).

However, in high frequency bands such as the 20/30 GHz or 40/50 GHz bands, most satellites will more likely deploy multiple beams with higher antenna gain, transmitting on several channels. In this case, the power density of each individual beam can be calculated as:

$$P_{ds} = 10\log\left(\frac{P_f}{BW_f}\right) = 10\log\left(\frac{\dfrac{P_{tot}}{N' \times N}}{\dfrac{BW_{tot}}{N'}}\right) = 10\log\left(\frac{P_{tot}}{N \times BW_{tot}}\right)$$ (2)

where:

P_{ds}:   satellite power density per beam (dB(W/MHz))

P_f: power per beam (W)

BW_f: beam bandwidth (MHz)

P_{tot}:   total radiated power available on the satellite (W)

BW_{tot}:   total bandwidth of the satellite (MHz)

N':   number of frequency channels in BW_{tot}

N: number of co-frequency beams.

On this basis, equations (1) and (2) allow to derive the following general equation:

$$G_b = pfd_m - 10\log\left(\frac{P_{tot}}{N \times BW_{tot}}\right) + 10\log(4\pi d^2)$$

which gives:

$$G_b = pfd_m - 10\log(P_{tot}) + 10\log(N) + 10\log(BW_{tot}) + 10\log(4\pi d^2)$$ (3)

where:

G_b: beam antenna gain (dBi)

pfd_m: the maximum value of the pfd mask (dB(W/(m$^2 \cdot$ MHz)))

P_{tot}:   total radiated power available on the satellite (W)

N: number of co-frequency beams

BW_{tot} :   total bandwidth of the satellite (MHz)

d :   distance from the satellite to the centre of its pointing zone (m).

Therefore, based on this equation (3) and using existing typical values that can generally be found in ITU-R texts, it is possible to define simple satellite models which could be used in sharing studies between FSS and terrestrial services.

As an example, and in order to facilitate the understanding of and support the statistical methodology presented in this Annex, example satellite models below, assumed to be consistent with equation (3) (with a -105 dB(W/(m$^2 \cdot$ MHz)) high elevation angle pfd level), have been considered:

GSO satellites:

Model GEO1:

–   beam antenna gain: 60 dBi

–   number of co-frequency beams: 6

–   total transmit power (for all beams): 3.5 kW

–   total bandwidth: about 1 000 MHz

Model GEO2:

–   beam antenna gain: 55 dBi

–   number of co-frequency beams: 4

–   total transmit power (for all beams): 3.5 kW

–   total bandwidth: about 500 MHz

Non-GSO satellites (10 000 km altitude assumed):

Model MEO1:

–   beam antenna gain: 50 dBi

–   number of co-frequency beams: 4

–   total transmit power (for all beams): 1.1 kW

–   total bandwidth: about 700 MHz

Model MEO2:

–   beam antenna gain: 45 dBi

–   number of co-frequency beams: 3

–   total transmit power (for all beams): 1.1 kW

–   total bandwidth: about 300 MHz

4   pfd distribution

4.1   Principles

As already stated above, the pfd produced by a given satellite, at any point on the surface of the Earth, depends on its transmitted power, antenna gain and antenna pattern.

Furthermore, as shown in Fig. 3, the maximum pfd available in the main beam is mainly controlled by the regulatory pfd limit and the antenna pattern. In many cases, depending on the pointing elevation of the satellite, the pfd in the main beam is lower than the one given by the pfd mask in order to stay within the mask for lower elevation (such as for Elevations *a* and *c* in Fig. 3).

FIGURE 3

0° elevation

Elevation a

Elevation b

Main beam
direction

Elevation c

1602-03
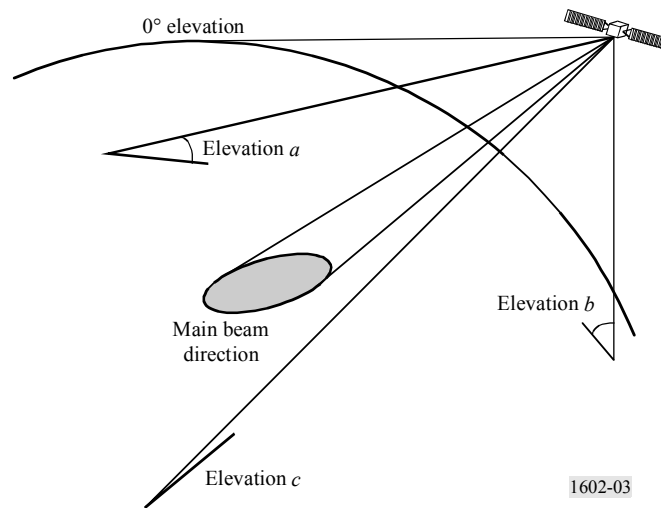
Furthermore, as described in Figs. 4 and 5, a satellite seen from a given point A on the Earth with an Elevation x, does not generally produce a constant pfd at A. The received pfd level at A varies based on the satellite downlink beam pointing direction and may also vary based upon traffic load. However, this latter characteristic is not taken into account in this methodology.
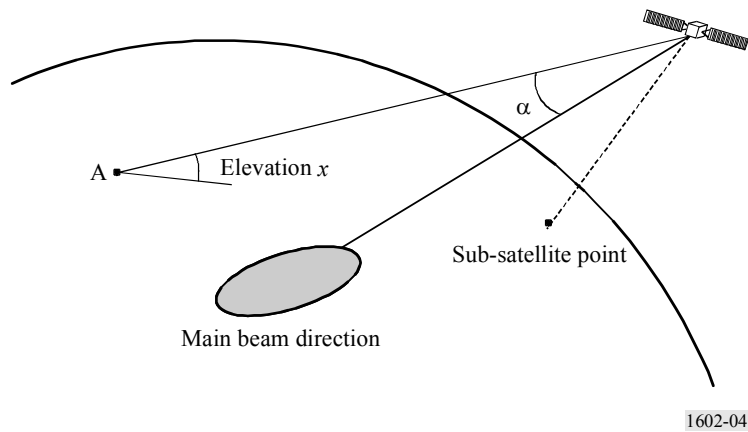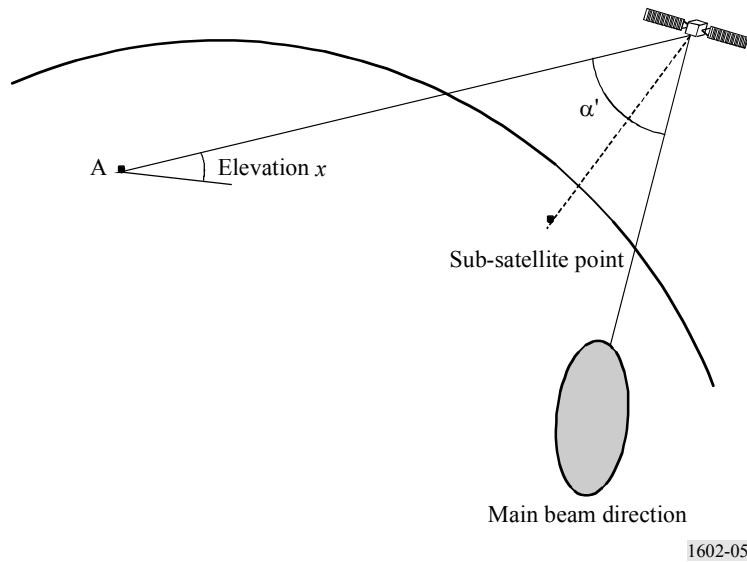
FIGURE 4

