International Telecommunication Union

ITU-R
Radiocommunication Sector of ITU

Recommendation ITU-R F.1249-3
(02/2013)

Technical and operational requirements that facilitate sharing between point-to-point systems in the fixed service and the inter-satellite service in the band 25.25-27.5 GHz

F Series
Fixed service

International Telecommunication Union

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.

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

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

Electronic Publication
Geneva, 2013

RECOMMENDATION ITU-R F.1249-3*

Technical and operational requirements that facilitate sharing between point-to-point systems in the fixed service and the inter-satellite service in the band 25.25-27.5 GHz

(Questions ITU-R 118/7 and ITU-R 252/5)

(1997-2000-2009-2013)

Scope

This Recommendation provides maximum e.i.r.p. density of transmitting point-to-point fixed service (FS) stations towards the direction of the geostationary-satellite orbit to enable sharing with the inter-satellite service in the band 25.25-27.5 GHz. The reference e.i.r.p. density in this Recommendation takes into account the need for transmission at the minimum necessary level while taking into account use of automatic transmitter power control (ATPC) at the FS stations for precipitation events.

The ITU Radiocommunication Assembly,

considering

a) that the frequency band 25.25-27.5 GHz is allocated to the inter-satellite service and the fixed service on a primary basis;

b) that this frequency band is used for space research and Earth exploration applications for return inter-satellite links to data relay satellites (DRSs) in the geostationary-satellite orbit (GSO);

c) that some transmitting stations in the fixed service (FS) may be able to use automatic transmit-power control (ATPC) to reduce their equivalent isotropically radiated power (e.i.r.p.) during clear-weather conditions;

d) that aggregate interference from the side lobes of the antennas of a large number of transmitting stations in the FS which do not point towards a DRS has been shown to be tolerable, but that main beam coupling from a single transmitting station in the FS service which does point towards a DRS satellite is considered to represent a potentially severe interference situation (see Annex 1);

e) that, whereas exceptionally long FS links require operation at elevated e.i.r.p. densities, these usually operate near or at zero elevation angles where atmospheric attenuation substantially reduces the potential interference;

f) that, under certain circumstances, topography and man-made structures obstruct FS radiation into space, or introduce substantial attenuation into the potential interference path;

g) that interference mitigation techniques can be used by both services to minimize the interference from the emissions of FS systems into DRS systems,

recognizing

a) that Recommendation ITU-R SA.1155 recommends that the maximum aggregate interference power spectral density levels received in the 25.25-27.5 GHz band by geostationary

---

[*] This Recommendation was jointly developed by Radiocommunication Study Group 7 and former Study Group 9, and future revisions should be undertaken jointly by Study Groups 5 and 7.

DRSs in the inter-satellite service should not exceed −178 dB(W/kHz) for more than 0.1% of the time;

b) that a limited number of DRS networks are used in the GSO as listed in Recommendation ITU-R SA.1276 (see Note 1);

c) that Recommendation ITU-R F.758 provides a large variety of fixed wireless system parameters generalized by representative systems for specific frequency ranges,

recommends

1 that the maximum e.i.r.p. within the channel bandwidth of such an FS station should, where practicable, be the minimum necessary for satisfactory operation;

2 that, for the GSO locations specified in Recommendation ITU-R SA.1276 (see Note 1):

2.1 as far as practicable, the e.i.r.p. density of such an FS station in the direction of the above locations should not exceed +24 dBW in any 1 MHz band (see Note 2);

2.2 during conditions when precipitation attenuation is experienced between the FS transmitting and receiving stations, the transmitting station may use ATPC to increase its transmitted power, by an amount not exceeding the precipitation attenuation, such that its e.i.r.p. density in the direction of the GSO locations referenced above does not exceed +33 dBW in any 1 MHz band;

2.3 when the atmospheric attenuation towards the GSO locations referenced above, calculated using the procedures in Annex 1 of Recommendation ITU-R P.676, taking into account the elevation angle towards these orbit locations, the altitude of the FS transmitting antenna and local information of average water vapour content in the driest month and of other meteorological parameters (see Note 3), exceeds 3 dB, this excess may be applied as an increase of the e.i.r.p. density of the FS station;

2.4 when the Fresnel zones on the path from such a transmitting FS station in the direction of the above orbit locations are completely or partially blocked, the e.i.r.p. density in this direction may be increased by an amount calculated using the methods of Recommendation ITU-R P.526, taking due account of atmospheric refraction on this path (see Recommendation ITU-R F.1333);

2.5 Annex 2 is a method which may be used to calculate separation angles from the specific locations on the GSO;

3 that, for all other locations on the GSO:

3.1 the e.i.r.p. density of such an FS station in the direction of the GSO should not exceed +33 dBW in any 1 MHz band;

3.2 Annex 2 to Recommendation ITU-R SF.765 is a method which may be used to calculate separation angles from the GSO (see Note 4);

4 the four following Notes 1, 2, 3 and 4 are part of this Recommendation:

NOTE 1 – Recommendation ITU-R SA.1276-3 identifies the following geostationary orbital positions:

10.6° E, 16.4° E, 16.8° E, 21.5° E, 47° E, 59° E, 77° E, 80° E, 85° E, 89° E, 90.75° E, 95° E, 113° E, 121° E, 133° E, 160° E, 171° E, 176.8° E, 177.5° E,

12° W, 16° W, 32° W, 41° W, 44° W, 46° W, 49° W, 62° W, 139° W, 160° W, 170° W, 171° W, 174° W.

When Recommendation ITU-R SA.1276 is revised so that new DRS orbital locations are added, protection of new orbital slots in revision to this Recommendation applies only to FS stations installed after the enforcement date of the revised Recommendation ITU-R SA.1276.

NOTE 2 – The interference potential to DRS satellites from point-to-point fixed wireless systems which exceed the e.i.r.p. density limits outlined in *recommends* 2.1, may be reduced by avoiding the use of the DRS centre frequencies, where practical. Further study of this mitigation technique is required.

NOTE 3 – Recommendation ITU-R F.1404 proposes the estimation of atmospheric attenuation using detailed information of local meteorological parameters for the band 25.5-27.5 GHz. Where this is not available a simple procedure, which assumes simplified climate models, is proposed on a provisional basis. This method requires further study. Administrations which have obtained local meteorological parameters for use in estimation of gaseous attenuation are requested to make those data available for the ITU-R (particularly Radiocommunication Study Groups 3 and 5).

NOTE 4 – Recommendation ITU-R SF.765 was originally developed to give precise separations up to 2°. It is to be noted that the algorithm used in this Recommendation is equally valid to be expanded up to 10° by using $B = 10°$ in § 1 of Annex 2 to Recommendation ITU-R SF.765.

Annex 1

Maximum e.i.r.p. density of point-to-point fixed wireless system transmitters operating in the band 25.25-27.5 GHz shared with the inter-satellite service

1 Introduction

This annex summarizes analyses that demonstrate that the protection criteria of Recommendation ITU-R SA.1155 for DRSs can be satisfied except in the case of main beam-to-main beam coupling by the emissions of point-to-point fixed wireless stations.

2 System models

2.1 Point-to-point FS deployment in the band 25.25-27.5 GHz

The following assumptions concerning the technical and operational characteristics of point-to-point FS stations are extrapolated from existing 23 GHz systems:

- 100 000 transmitters assumed worldwide in the band 25.25-27.5 GHz (the 26 GHz band).
- Estimated distribution of transmitter e.i.r.p. density levels:
  - more than 70% of all FS links in the 25.25-27.5 GHz band are estimated to operate below +24 dB(W/MHz);
  - less than 25% are estimated to operate in the range of +24 dB(W/MHz) to +33 dB(W/MHz);
  - less than 5% are estimated to operate above +33 dB(W/MHz).
- Single frequency per transmitter. Half transmitters are “go”, half “return”.

- Frequency channelization in accordance with Recommendation ITU-R F.748 (the recommended channel bandwidths range from 112 MHz to 3.5 MHz and 2.5 MHz, there is a possibility of adding 1.75 MHz and 1.25 MHz bandwidths in the future).
- Operating channels are distributed across the band.
- Elevation angles are typically in the 0° to 5° range.
- Path length is typically in the 2 to 5 km range.
- Large rain fade margins are required in the 26 GHz band to achieve 99.999% availability.
- Large-scale point-to-point FS providers increasingly use the lowest possible transmitter power options in order to reduce frequency reuse distances.
- Only a minor number of equipment types are currently available with automatic power control.

2.2 Deployment of DRSs that use space-to-space links in the inter-satellite service

The technical and operational characteristics of DRSs to be operated by NASA of the United States of America, the European Space Agency (ESA), the Russian Space Agency, and the Japan Aerospace Exploration Agency of Japan (JAXA) that will use space-to-space links in the 26 GHz band are summarized below:

- Orbital locations are given in Recommendation ITU-R SA.1276.
- Typical DRS characteristics:
  - has two high gain single access antennas with a peak gain of 58 dBi;
  - receiving antenna 3 dB beamwidth is less than 0.2°;
  - receiving antenna can support one 20/30 GHz band return signal at a time;
  - DRS receiver noise temperature, $T = 703$ K (–140.13 dB(W/MHz) noise density);
  - return data rates: 1 kbit/s-300 Mbit/s in a 225 MHz bandwidth;
  - return data rates: 1 kbit/s-800 Mbit/s in a 650 MHz bandwidth;
  - •– receiving centre frequency is tunable in 25 MHz (or smaller) steps.
- DRS centre frequencies selected in conformance with Space Network Interoperability Panel (SNIP) recommendations for common DRS return channels will have centre frequencies at: 25.60 GHz, 25.85 GHz, 26.10 GHz, 26.35 GHz, 26.60 GHz, 26.85 GHz, 27.10 GHz or 27.35 GHz.