α

A

Elevation x

Sub-satellite point

Main beam direction

1602-04

FIGURE 5

1602-05

In Fig. 4, it can be seen that the pointing direction of the satellite beam is close to point A and that the antenna discrimination angle, α, is relatively small. On the other hand, in Fig. 5, the pointing direction of the satellite beam is different and the antenna discrimination angle, α', is bigger than α. Furthermore, and as explained above, the pfd in the main beam for these two examples can be different.

Therefore, the pfd produced at point A can be different even though the satellite is at exactly the same position.

The pfd radiated in A can be easily calculated as follows:

$$pfd_A = pfd_{mb} + L_{mb} - G_{max} + G_{discri} - L_A \qquad (4)$$

where:

pfd_A : pfd radiated in A (dB(W/MHz))

pfd_{mb} : pfd radiated in the main beam (dB(W/MHz))

L_{mb} : free space losses between the satellite and the centre of its beam at the Earth's surface (dB)

G_{max} : maximum satellite antenna gain (dBi)

G_{discri} : relative antenna gain in the direction of point A (dBi)

L_A : free space losses between the satellite and A (dB).

On this basis, and by varying the pointing direction of the satellite in all possible directions from its position, it is possible to determine the distribution of the pfd values that a satellite can produce for a given elevation as described in Fig. 6.

FIGURE 6

pfd distributions at 30° elevation for GEO1 model (60 dBi multibeam)
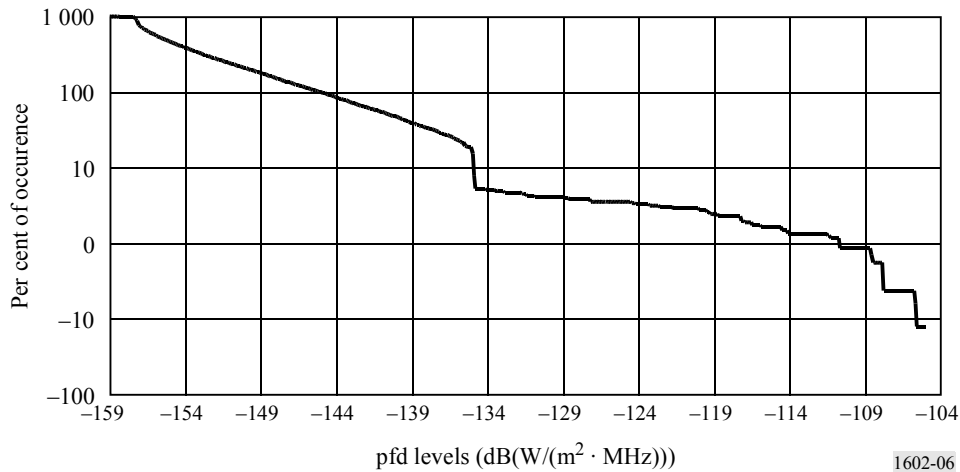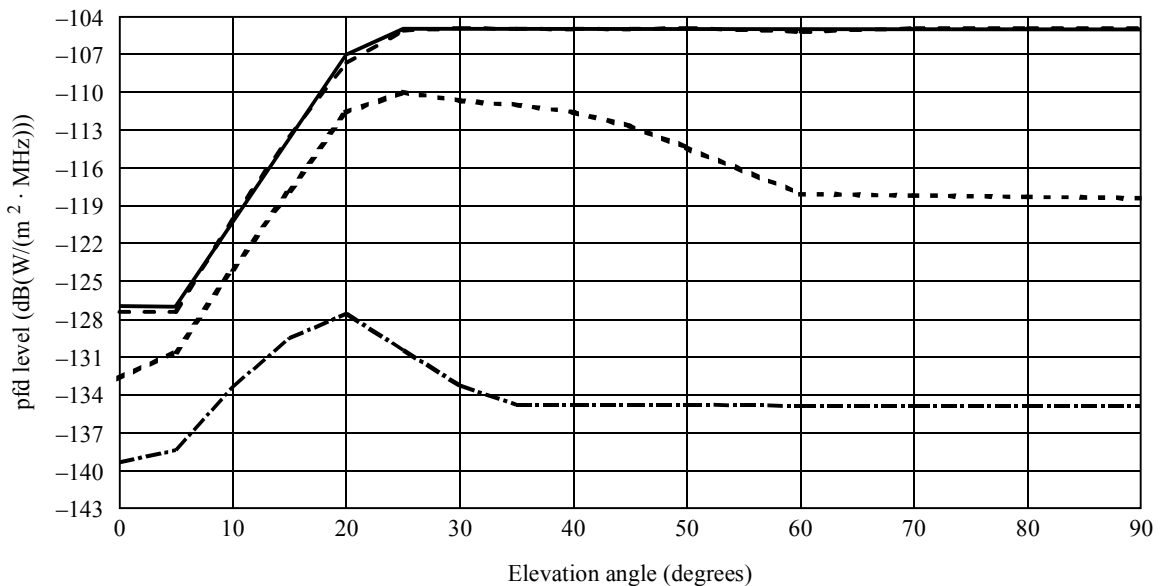

1602-06

In addition, considering all the elevation angles for a given case (see calculation in Appendix 1), it is possible to draw the worst-case pfd mask by combining the maximum from each distribution and to compare it, such as on Fig. 7, with the regulatory pfd mask.

It is also possible, such as on Fig. 7, to plot a similar combined pfd mask representing a given percentage (e.g. 99.9% and 99.5% of the cases).

FIGURE 7

Aggregate pfd masks for GEO1 model (60 dBi multibeam)

Regulatory mask

Maximum

99.9%

99.5%

1602-07

4.2 Antenna models

4.2.1 Single beam satellite models

For a single beam satellite, Figs. 4 and 5 give an adequate representation of the situation, but the resulting pfd depends on the assumed antenna pattern.

Recommendation ITU-R S.672 provides satellite antenna radiation pattern for use as a design objective in the fixed-satellite service employing geostationary satellites. For non-GSO satellites, there is no such general Recommendation, but Recommendation ITU-R S.1528 provides patterns for non-GSO satellites below 30 GHz and guidance for the bands above 30 GHz.

It has to be noted that the single beam satellite model may not be appropriate for use in all frequency bands.