Interference mitigation techniques have neither been studied nor implemented on the current generation of 26 GHz DRS.

3 Interference assessment

3.1 DRS protection criteria

Recommendation ITU-R SA.1155 – Protection criteria related to the operation of data relay satellite systems, recommends that the maximum aggregate interference power spectral density level from all sources to be exceeded for no more than 0.1% of the time be –178 dB(W/kHz) in the 25.25-27.5 GHz band (this is equivalent to –148 dB(W/MHz)). This level is based on an $I/N = -10$ dB and a link margin degradation of 0.4 dB. The recommended maximum reference bandwidth is 1 kHz. The protection criteria translates to a maximum FS interference e.i.r.p. density of 13.5 dB(W/MHz) in the direction of the DRS when there is main beam coupling as shown in Table 1.

TABLE 1

Maximum FS e.i.r.p. density in the direction of a DRS for main beam coupling

FS e.i.r.p. density (dB(W/MHz))	13.5
Atmospheric loss (dB)	3
Polarization loss (dB)	3
Free space loss (dB)	213.5
DRS peak receive antenna gain (dBi)	58
Maximum interference density (dB(W/MHz))	–148

3.2 Main beam interference

The main beam interference criteria include:

– the tolerable FS e.i.r.p. density limit that satisfies the DRS protection criteria of Recommendation ITU-R SA.1155;

– the probability of main beam interference occurrence. The tolerable FS e.i.r.p. density limit is calculated under the assumptions of co-channel interference into a non-inclined DRS orbit. The assessment of the probability of main beam interference occurrence is based on the operating conditions of the two systems.

The case of a FS radio-relay radiating towards a DRS and coupling into the main beam of the DRS high gain antenna is considered for a range of e.i.r.p. density levels. The results are given in Table 2. The table shows that an e.i.r.p. spectral density in excess of 13.5 dB(W/MHz), assuming 3 dB loss due to atmospheric absorption and 3 dB polarization loss, will result in an interference level greater than the value specified in Recommendation ITU-R SA.1155 when there is direct alignment.

TABLE 2

Amount interference criteria is exceeded versus FS e.i.r.p. density radiated towards the DRS

FS e.i.r.p. density (dB(W/MHz))	13.5	24	33
DRS spacecraft Rx antenna gain (dBi)	58	58	58
Free space loss (dB)	213.5	213.5	213.5
Atmospheric loss (dB)	3	3	3
Polarization loss (dB)	3	3	3
Interference power, I (dB(W/MHz))	– 148	–137.5	–128.5
Maximum interference criteria (dB(W/MHz))	– 148	–148	–148
Criteria exceeded by (dB)	*0*	*10.5*	*19.5*

It should be noted that atmospheric loss may be less than 3 dB under some climatic conditions for higher elevation angles.

Simulations were performed to evaluate the interference as a percentage of time as the DRS tracks a low-Earth orbiting (LEO) satellite. To analyse the interference versus percentage of time, it is necessary to simulate the orbital flight of the LEO satellite. A range of inclination angles for the LEO satellites was used. In each case, the terrestrial station longitude was set so that the DRS would be in the terrestrial station antenna main beam, which is directed in the horizontal plane.

Three different simulations were performed. Each simulation was run for 100 days at a time increment of 0.1 min and the level of the received interference relative to the level received for boresight coupling at the receiver of the DRS was calculated at each increment. The simulations were run for three cases, with the results plotted in Fig. 1. The cases are:

Case 1: low-orbiting user satellite orbital altitude of 300 km, an inclination of 85° and an FS station latitude of 50°;

Case 2: low-orbiting user satellite orbital altitude of 300 km, an inclination of 65° and an FS station latitude of 60°;

Case 3: low-orbiting user satellite orbital altitude of 300 km, an inclination of 28.5° and an FS station latitude of 28.5°.

The curves given in Fig. 1 may be used to determine the e.i.r.p. spectral density obtained under free space propagation conditions that will ensure that the interference power received by the DRS does not exceed –148 dB(W/MHz) for more than 0.1% of the time. The calculations are summarized in Table 3. The table shows that the e.i.r.p. spectral density required to satisfy the criteria is a function of the orbital parameters of the LEO satellite that the DRS is tracking and the location of the FS transmitting station. The acceptable level of e.i.r.p. spectral density ranges from 31.5 dB(W/MHz) for case 1, down to 17.5 dB(W/MHz) for case 3. For the purpose of this Recommendation, a single value of 24 dB(W/MHz) is acceptable. The e.i.r.p. spectral density is obtained under free space propagation conditions.

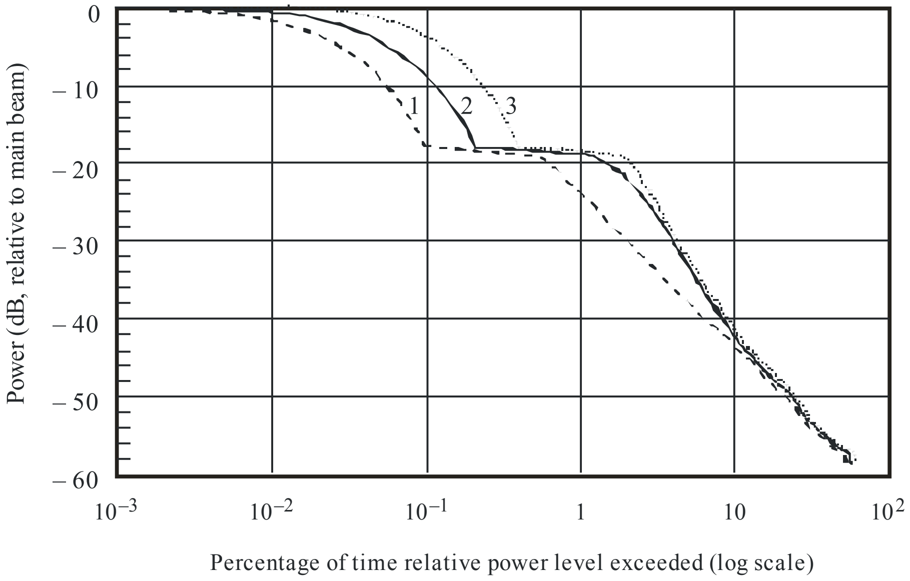
Several operating conditions substantially reduce the probability and effects of FS-to-DRS interference, such as:

- the distribution of FS e.i.r.p. density levels (see § 2.1), which indicates that less than 30% of FS systems are likely to operate above the +24 dB(W/MHz) limit;
- the different frequency band usage of the FS and DRS systems (see Table 5), which indicates that only about 4% of direct beam coupling occurrences are likely to result in interference;
- the pointing of the FS transmitter antenna both at a random azimuth angle that is uniformly distributed between 0° and 360°, and at a uniformly distributed random elevation angle between 0° and 5° (see § 3.1 and 3.3 of this annex), which further reduces the probability of direct beam coupling by at least three orders of magnitude.

The resulting order-of-magnitude probability of direct beam coupling occurrence is lower than 10^{-5}.

FIGURE 1

Percentage of time the relative interference power is exceeded



F.1249-01

TABLE 3

Summary of calculations to determine the acceptable e.i.r.p. spectral density of FS station emissions in the direction of a DRS

Case	Power relative to main beam at the 0.1 percentile level (see Fig. 1) (dB)	e.i.r.p. density for I = –148 dB(W/MHz)	Acceptable e.i.r.p. density (dB(W/MHz))
1	–18	13.5	31.5
2	–9	13.5	22.5
3	–4	13.5	17.5

3.3 Aggregate interference

The maximum e.i.r.p. density was derived from the maximum value in each range of the distribution of FS radio-relay transmitter power density given in § 2.1 of this annex. The worst-case weighted average of the distribution yields an e.i.r.p. density level of 36.2 dB(W/MHz) as shown in Table 4.

TABLE 4

Estimated distribution of FS transmit e.i.r.p. density levels

50%	26 dB(W/MHz)	398 W/MHz
40%	33 dB(W/MHz)	1 995 W/MHz
10%	45 dB(W/MHz)	31 623 W/MHz
Weighted average		36.19 dB(W/MHz)

The number of co-channel interferers was derived from the deployment model in § 2.1 of this annex. It has been estimated that there could be as many as 100 000 FS transmitters deployed in the 25.25-27.5 GHz band worldwide. Based on the "German Plan" example in Recommendation ITU-R F.748, it can be assumed that there are:

– 50 000 transmitters in lower half band (25.56-26.06 GHz);

– 50 000 transmitters in upper half band (26.68-27.18 GHz).

The distribution of the channels used in the Monte Carlo simulations is given in Table 5 for one 500 MHz band segment in the German type Plan. Out of a total number of 100 000 transmitters deployed worldwide, there could be a total of 2 001 co-channel emitters in any 1 MHz band.

TABLE 5

Assumed distribution of the channel bandwidth used by the FS point-to-point stations

Channel bandwidth (MHz)	Estimated usage (%)	No. in 50 000	Co-channel No.
112	5	2 500	625
56	5	2 500	312
28	10	5 000	312
14	30	15 000	428
7	30	15 000	210
3.5	15	7 500	106
1.75	5	2 500	8
		Total	2 001

The spatial distribution of the interference is determined from a Monte Carlo simulation assuming the equivalent of 2 000 FS transmitters deployed around the major cities of the world. The transmitters were co-channel with an average e.i.r.p. density of 36 dB(W/MHz) and the FS antennas were pointed at a random azimuth angle that was uniformly distributed between 0° and 360°. Figures 2 and 3 represent the aggregate interference density as received by a DRS located at 41° W and 174° W, respectively, as a function of the spacecraft antenna pointing angle (roll and pitch).

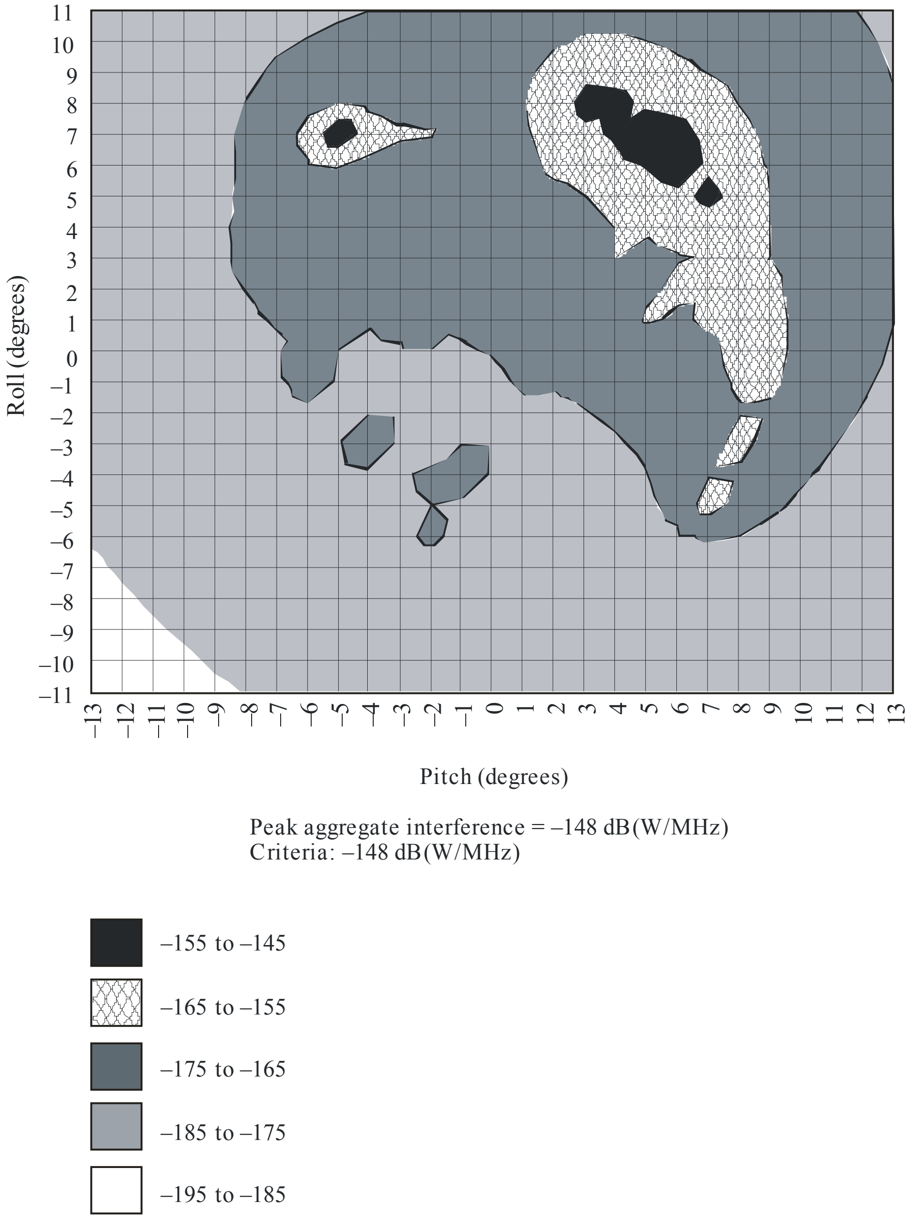
For the DRS at 41° W (see Fig. 2), the maximum aggregate interference level is –148 dB(W/MHz) and the protection criteria would be met except in the case of main beam coupling where a single, co-channel FS transmitter can cause interference in excess of the criterion.

Figure 3 shows that the maximum aggregate interference level in the case of a DRS at 174°W is –149.5 dB(W/MHz) or 1.5 dB below the criterion. Again, the DRS protection criterion would be met except in main beam coupling cases.

As Figs 2 and 3 show, the aggregate interference from the random deployment of radio-relay systems as assumed for the Monte Carlo simulations does not appear to cause interference in excess of the criteria given in Recommendation ITU-R SA.1155. It is concluded from these simulations that the aggregate interference to DRSs from the emissions of randomly deployed point-to-point FS stations will not exceed a value of –148 dB(W/MHz), and that main beam-to-main beam coupling, as discussed in § 3.2, will result in interference in excess of the criteria given in Recommendation ITU-R SA.1155.

FIGURE 2

Aggregate interference (dB(W/MHz)) to a DRS located at 41° W, as a function of spacecraft antenna pointing angles



Peak aggregate interference = –148 dB(W/MHz)
Criteria: –148 dB(W/MHz)

F.1249-02

4 Interference mitigation techniques

4.1 FS systems

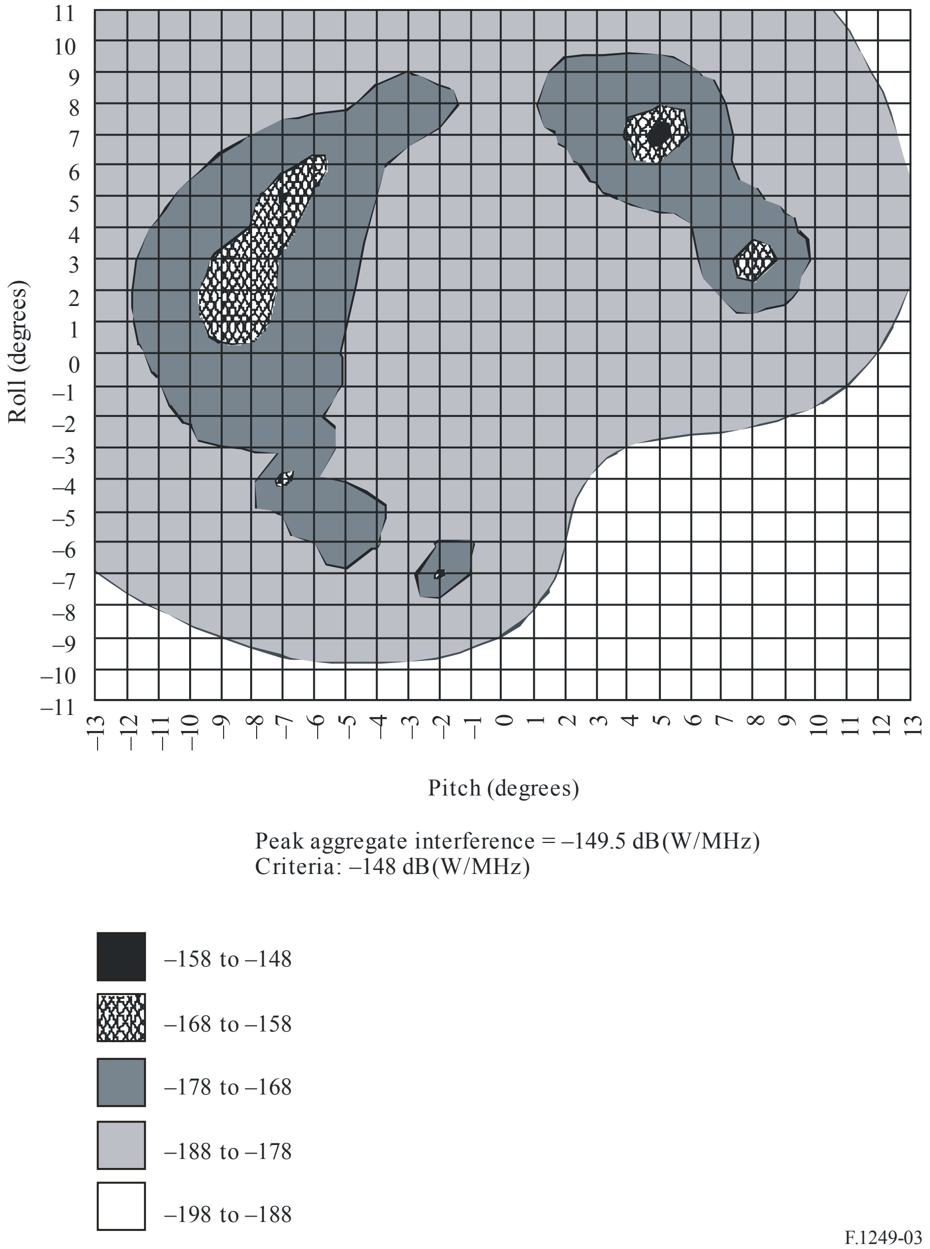
Interference mitigation encompasses sound basic system design practices, as well as the use of techniques developed for the specific purpose of interference reduction, which includes:

- operation with the minimum necessary e.i.r.p. density, which is practiced for economic and operational reasons, such as lower equipment and maintenance costs, smaller and lighter equipment, lower primary power consumption, and shorter frequency reuse distances;
- system design that takes into account the effect of atmospheric attenuation;

- site selection and configuration that substantially reduces radiation beyond the required FS range either through blockage by natural and/or man-made obstacles, or through partial Fresnel zone blockage that causes diffraction attenuation (see Annex 3);
- the use of automatic transmitter power control.