4.2.2 Multibeam satellite models

For multibeam satellite models such as the GEO or MEO models described in § 3, the representation of the situation is different since in this case the aggregate impact of all the antennas has to be taken into account, as shown on Fig. 8.
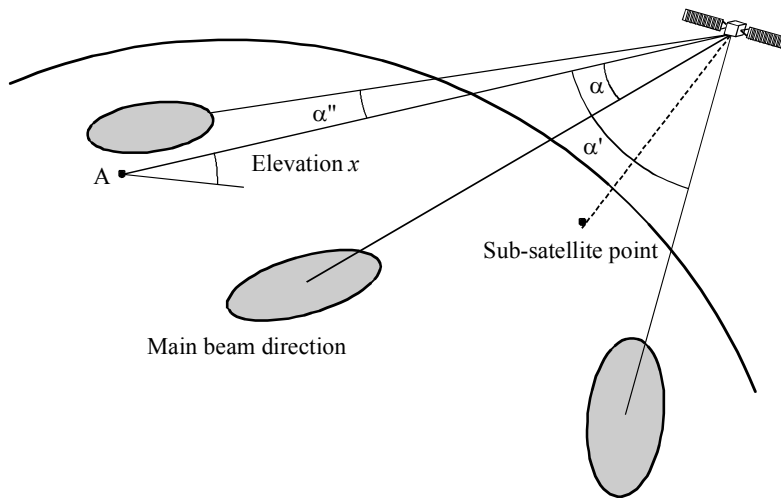
FIGURE 8

The pfd value at point A is the aggregation of the pfd produced by each single beam antenna in the direction of point A, each with a specific antenna discrimination (α, α' or α'' in the above example).

Based on the regulatory pfd mask, this pfd radiated to A can be calculated as follows:

$$pfd_A = \sum_{j=1}^{N}(pfd_{mbj} + L_{mbj} - G_{max} + G_{discrij} - L_A)$$ (5)

where:

pfd_A: pfd radiated to A (dB(W/(m^2 · MHz)))

N: number of co-frequency beams per satellite

pfd_{mbj}: pfd radiated in the main beam j (dB(W/(m^2 · MHz)))

L_{mbj}: free space losses between the satellite and the centre of the spot beam j at the Earth's surface (dB)

G_{max}: maximum satellite antenna gain (dBi)

$G_{discrij}$: relative antenna gain in the direction of point A for the beam j (dBi)

L_A: free space losses between the satellite and A (dB).

Since these beams are assumed to be co-frequency and due to self-interference issues, their main beams will not cover the same zone at the same time.

Therefore, except in some cases where (for which none of the main beams covers point A) for which the aggregate pfd is only produced by far side lobes of all the beams, this aggregate pfd will be dominated by one beam at each time.

Instead of running complicated calculations involving multibeams scenarios, the pfd at A can hence be approximated considering one single beam as follows:

$$pfd_A = pfd_{mb} + L_{mb} - G'_{max} + G'_{discrij} - L_A \qquad (6)$$

where:

pfd_A: pfd radiated in A (dB(W/(m^2 · MHz)))

pfd_{mb}: pfd radiated in the main beam (dB(W/(m^2 · MHz)))

L_{mb}: free space losses between the satellite and the centre of the spot beam j at the Earth's surface (dB)

G'_{max}: maximum satellite aggregate antenna gain (dBi)

$G'_{discrij}$: relative aggregate antenna gain in the direction of point A for the beam j (dBi)

L_A: free space losses between the satellite and A (dB)

and where the aggregate antenna pattern G' represents the pattern of one single antenna, G, plus the effect of the off-axis gain, $G_{offaxis}$, of the N other satellite antennas. It is defined as follows:

$$G' = 10\log\left(10^{\frac{G}{10}} + N \times 10^{\frac{G_{offaxis}}{10}}\right) \qquad (7)$$

As an example, and assuming a 0 dBi off-axis antenna gain, the resulting antenna pattern used for the multibeam models GEO1 (antenna gain 60 dBi) or MEO2 (antenna gain 45 dBi) satellites are described in Figs. 9a and 9b.
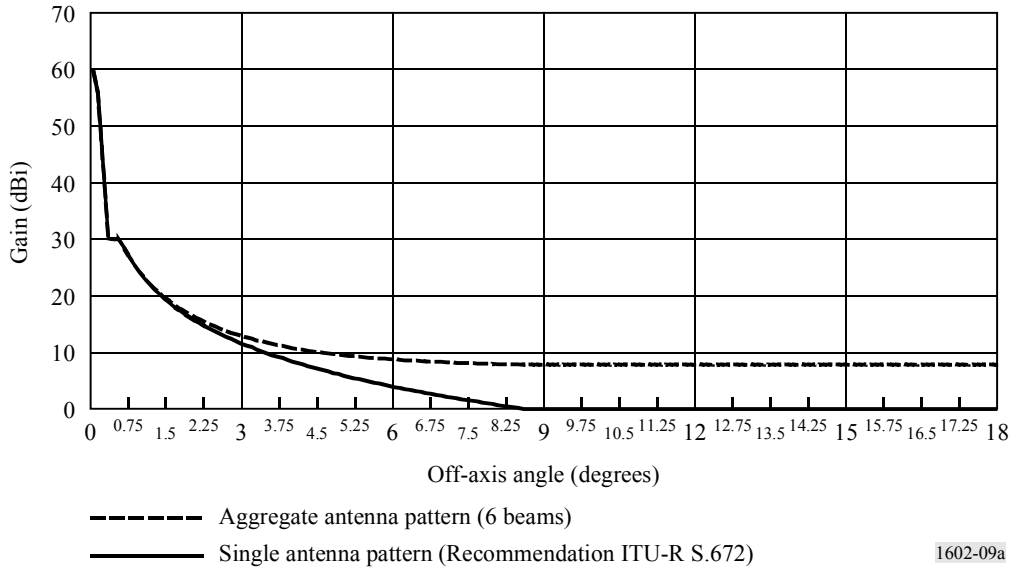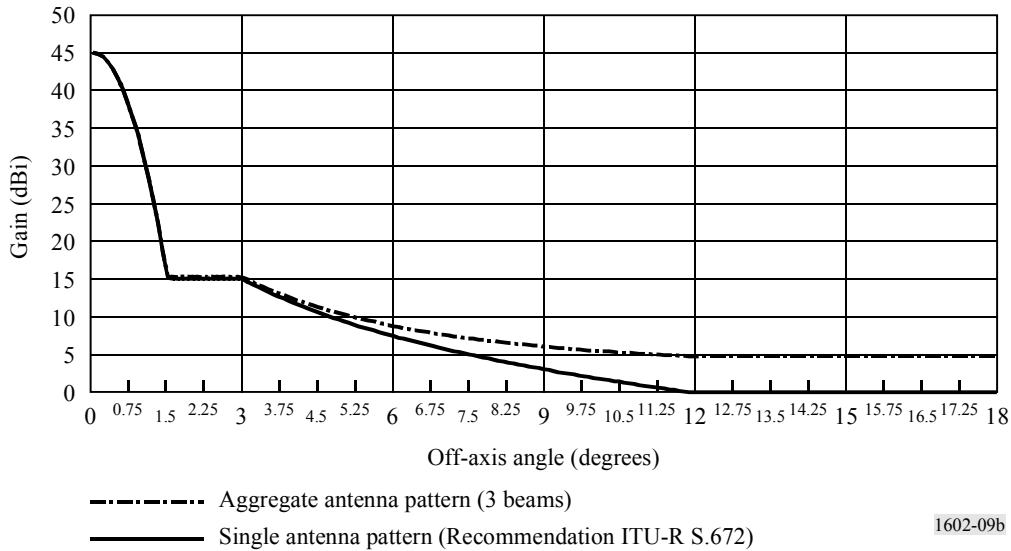
FIGURE 9a