FIGURE 3

Aggregate interference (dB(W/MHz)) to a DRS located at 174° W, as a function of spacecraft antenna pointing angles



Peak aggregate interference = –149.5 dB(W/MHz)
Criteria: –148 dB(W/MHz)

F.1249-03

4.2 DRS systems

Interference mitigation techniques to be used in DRS systems could include frequency agility and/or redundancy, bridging interference events and adaptive interference cancellation. The ITU-R has initiated a study of interference mitigation techniques.

4.3 Cooperative sharing framework

The planned coexistence of the FS and the DRS service presents a new set of frequency sharing problems which require a fresh approach. The most promising approach is the establishment of a cooperative framework, at the working level, that:

– facilitates the mutual understanding of the service requirements and operating conditions;

– develops the appropriate sharing practices;

– promotes the implementation of interference countermeasures in both services.

5 Conclusions

Assuming an average point-to-point FS e.i.r.p. density of 36 dB(W/MHz) radiating at low elevation angles and random azimuth angles; the use of high gain, narrow antenna beams by both FS and DRS stations, and FS frequency channelization plans, it appears that the DRS protection criteria of Recommendation ITU-R SA.1155 can be satisfied except in the cases of main beam or near main beam coupling. A limit of 24 dB(W/MHz) on the emissions of point-to-point FS stations towards the orbital locations of DRS satellites is required to satisfy the protection criteria of Recommendation ITU-R SA.1155. This value applies to free-space propagation conditions.

The establishment of a cooperative sharing framework would be helpful in the practical implementation of this Recommendation.

Annex 2

Method for calculating separation angles between point-to-point FS transmitting antenna beams and the directions towards geostationary data relay satellites

1 Introduction

This Annex provides a method for calculating separation angles between FS transmitting antenna beams and the directions towards geostationary DRSs located at the positions specified in *recommends* 2 of the main text of this Recommendation, taking into account the effects of atmospheric refraction and the local horizon.

2 FS station parameters

The parameters of a FS station are defined as follows:

ζ: latitude of the station (absolute value);

α_r: azimuth of the antenna beam measured clockwise from the North;

ε_r: elevation angle of the antenna beam;

h: altitude of the antenna above sea level (km);

δ: longitudinal difference (absolute value) between the station and one of the satellites specified in *recommends* 2.

If δ is larger than 90° (more precisely, if $\cos \delta < 0$), then the satellite is not visible from the FS station and, therefore, it is not necessary to carry out further calculations. (Even when δ is slightly less than 90°, the satellite may not be visible, but it will be determined later.)

3 Determination of the azimuth of the satellite

Using an ellipsoidal model, the Earth's shape is characterized by R = 6 378.14 km (Earth's equatorial radius) and $f = 1/298.25$ (Earth's flatness factor). Hence, the Earth's polar radius is given by $(1 - f)R$.

In this case, the geocentric latitude ζ_1 and the effective Earth's radius R_1 at geographical latitude ζ and antenna altitude h are given by:

$$\zeta_1 = \arctan\left[(1 - f)^2 \tan \zeta\right] \tag{1}$$

$$R_1 = R(1 - f \sin^2 \zeta_1) + h \tag{2}$$

Next, calculate the value of Ψ (great circle arc between the FS station and the sub-satellite point) as follows:

$$\Psi = \arccos(\cos \zeta_1 \cos \delta) \tag{3}$$

Then, the azimuth (α_s) of the satellite as seen from the FS station is given as follows:

$$\alpha'_s = \arccos(\tan \zeta_1 \cot \Psi) \tag{4}$$

$\alpha_s = \alpha'_s = 180°$ for a FS station located in the Northern Hemisphere and satellites located West of the FS station (5a)

$\alpha_s = 180° - \alpha'_s$ for a FS station located in the Northern Hemisphere and satellites located East of the FS station (5b)

$\alpha_s = 360° - \alpha'_s$ for a FS station located in the Southern Hemisphere and satellites located West of the FS station (5c)

$\alpha_s = \alpha'_s$ for a FS station located in the Southern Hemisphere and satellites located East of the FS station (5d)

4 Determination of the elevation of the satellite

First, the elevation (ε'_s) of the satellite as seen from the FS station is calculated as follows assuming that there is no effect of atmospheric refraction:

$$\varepsilon'_s = \arctan\left(\frac{K \cos \Psi - 1}{K \sin \Psi}\right) \tag{6}$$

where:

$K = R_S R_1$;

R_S = 42 164 km (orbit radius).

In order to take account of the effects of atmospheric refraction and the local horizon, the following elevation angles are defined:

ε_{m1}: elevation angle towards the local horizon at maximum atmospheric bending, as seen from the altitude of the FS antenna at the azimuth of the satellite (α_s) (see Note 1);

ε_{m2}: elevation angle towards the local horizon at minimum atmospheric bending, as seen from the altitude of the FS antenna at the azimuth of the satellite (α_s) (see Note 1).

Next, the visibility of the satellite is determined as follows:

- calculate $\varepsilon_1 = \varepsilon_{m1} - \tau_{max}(\varepsilon_{m1}, h)$ and $\varepsilon_2 = \varepsilon_{m2} - \tau_{min}(\varepsilon_{m2}, h)$, where $\tau_{max}(\varepsilon, h)$ and $\tau_{min}(\varepsilon, h)$ are the maximum and minimum atmospheric bendings corresponding to elevation angle ε, respectively, the numerical formulae of which are given in Note 2;
- if $\varepsilon_2 \leq \varepsilon'_{s,}$ the satellite is always visible;
- if $\varepsilon_1 \leq \varepsilon'_s < \varepsilon_2$, the satellite is visible for some percentage of time;
- if $\varepsilon'_s < \varepsilon_1$, the satellite is not visible in any conditions of atmospheric refraction and, therefore, there is no need of further calculations.

When $\varepsilon_2 \leq \varepsilon'_{s,}$ the elevation angles $\varepsilon_{1s\,max}$ and $\varepsilon_{s\,min}$ of the satellite corresponding to the maximum and minimum atmospheric bendings, respectively, can be calculated by solving the following equations (see Note 3):

$$\varepsilon_{s\,max} - \tau_{max}(\varepsilon_{s\,max}, h) = \varepsilon'_s \tag{7a}$$

$$\varepsilon_{s\,min} - \tau_{min}(\varepsilon_{s\,min}, h) = \varepsilon'_s \tag{7b}$$

When $\varepsilon_1 \leq \varepsilon'_s < \varepsilon_2$, it is not necessary to solve equation (7b) but only equation (7a). In this case, $\varepsilon_{s\,min} = \varepsilon_{m2}$ should be used.

The elevation angle ε_s which gives the minimum separation angle with sufficient accuracy is determined as follows:

$$\varepsilon_s = \varepsilon_{s\,max} \qquad \text{for } \varepsilon_{s\,max} \leq \varepsilon_r \tag{8a}$$

$$\varepsilon_s = \varepsilon_r \qquad \text{for } \varepsilon_{s\,min} \leq \varepsilon_r < \varepsilon_{s\,max} \tag{8b}$$

$$\varepsilon_s = \varepsilon_{s\,min} \qquad \text{for } \varepsilon_r < \varepsilon_{s\,min} \tag{8c}$$

5 Determination of the separation angle

The minimum separation angle, SA, between the FS antenna beam and the direction of a geostationary DRS as seen from the FS station can be calculated by:

$$SA = \arccos\left[\cos\varepsilon_r \cos\varepsilon_s \cos(\alpha_r - \alpha_s) + \sin\varepsilon_r \sin\varepsilon_s\right] \tag{9}$$

The separation angle should be calculated for each of the geostationary DRSs as specified in *recommends* 2.

NOTE 1 – If the local horizon is formed by a flat terrain or sea, ε_m is given by:

$$\varepsilon_m = -\arccos\left[\frac{R + h_1}{R + h} \times \frac{1 + N_0 \times 10^{-6}(1 + \Delta N/N_0)^{h_1}}{1 + N_0 \times 10^{-6}(1 + \Delta N/N_0)^{h}}\right] \tag{10}$$

where:

h : antenna altitude (km) of the station above sea level;

h_1 : altitude (km) of the local horizon ($h \geq h_1$);

R : Earth radius assumed to be 6 370 km.