GEO 60 dBi antenna ($L_s = 30$)

Off-axis angle (degrees)

- - - - - Aggregate antenna pattern (6 beams)
———— Single antenna pattern (Recommendation ITU-R S.672)

1602-09a

FIGURE 9b

MEO 45 dBi antenna ($L_s = 30$)

Off-axis angle (degrees)

—·—·—·— Aggregate antenna pattern (3 beams)
———— Single antenna pattern (Recommendation ITU-R S.672)

1602-09b

Finally, once the pfd distribution such as the one given in Fig. 6 is calculated for one beam on the basis of the aggregate antenna pattern, the pfd distribution for the N beams of the satellite can be derived as follows:

$$p' = 1 - (1 - p)^N \qquad (8)$$

where:

p : probability of a pfd level radiated in A for one beam

p' : probability of a pfd level radiated in A for all the beams

N : number of co-frequency beams per satellite.

NOTE 1 – Equation (8) is generally used for independent events which, however, is not the case for the *N* aggregate antenna patterns. In this example, the dependency of these beams is taken into account by the use of an aggregate antenna pattern as expressed in equations (6) and (7). Other dependency models may be applied to this methodology.

On this basis, Fig. 10 describes the pfd distribution calculated for a single beam (using aggregate antenna pattern) and one calculated for multibeams using equation (8), achieved by varying the pointing direction of the satellite beams in all possible directions.

FIGURE 10

pfd distributions at 30° elevation for GEO1 model
(6 co-frequency beams of 60 dBi)

Multibeam distribution

·········· Single beam aggregate distribution

1602-10
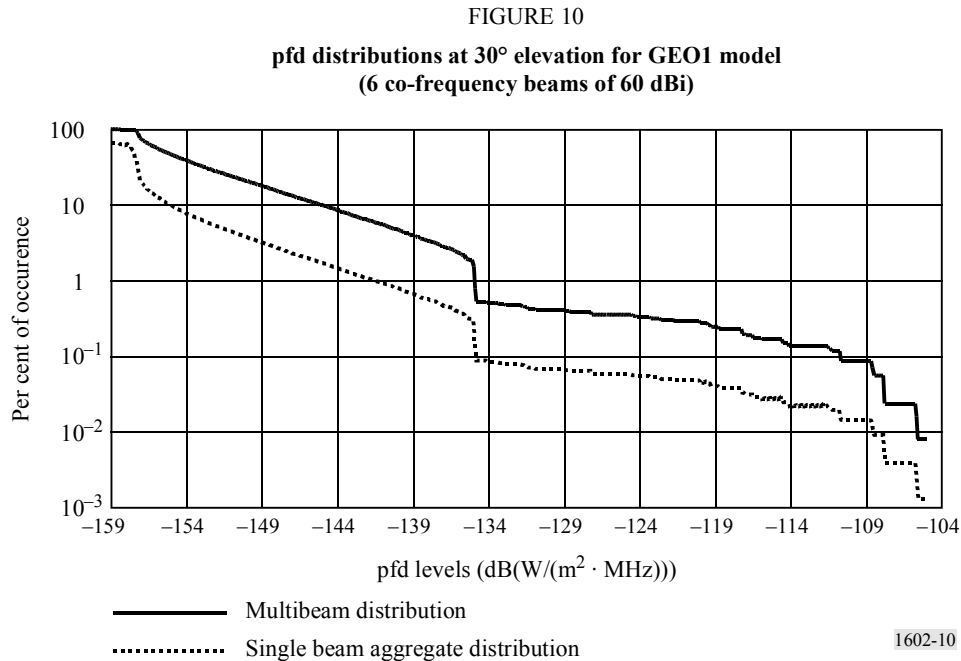
4.3   Minimum pointing elevation angle

Depending on the considered frequency band, the attenuation due to rain or other technical constraints can have an impact on satellite design which may lead to systems not designed for low elevation angles.
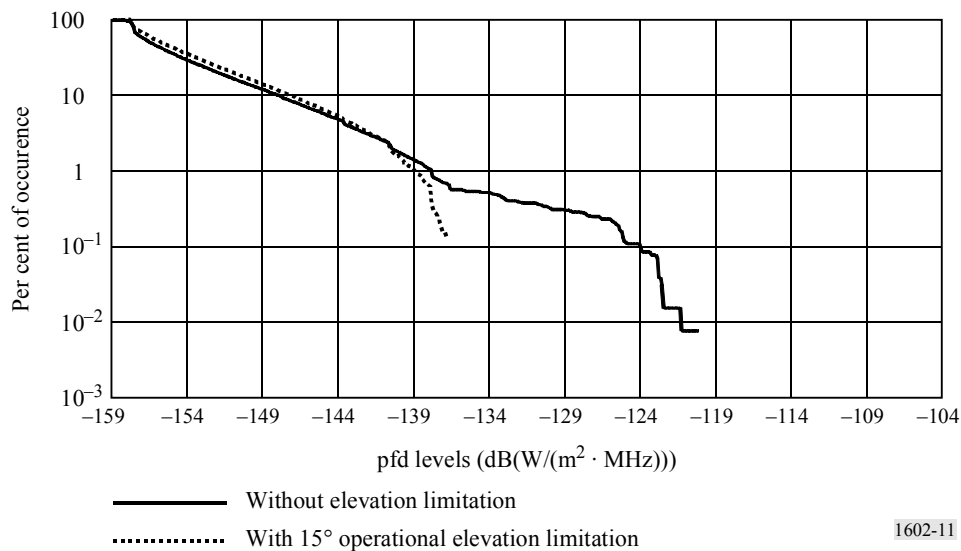
The minimum elevation angle has a significant impact on the sharing conditions between FSS and FS since all FS stations pointing to a satellite with an elevation lower than the satellite minimum operational elevation will not suffer main beam to main beam interference.

As an example, Fig. 11 provides a comparison of two pfd distributions, one taking into account a 15° operational elevation limitation for the GSO FSS satellite and the second without elevation limitation. This Figure shows a difference of more than 15 dB on the maximum pfd value that confirms the impact of the minimum operational elevation angle.

4.4   Further considerations

The analysis in the previous sections assumes a uniform distribution of the satellite beam orientation. In practice and depending on the frequency band and applications, the satellites would tend to orient their beams toward landmasses and in particular population centres. Similarly, depending on the frequency band and applications, FS networks, and in particular high density FS networks, are also likely to be deployed in the same population centres.

FIGURE 11

pfd distributions at 10° elevation for GEO1 model
(60 dBi multibeams)

Per cent of occurence

pfd levels (dB(W/(m^2 · MHz)))

——————— Without elevation limitation

················ With 15° operational elevation limitation

1602-11

Correlation distribution of the two services may need to be taken into account when applying the methodology.

5 Conclusion

This Annex proposes a statistical methodology for computing interference from satellites into FS receivers. The methodology takes into account realistic satellite characteristics (such as maximum power, number of beams, antenna gain and pattern and minimum pointing elevation angle). It permits a detailed analysis of the impact of satellites on FS systems and could be used in sharing studies pertaining to the assessment of pfd limits to be applied to satellite services to protect the FS in a multi-satellite environment. On this basis, examples of calculations using this methodology are given in Appendices 1-6 for the satellite models described in § 3:

– For GSO satellites (without operational elevation limit):

  – model GEO1 (6 co-frequency beams with 60 dBi antenna gain), Appendix 1.

– For GSO satellites (with 15° operational elevation limit):

  – model GEO1 (6 co-frequency beams with 60 dBi antenna gain), Appendix 2;

  – model GEO2 (4 co-frequency beams with 55 dBi antenna gain), Appendix 3.

– For non-GSO satellites (with 20° operational elevation limit):

  – model MEO1 (4 co-frequency beams with 50 dBi antenna gain), Appendix 4;

  – model MEO2 (3 co-frequency beams with 45 dBi antenna gain), Appendix 5.

Finally, Appendix 6 provides an example of implementation of the statistical pfd levels obtained with this methodology based on the case of non-GSO satellites.
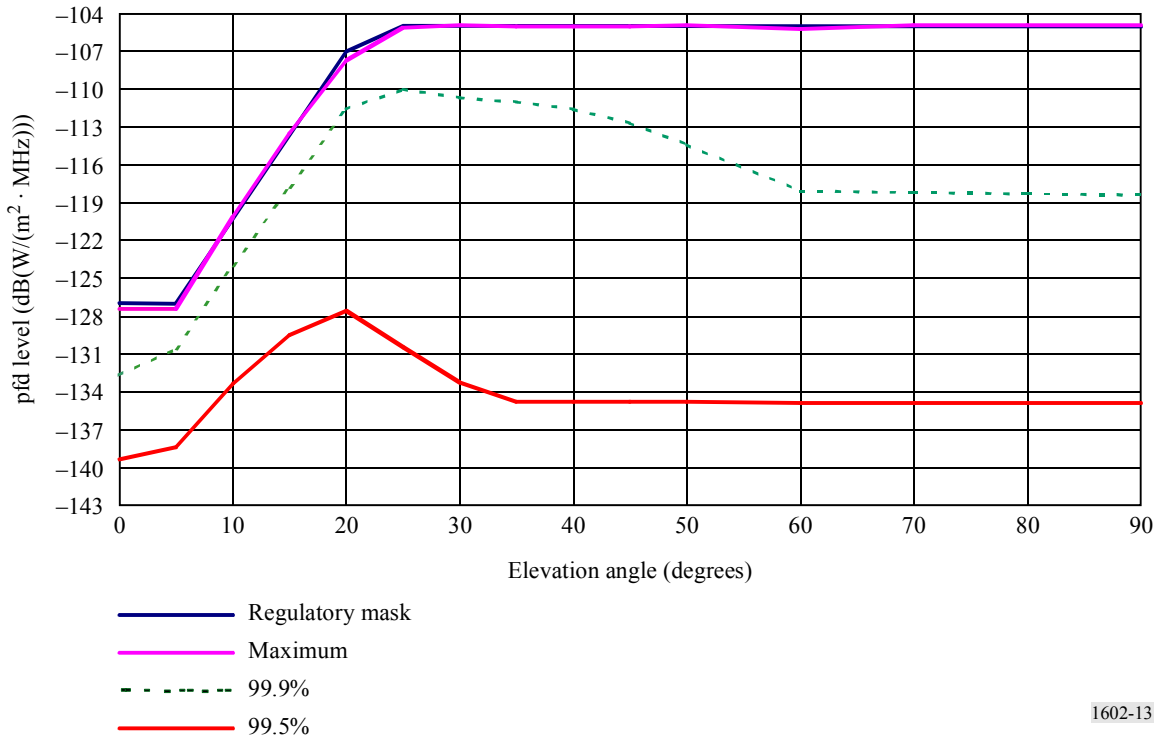
Appendix 1
to Annex 1

FIGURE 12

pfd distributions for GEO1 model (60 dBi multibeam) without operational elevation limitation
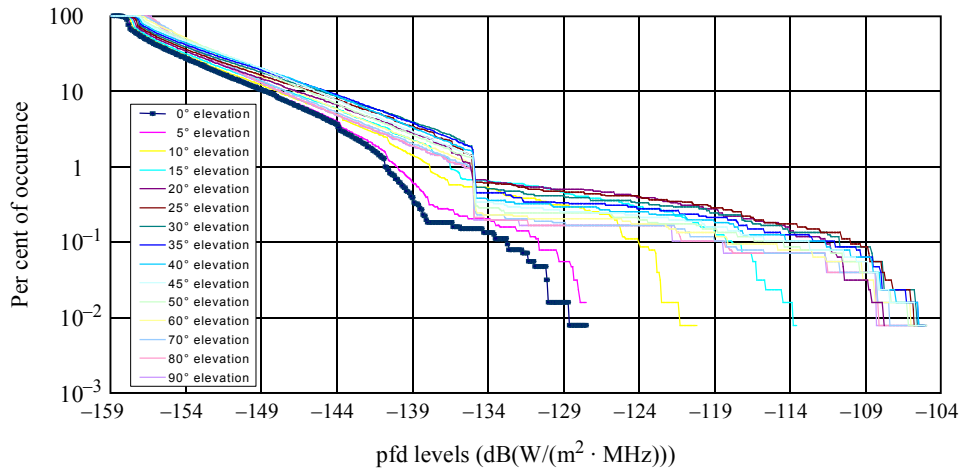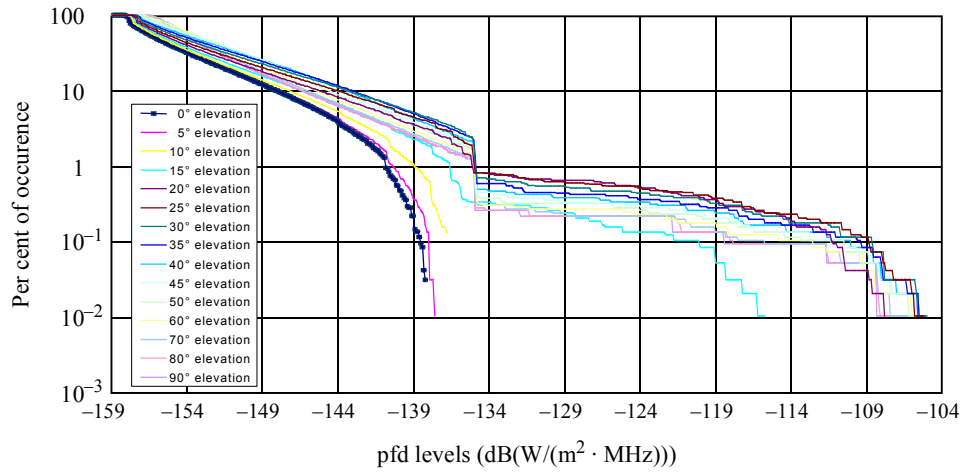