According to Recommendation ITU-R SF.765, ε_{m1} is an elevation angle corresponding to maximum atmospheric bending (N_0 = 400 and ΔN = –68) and ε_{m2} is an elevation angle corresponding to minimum atmospheric bending (N_0 = 250 and ΔN = –30). It should be noted that $\varepsilon_{m1} \geq \varepsilon_{m2}$.

In practice it may be cumbersome to estimate the precise values of ε_{m1} and ε_{m2} taking into account the complicated skyline of the local horizon. In such a case, it may be simpler to estimate the values of ε_{m1} and ε_{m2} using formula (10) under an assumption of $h_1 = 0$. This will generally give an accurate separation angle. However, if $\varepsilon_{s\,max}$ is larger than ε_{m1} but very close to ε_{m1}, there is a possibility that the satellite may not be visible due to the effect of the local horizon. In this case, the calculation should be carried out again using the actual values of ε_{m1} and ε_{m2}.

NOTE 2 – Atmospheric bending (degrees) can be calculated by using the following formulae, based on Annex 2 to Recommendation ITU-R SF.765:

$$\tau_{max}(\varepsilon, h) = 1 / [0.7885809 + 0.175963\, h + 0.0251620\, h^2 + \varepsilon\,(0.549056 + 0.0744484\, h + 0.0101650\, h^2) + \varepsilon^2\,(0.0187029 + 0.0143814\, h)] \tag{11a}$$

$$\tau_{min}(\varepsilon, h) = 1 / [1.755698 + 0.313461\, h + \varepsilon\,(0.815022 + 0.109154\, h) + \varepsilon^2\,(0.0295668 + 0.0185682\, h)] \tag{11b}$$

where:

ε : elevation angle (degrees);

h : antenna height (km) of the station above sea level.

The above formulae are valid for the range of $\varepsilon \geq \varepsilon_{m1}$ or $\varepsilon \geq \varepsilon_{m2}$. The algorithm in this annex guarantees that the above formulae are applied only where they are valid.

NOTE 3 – Some precaution with respect to convergence is necessary for solving equation (7a), especially when h is large and ε'_s is negative. Therefore, one approach to solve equation (7a) is to apply the Newton-Raphson's method with $\varepsilon_{s\,max} = \max\,(\varepsilon'_s, \varepsilon_{m1})$ as an initial value. After several iterations, it will reach convergence.

A similar approach can be applied to solving equation (7b). In this case, the initial value should be $\varepsilon_{s\,min} = \max\,(\varepsilon'_s, \varepsilon_{m2})$.

NOTE 4 – A computer program for calculating separation angles on the basis of this Annex is given in Appendix 1.

Appendix 1
to Annex 2

```
/************************************************************************/
/* file name : drsang_b.c                                               */
/* language : C                                                         */
/* function : Calculate separation angles between fixed service         */
/*    transmitting antenna beams and the directions                     */
/*    towards geostationary data relay satellites                       */
/************************************************************************/

/*----- include files ---------------------------------------------------*/
#include <stdio.h>
```

```
#include <math.h>
#include <errno.h>

static    double  pi,rd,dr,em1,em2,a[3],b[3];

/*-----------------------------------------------------------------------------------------------------------------*/
/* module : bending                                                                                                */
/* function : setup atmospheric bending characteristics                                                            */
/* in h0 : antenna altitude (km) of the station above sea level                                                    */
/*  h1 : altitude (km) of the local horizon (h0>=h1)                                                               */
/* out em1,2 : elevation angles towards the local horizon at maximum                                               */
/*    and minimum atmospheric bending (see eq.(8))                                                                 */
/*  a,b : coefficients of atmospheric bending                                                                      */
/*    at maximum and minimum atmospheric bending                                                                   */
/*-----------------------------------------------------------------------------------------------------------------*/

void      bending(h0,h1)

          double  h0,h1;

{
          double  r=6378.0;                     /* earth radius (km) */
          em1=-acos((r+h1)/(r+h0)*
               (1+0.00040*pow(0.83,h1))/(1+0.00040*pow(0.83,h0)));
          em2=-acos((r+h1)/(r+h0)*
               (1+0.00025*pow(0.88,h1))/(1+0.00025*pow(0.88,h0)));

          a[0]=(0.7885809+0.1759630*h0+0.0251620*h0*h0)*rd;
          a[1]=(0.5490560+0.0744484*h0+0.0101650*h0*h0)*rd*rd;
          a[2]=(0.0187029+0.0143814*h0)*rd*rd*rd;
          b[0]=(1.7556980+0.3134610*h0)*rd;
          b[1]=(0.8150220+0.1091540*h0)*rd*rd;
          b[2]=(0.0295668+0.0185682*h0)*rd*rd*rd;

}
/*-----------------------------------------------------------------------------------------------------------------*/
/* module : tmax,tmin,dtmax,dtmin                                                                                  */
/* function : calculate atmospheric bending in degree                                                              */
/* in e  : elevation angle (degree)                                                                                */
/* out tmax : atmospheric bending (see eq.(11a))                                                                   */
/*  dtmax : derivative of tmax                                                                                     */
/*  tmin : atmospheric bending (see eq.(11b))                                                                      */
/*  dtmin : derivative of tmin                                                                                     */
/*----------------------------------------------------------------------------------------------------------------*/
double  tmax(e)
          double  e;
          {return (1.0/(a[0]+e*(a[1]+a[2]*e)));}

double  dtmax(e)
          double  e;
          {return (-(a[1]+2.0*a[2]*e)*pow(tmax(e),2.0));}

double  tmin(e)
          double  e;
          {return (1.0/(b[0]+e*(b[1]+b[2]*e)));}
```

```
double  dtmin(e)
        double  e;
        {return (-(b[1]+2.0*b[2]*e)*pow(tmin(e),2.0));}

/*----------------------------------------------------------------------------------------------------------------*/
/* module : sangle                                                                                                  */
/* function : calculate separation angle in degrees                                                                 */
/* in slon : longitude of the data-relay satellite (radian)                                                         */
/*  ilat : northern or southern hemisphere                                                                          */
/*  rlat : latitude of the radio-relay station (radian)                                                             */
/*  rlon : longitude of the radio-relay station (radian)                                                            */
/*  az0 : azimuth of the antenna beam (radian)                                                                      */
/*  e0 : elevation angle of the antenna beam (radian)                                                               */
/*  h0 : antenna altitude (km) of the station above sea level                                                       */
/* out sa : separation angle                                                                                        */
/*----------------------------------------------------------------------------------------------------------------*/
double  sangle(slon,ilat,rlat,rlon,az0,e0,h0)
        double  slon,ilat,rlat,rlon,az0,e0,h0;

{
 double delta,zeta,r1,arc,tanarc;
 double azss,azs,ees,e1,e2,es1,esmax,es2,esmin,es,sa;
 double r=6378.14;      /* earth's equatorial radius        */
 double f=1/298.25;    /* earth's flatness factor           */
 double rs=42164;     /* orbit radius                       */

        delta=rlon-slon;
        if(cos(delta)<=0) {sa=500.0;goto end_sa;}
        /* ----- Determination of the satellite azimuth ----------------*/
        zeta=atan(pow(1-f,2.0)*tan(rlat));    /* eq.(1)              */
        r1=r*(1-f*pow(sin(zeta),2.0))+h0;    /* eq.(2)              */
        arc=acos(cos(zeta)*cos(delta));       /* eq.(3)              */
        tanarc=tan(arc); if(tanarc<tan(zeta)) tanarc=tan(zeta);
        if(tanarc==0.0) azss=0.0;
        else azss=acos(tan(zeta)/tanarc);                    /* eq.(4)        */
        if((ilat>0)&&(sin(delta)>=0)) azs=azss+pi;           /* eq.(5a)       */
        else if((ilat>0)&&(sin(delta)<0)) azs=pi-azss;       /* eq.(5b)       */
        else if(sin(delta)>=0) azs=2*pi-azss;                /* eq.(5c)       */
        else azs=azss;                                       /* eq.(5d)       */
        /* ----- Determination of the satellite elevation ------------------------*/
        if(arc==0.0) ees=pi/2.0;
        else ees=atan((cos(arc)-r1/rs)/sin(arc));            /* eq.(6)        */
        e1=em1-tmax(em1);
        e2=em2-tmin(em2);
        if(ees<e1) {sa=500.0; go to end_sa;}
else{
            /* ----- solve eq.(7a), (see Note 3) ----- */
            es1=10.0;if(ees<em1) esmax=em1; else esmax=ees;
            while(fabs(esmax-es1)>1.0e-5){
                 es1=esmax;
                 esmax=es1-(es1-tmax(es1)-ees)/(1.0-dtmax(es1));
        }
        if(ees<e2) esmin=em2;
```

```
        else{
            /* ----- solve eq.(7b), (see Note 3) ----- */
            es2=10.0;if(ees<em2) esmin=em2; else esmin=ees;
            while(fabs(esmin-es2)>1.0e-5){
                es2=esmin;
                esmin=es2-(es2-tmin(es2)-ees)/(1.0-dtmin(es2));
        }
        if(esmax<=e0) es=esmax;                          /* eq.(8a)      */
        else if(esmin<=e0) es=e0;                        /* eq.(8b)      */
        else es=esmin;                                   /* eq.(8c)      */
        /* ----- Determination of the separation angle ---------- eq.(9)     */
        sa=rd*acos(cos(e0)*cos(es)*cos(az0-azs)+sin(e0)*sin(es));
        end_sa:
        return   sa;
}
/*-----------------------------------------------------------------------------------*/
/*  main program     */
/*-----------------------------------------------------------------------------------*/
void     main()
{
        double  lonsat[32]={-174,-171,-170,-160,-139,-62,-49,
                -46,-44,-41,-32,-16,-
12,10.6,16.4,16.8,21.5,47,59,77,80,85,89,90.75,95,113,121,133,160,171,176.8,177.5};
        double  sa[34];
        char    str[1];
        double  ilat,latd,latm,lats,rlat;
        double  ilon,lond,lonm,lons,rlon;
        double  az0d,az0,e0d,e0,h0m,h0,h1m,h1;
        double  slon,samin;
        int     isat;

        pi=4.0*atan(1.0);                           /* circular constant */
        rd=180.0/pi;                                /* radian to degree */
        dr=pi/180.0;                                /* degree to radian */
        /* ----- Parameter input ---------------------------------------------- */
        printf("Parameters of the fixed service station \n");
        input_NS:
        printf("Hemisphere of the station : northern or southern (N/S) ? \n");
        scanf("%s",&str);
        if(*str=='N' || *str=='n') ilat=1;
        else if(*str=='S' || *str=='s') ilat=-1;
        else go to input_NS;
        input_LAT:
        printf("LAT : latitude (degree,minute,second) ? \n");
        scanf("%le,% le,%le",&latd,&latm,&lats);
        latd=ilat*(latd+latm/60.0+lats/3600.0); rlat=fabs(latd*dr);
        input_EW:
        printf("Longitude : east or west (E/W) ? \n");
        scanf("%s",&str);
        if(*str=='E' || *str=='e') ilon=1.0;
        else if(*str=='W' || *str=='w') ilon=-1.0;
```

```
else go to input_EW;
input_LON:
printf("LON : longitude (degree,minute,second) ? \n");
scanf("%le,%le,%le",&lond,&lonm,&lons);
lond=ilon*(lond+lonm/60.0+lons/3600.0);rlon=lond*dr;
input_AZ:
printf("AZ0 : antenna azimuth, clockwise from the North (degree) ?\n");
scanf("%le",&az0d); az0=az0d*dr;
input_E0:
printf("E0 : antenna elevation (degree) ? \n");
scanf("%le",&e0d); e0=e0d*dr;
input_ALT:
printf("H0 : antenna altitude (m) ? \n");
scanf("%le",&h0m); h0=h0m/1 000.0;
printf("H1 : horizon altitude (m) ? \n");
scanf("%le",&h1m); h1=h1m/1 000.0;
if(h1>h0) {printf("h1<=h0"); go to input_ALT;}

/* ----- Calculations ------------------------------------------------- */
bending(h0,h1);
samin=1 000.0;
for(isat=0;isat<23;isat++){
    slon=dr*lonsat[isat];
    sa[isat]=sangle(slon,ilat,rlat,rlon,az0,e0,h0);
    if(sa[isat]<samin) samin=sa[isat];
}
/* ----- Print separation angle ------------------------------------ */
printf("\nParameters of the fixed service station \n");
printf(" latitude   : %7.2f (degree) \n",latd);
printf(" longitude   : %7.2f (degree) \n",lond);
printf(" antenna azimuth : %7.2f (degree) \n",az0d);
printf(" antenna elevation : %7.2f (degree) \n",e0d);
printf(" antenna altitude : %7.0f (m) \n",h0m);
printf(" horizon altitude : %7.0f (m) \n",h1m);
printf("\nGeostationary data relay satellites \n");
printf(" No. Longitude Separation angle \n");
for(isat=0;isat<23;isat++){
    printf("%5d %7.2f %7.2f \n",
    isat+1,lonsat[isat],sa[isat]);
}
printf("Minimum separation angle = %7.2f (degree) \n",samin);
```

Annex 3

Interference mitigation through diffraction attenuation

1 Introduction

Under certain circumstances Fresnel zone blockage will reduce the e.i.r.p. spectral density of the emissions from an FS station towards DRS orbital locations. The great majority of point-to-point fixed wireless systems deployed in the 26 GHz band are located in urban areas where a building may obstruct the transmission path between the transmitting FS station and the DRS orbit location. It should be noted that this obstruction is not necessarily the same building as that on which the receiving FS antenna is mounted.

It can be shown that this blockage is sensitive to small changes in the location of the transmitting FS station such that a small change in this location can substantially reduce the potential interference. Moreover, it can be shown that this blockage is sensitive to small changes in the location of the DRS due to normal orbit perturbations, such that the interference caused by successive occurrences of the potentially harmful geometry of low orbiting satellites, FS transmitter and DRS will vary significantly so that an occurrence of significant interference may be followed by an occurrence of acceptable interference.

This annex demonstrates by way of a simplified example the range of diffraction loss that may be realized by Fresnel zone blockage.

2 Basic calculations of diffraction attenuation

Recommendation ITU-R P.526 contains the basic methods and formulae for calculations of diffraction attenuation. Section 4 of the Recommendation deals with the diffraction attenuation as a function of the extent of Fresnel zone blockage, and of the features of the blocking obstacle. The resulting attenuation values represent sums of two contributions:

a) the diffraction attenuation obtained by using a single knife-edge model of the obstacle;

b) an additional contribution due to the physical features of the actual obstacle, which differ from those of the knife-edge model.

The combined result may substantially exceed the single knife-edge attenuation contribution.

Contribution a) above, the basic single knife-edge model, is dealt with in § 4.1 of Recommendation ITU-R P.526. It contains formulae for diffraction attenuation calculations using a dimensionless parameter that specifies the extent of first Fresnel zone blockage; Fig. 4 (same as Fig. 7 of Recommendation ITU-R P.526) provides a graph of the resulting diffraction attenuation as a function of this dimensionless parameter. For example, a diffraction attenuation of 6 dB results if one half of the first Fresnel zone is blocked; the corresponding attenuation values for 1/4, 3/4 and complete blockage are 2 dB, 10 dB and 14 dB, respectively. Extending the blockage to the entire second Fresnel zone would increase the diffraction attenuation to 22 dB.

Contribution b), additional contribution to the diffraction attenuation, due to obstacle features that differ from a single knife-edge model, are dealt with in § 4.2 through 4.5 of Recommendation ITU-R P.526.

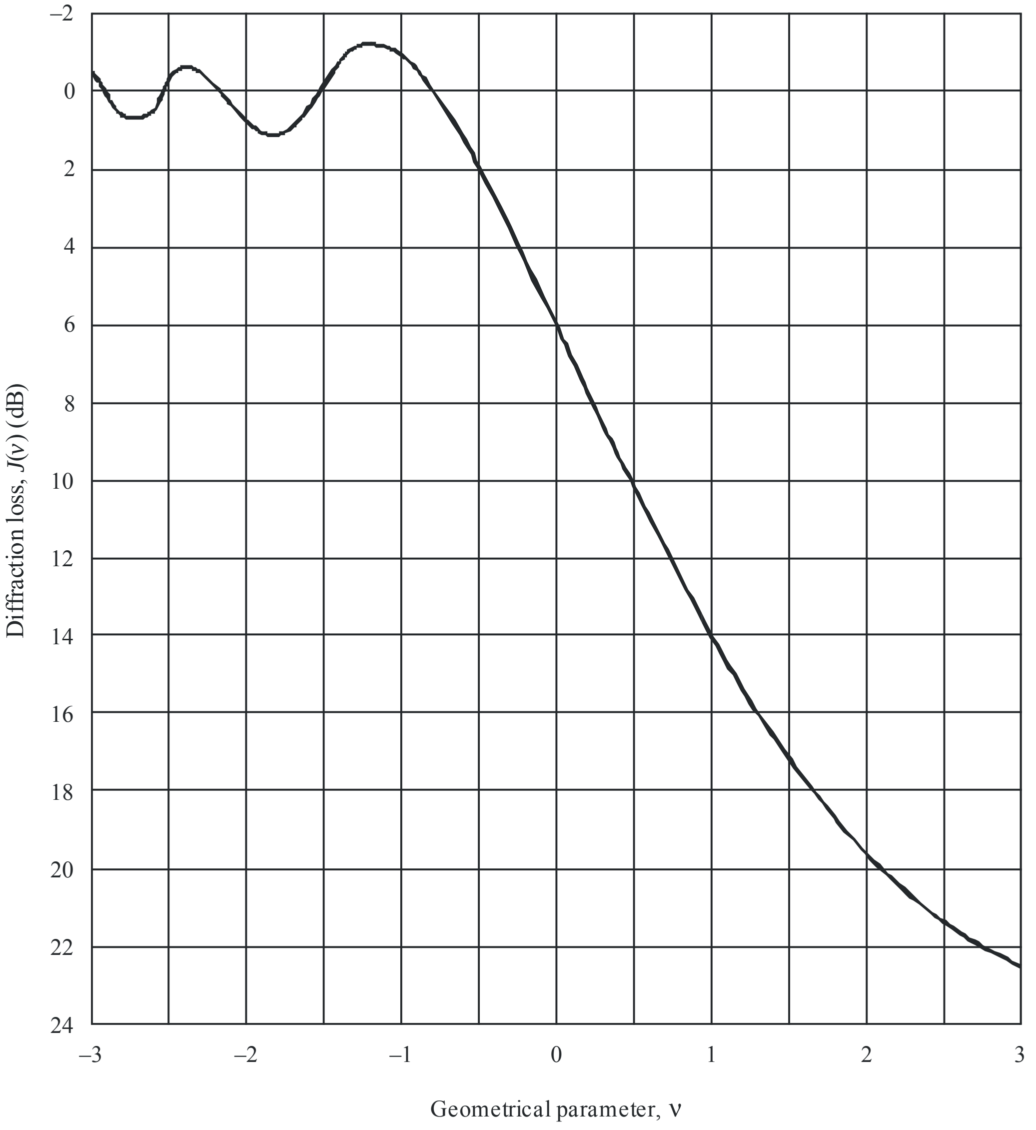
Section 4.3 of Recommendation ITU-R P.526 deals with the case of a single rounded obstacle. It is applicable where the shape of the building top obstructing the path towards the DRS orbit station can be modelled in this way. The presented method can be used to calculate the additional attenuation due to the shape and depth of the obstacle.