1602-12

FIGURE 13

Aggregate pfd masks for GEO1 model (60 dBi multibeam) without operational elevation limitation
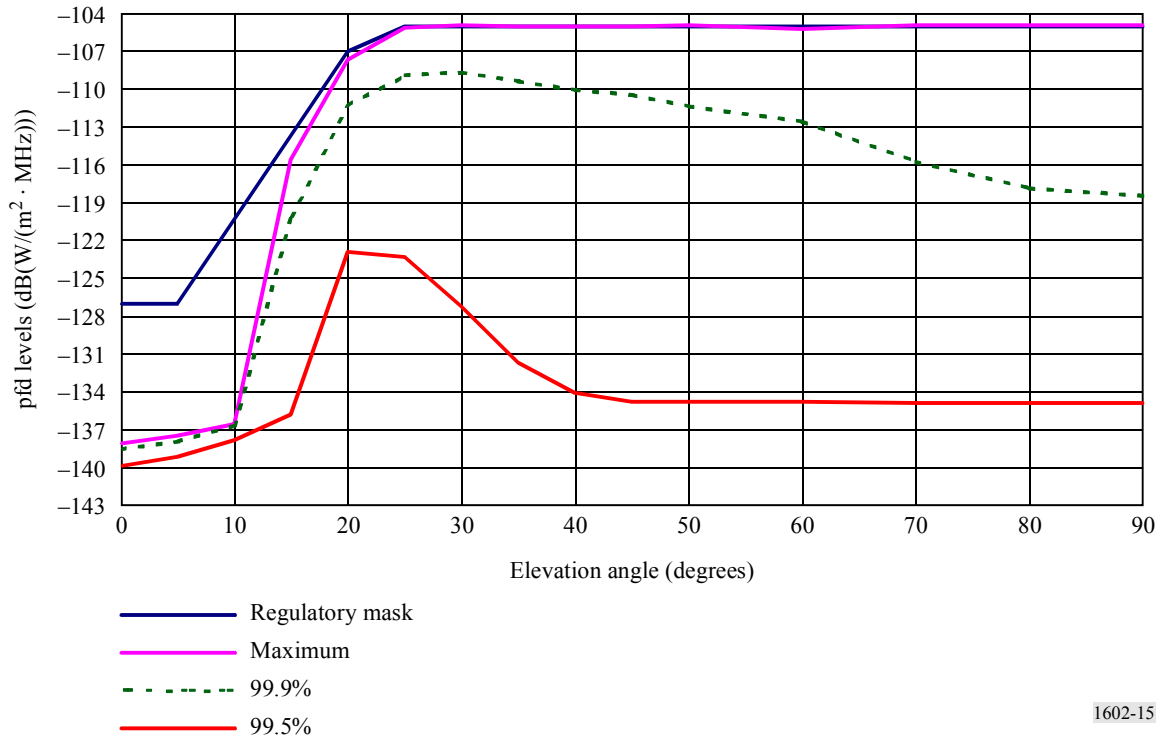

1602-13

Appendix 2
to Annex 1

FIGURE 14

pfd distributions for GEO1 model (60 dBi multibeam)
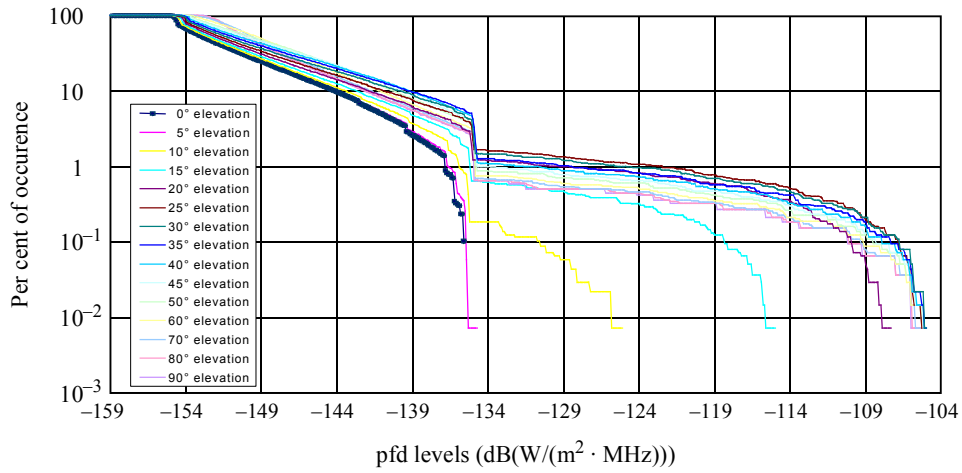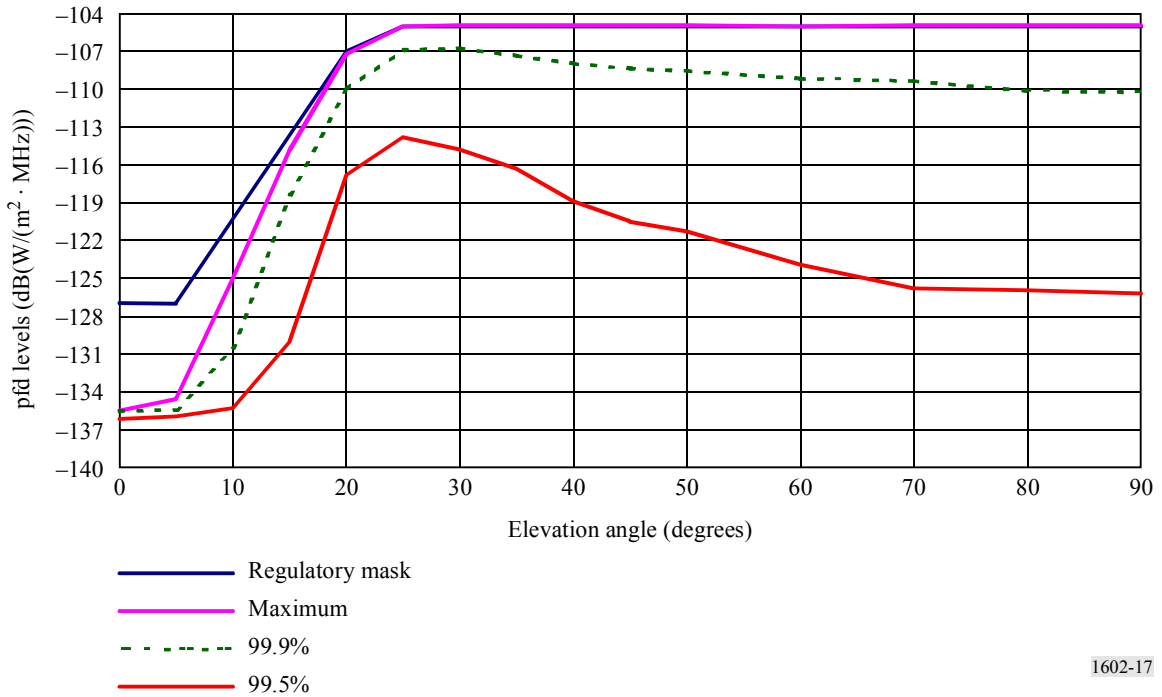**with 15° operational elevation limitation**