3 Examples of diffraction attenuation

A first-order analysis using the calculation methods of Recommendation ITU-R P.526 is intended to provide insight into the significance of variable diffraction attenuation as a factor leading to the relaxation of e.i.r.p. spectral density limits on the emissions of FS stations towards DRS orbital locations.

FIGURE 4

Knife-edge diffraction loss
(see Recommendation ITU-R P.526)



F.1249-04

It is assumed that the FS station is on the horizon as seen by the DRS and is directed towards the DRS. The emissions of the FS station towards the DRS are partially blocked by an obstacle at or near the FS receiving antenna. The obstacle is modelled as a single knife edge as shown in Fig. 5. The transmitting station is located at P_1 and the receiving DRS is located at P_2. The distance from the transmitting station to the diffracting obstacle is d_1. The distance to the DRS is so great that it is not a factor in the calculation of the diffraction loss. The height of the obstacle above the direct path is denoted by h. The angle of diffraction, denoted by θ, and has the same sign as h. (The angle θ is assumed to be less than 0.2 rad, or 12°.)

A dimensionless parameter ν is introduced that permits the calculation of the resultant field from Fig. 4 based on the geometrical factors listed above and the wavelength λ of the operating frequency. It is derived from equation (14) of Recommendation ITU-R P.526.

$$\nu = \theta \sqrt{\frac{2d_1}{\lambda}} \tag{12}$$

An example will provide some bounds on the amount of attenuation of the emissions that may be expected from sites where Fresnel zone blockage is a factor.

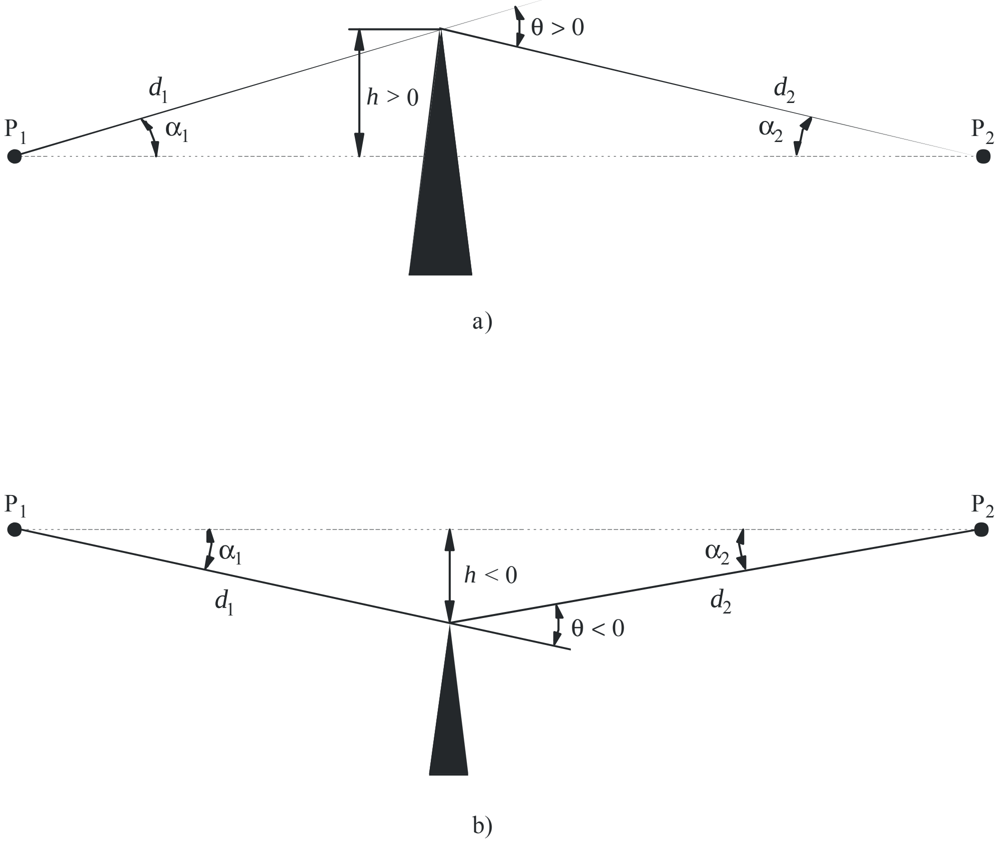
Assume that the obstacle is a building that is 4 km from the transmitting antenna. The top of the building approximates a single knife-edge obstacle. The transmitting antenna has a gain of 40 dB, a 3 dB beamwidth of 1.64° and an unobstructed path to the receiving antenna. It is further assumed that the beam of the transmitting antenna lies equally above and below the top of the building. For an operating frequency of 26 GHz, equation (12) evaluates to:

$$\nu = 833 \ \theta \tag{13}$$

When $\theta = 0$, the parameter ν is 0 for an off-axis angle of 0°. From Fig. 4, this leads to a diffraction loss of 6 dB for a DRS receiving antenna that is located beyond the obstacle on a straight line that connects the three points: the transmitting antenna, the top of the obstacle and the receiving DRS antenna.

FIGURE 5

Geometrical elements
(Recommendation ITU-R P.526)



α_1 and α_2: angle between the top of the obstacle and one end, as seen from the other end

F.1249-05

However, if the top of the obstacle is 0.0017 rad or 0.1° above the line from the FS transmitting antenna to the DRS station corresponding to either the obstacle being 7 m taller or the FS transmitting antenna being mounted 7 m lower, then $\nu = 1.45$, and the diffraction loss would be increased to 16.5 dB.

On the other hand, if the top of the obstacle is 7 m below the interference path $\nu = –1.45$, and the diffraction loss, for the single knife-edge model, would cause signal enhancement of around 1 dB.

4 Variability of diffraction attenuation in DRS interference exposures

For this example, the variation of the level of interference to a DRS in an orbit inclined by 0.1° has been evaluated for an FS station located at 45° N latitude. It was assumed that the DRS was on a straight line connecting the FS transmitting station, the top of the knife-edge obstacle and the DRS. The DRS was at its nominal orbital location, i.e. it was on the equatorial plane. Thus, the nominal interference level was –6 dB from the free space level as discussed above.

With a finite, but small orbital inclination angle, the latitude and longitude of the DRS sub-satellite point over a 24-h period is given by:

$$\varphi_s = i \sin(\omega_e t) \tag{14a}$$

$$\Delta\lambda_s = \frac{i^2}{4} \sin(2\omega_e t) \tag{14b}$$

where:

φ_s: latitude of the DRS sub-satellite point

$\Delta\lambda_s$: incremental change in the longitude of the DRS sub-satellite point