1602-14

FIGURE 15

Aggregate pfd masks for GEO1 model (60 dBi multibeam) with 15° operational elevation limitation

1602-15

Appendix 3
to Annex 1

FIGURE 16

pfd distributions for GEO2 model (55 dBi multibeam)
with 15° operational elevation limitation

1602-16

FIGURE 17

Aggregate pfd masks for GEO2 model (55 dBi multibeam) with 15° operational elevation limitation
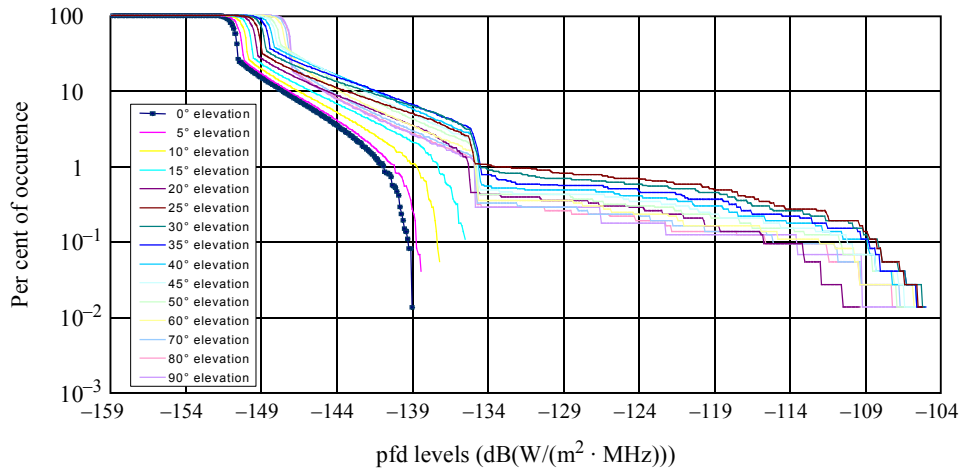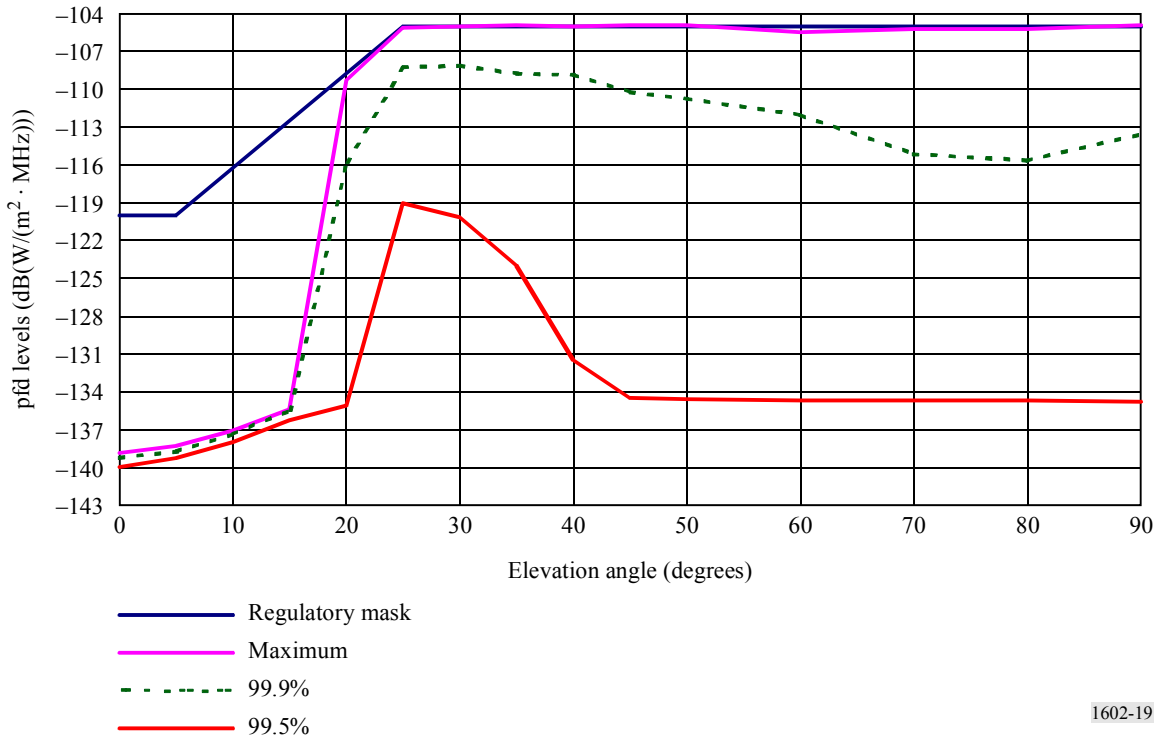

1602-17

Appendix 4
to Annex 1

FIGURE 18

**pfd distributions for ME01 model (50 dBi multibeam)
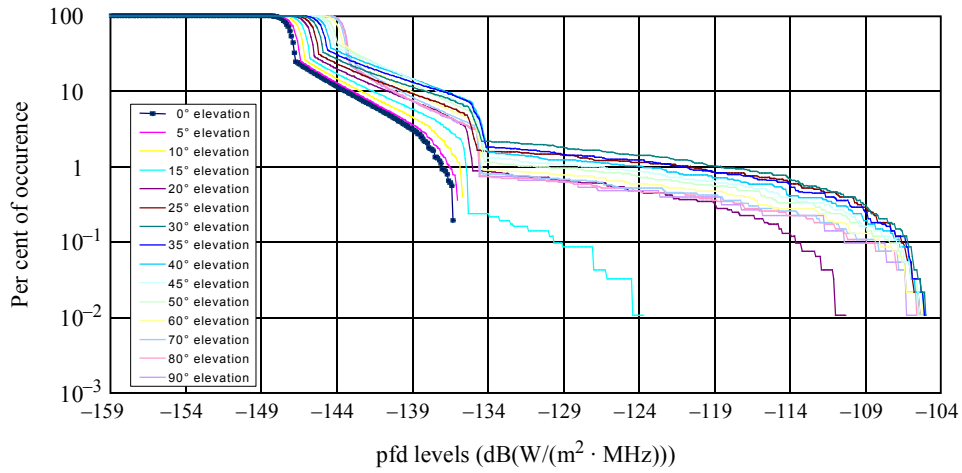with 20° operational elevation limitation**

1602-18

FIGURE 19

Aggregate pfd masks for GEO1 model (50 dBi multibeam) with 20° operational elevation limitation

— Regulatory mask

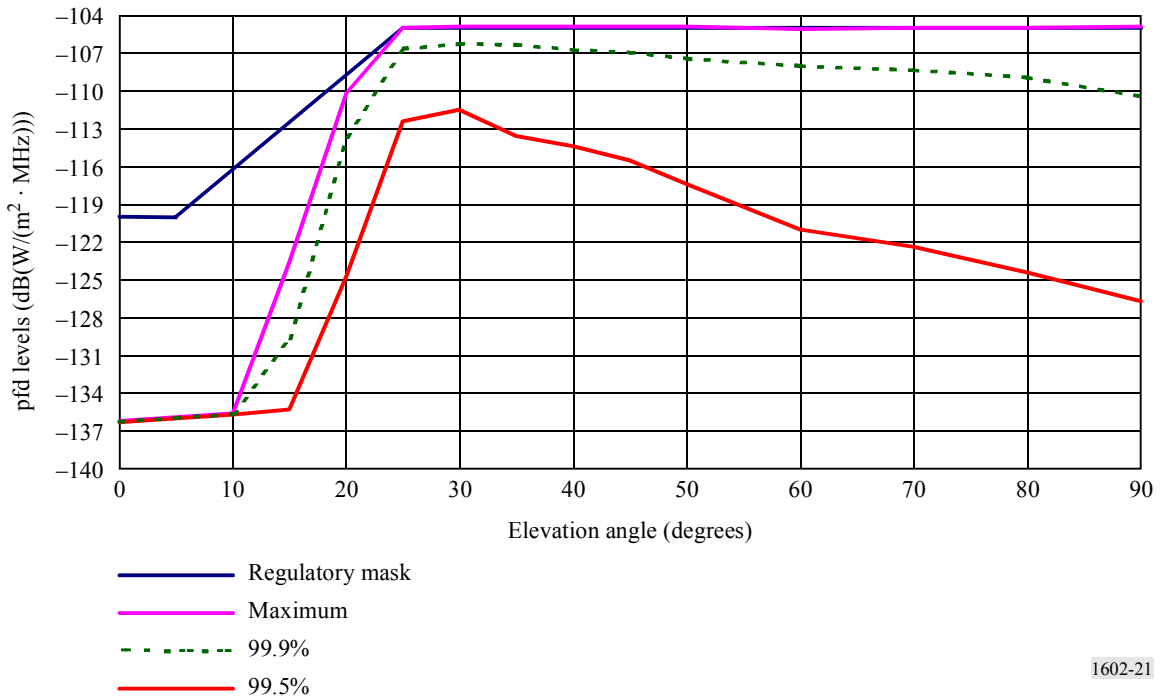— Maximum

---- 99.9%

— 99.5%

1602-19

Appendix 5
to Annex 1

FIGURE 20

**pfd distributions for ME02 model (45 dBi multibeam)
with 20° operational elevation limitation**

1602-20

FIGURE 21

Aggregate pfd masks for MEO2 model (45 dBi multibeam) with 20° operational elevation limitation

Regulatory mask

Maximum

99.9%

99.5%

1602-21

Appendix 6
to Annex 1

Example implementation of the methodology for non-GSO case

As described in § 2 of Annex 1, the calculations of interference from a non-GSO FSS system to an FS station are typically presented as an I/N distribution, as the curves in Fig. 2.

The maximum short-term I/N scenarios represent the interference caused by a satellite passing through the main beam of the considered FS station, under the assumption that this satellite produces the maximum pfd level with regard to the pfd mask under consideration.

The examples in the Figures in Appendices 4 and 5 show, for all elevation angles, that the occurrence of the maximum pfd scenario is small and that, in a large majority of the cases, the pfd produced by the non-GSO satellite is below the pfd mask under consideration.

The combined effect of the low occurrence of the maximum pfd scenario and the lower pfd levels in the large majority of the cases will tend to decrease the percentage related to the maximum I/N distribution.

Acknowledging that the short-term part of the distribution is produced in the main beam of the FS and hence is related to the same elevation with regard to the pfd value, the combined effect on the tail of the distribution can be obtained by convolving the I/N distribution (for the low percentages) with the corresponding pfd distribution for the considered FS elevation such as given on Fig. 22 (using the methodology described in this Recommendation).

FIGURE 22

Typical pfd distribution produced by a non-GSO system
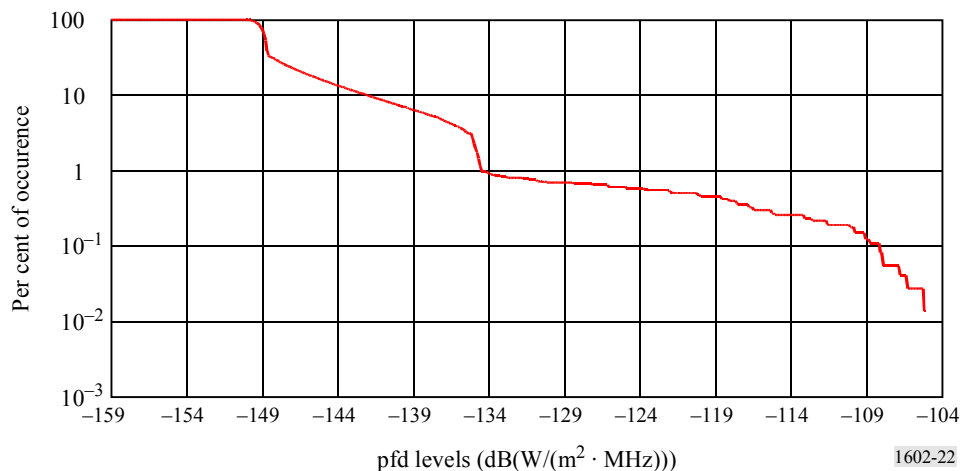
1602-22

On this basis, Fig. 23 provides the convolved *I/N* result of this example compared with the *I/N* derived from the pfd mask under consideration.

FIGURE 23

Comparison of example maximum and convoluted interference distribution

Maximum *I/N* scenario
Criteria
Convoluted *I/N* scenario

1602-23