i: inclination angle of the DRS orbital plane

ω_e: rotational rate of the Earth

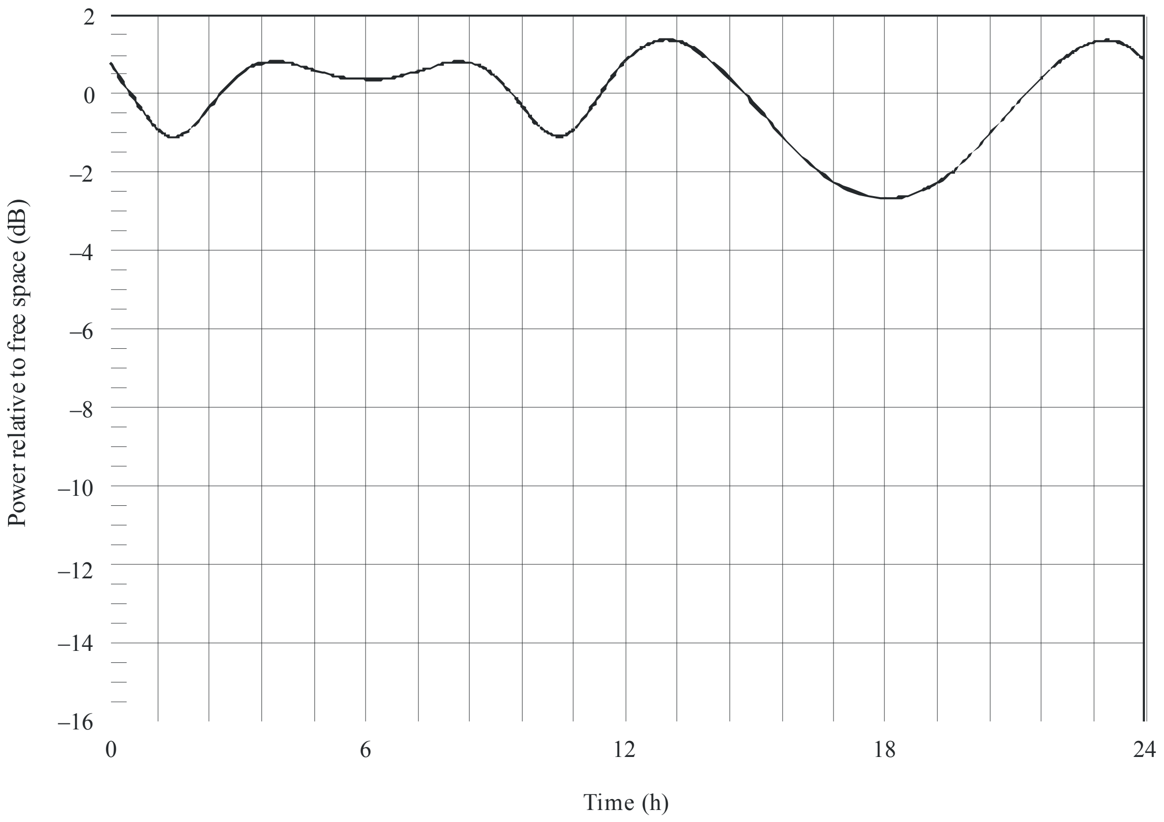
t: elapsed time.

The diurnal variation of the interference power received by the DRS may be evaluated using equation (13) for changes in the elevation angle. It is assumed that the top of the obstacle is parallel to the local horizontal plane.

Two cases have been analysed to determine the effect of a bias in the nominal position of the DRS. For the first case, it was assumed that the nominal position of the DRS was 0.1° above the line connecting the FS transmitting antenna and the edge of the obstructing building, and for the second case, it was assumed that the nominal position of the DRS was 0.1° below the line connecting the FS transmitting antenna and the edge of the obstructing building. These deviations are well within one-half of the 3 dB beamwidth of 1.64°. It is further assumed that the FS station is located at 45° N latitude and that the DRS orbital plane is inclined by 0.1° with respect to the equatorial plane. The diurnal variation of the interference power received by the DRS relative to the free space value is shown in Figs 6 and 7 for these two cases. Figure 6 shows relatively small diurnal variations in the interference power, whereas Fig. 7 shows that the diurnal variation ranges from about –9.5 dB to –21 dB.

FIGURE 6

Diurnal variation in the interference power as received by a DRS in an inclined orbit of 0.1°: DRS orbit location offset by 0.1° in the elevation plane, FS station located at 45 °N latitude



F.1249-06

5 FS link design and implementation practices that increase the effectiveness of interference mitigation through diffraction attenuation

As follows from *recommends* 2.4 of this Recommendation, the objective is to promote, where necessary, FS link design and implementation practices that assure the greatest possible blockage of the potential DRS interference paths, such that levels of interfering FS transmissions are effectively reduced through diffraction attenuation.

This FS-DRS interservice sharing objective is in line with the FS intraservice objective of interference control, for the purpose of shortening frequency reuse distances in urban and suburban large-scale deployment that accounts for the great majority of existing and future 26 GHz band FS applications. For this purpose, FS station antennas are preferably mounted on building sides instead of on building tops, and if they need to be mounted on building tops, they are preferably placed as low as possible.

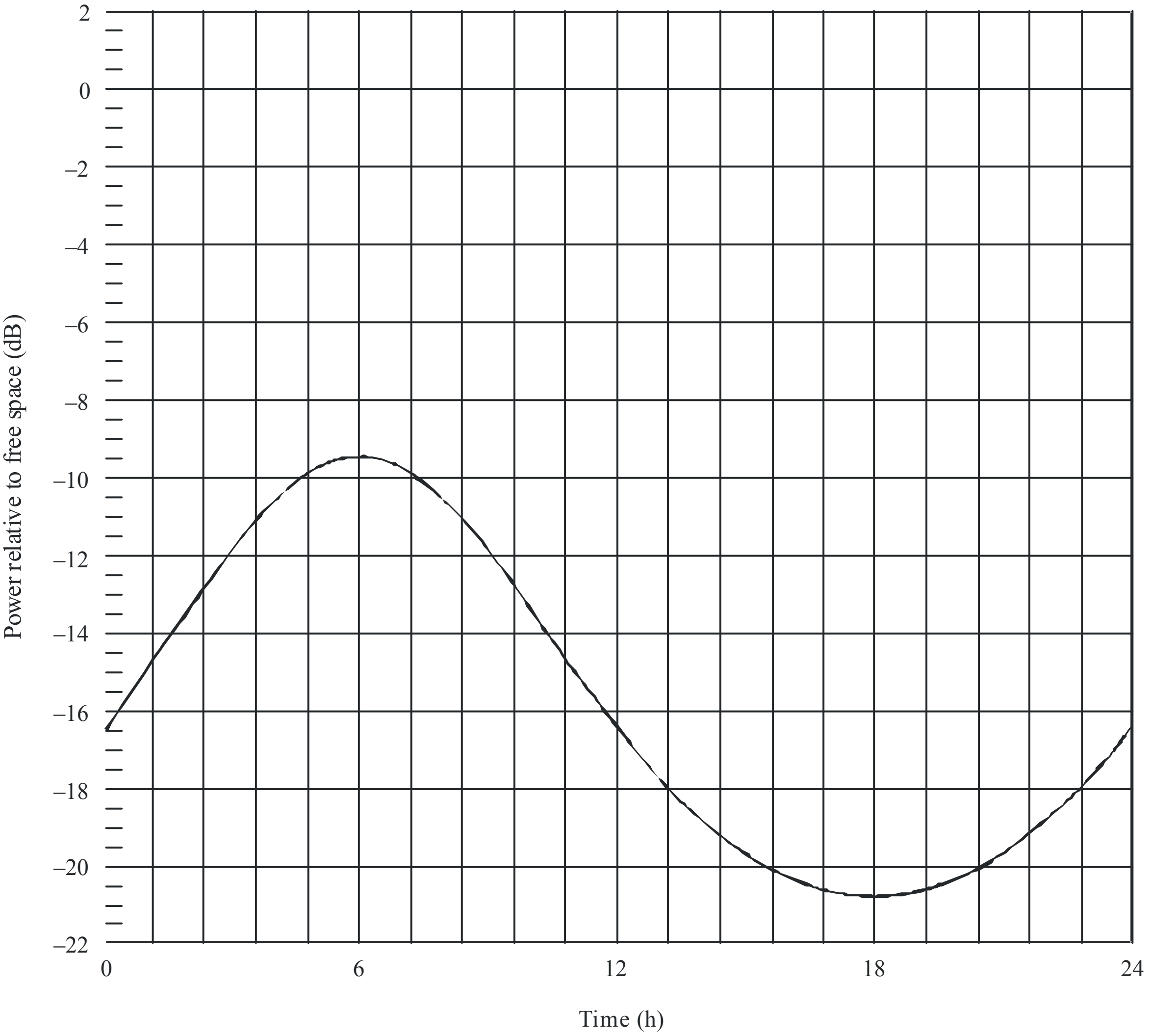
These widespread practices assure the highest practicable diffraction attenuations not only on potential FS intraservice interference paths, but also on potential FS-DRS interservice interference paths. Nevertheless, there is room for improvement that can be achieved through:

- effective dissemination of relevant information on the potential interference problem;
- simple, easy-to-follow instructions for maximizing diffraction attenuation on potential interference paths where FS emissions would otherwise exceed the recommended e.i.r.p. spectral density limit.

FS antenna mounting on towers is the most unfavourable case from the viewpoint of interference, because the obtainable diffraction attenuation is negligible unless the potential interference path is blocked behind the tower by a natural or man-made obstacle. Where unavoidable for operational reasons, such potentially interfering links should be given due attention if the FS emissions would otherwise exceed the recommended e.i.r.p. spectral density limit. In this case it is also important to provide simple, easy-to-follow instructions that facilitate compliance.

FIGURE 7

Diurnal variation in the interference power as received by a DRS in an inclined orbit of 0.1°: DRS orbit location offset by –0.1° in the elevation plane, FS station located at 45 °N latitude



F.1249-07

6 Summary and conclusions

Point-to-point FS site selections and their configurations in large-scale deployment that typifies 26 GHz band applications, aim at intraservice interference mitigation through diffraction attenuation. This also helps to mitigate potential interservice interference from point-to-point FS transmitting stations into a geostationary DRS receiver that tracks a low-Earth orbiting spacecraft. While the “static” intraservice case lends itself to simple analysis based on Recommendation ITU-R P.526, the interservice case presents a much more complex problem.

The presented first-order analysis, aimed at providing an insight into the significance of Fresnel zone blockage as a factor that might lead to the relaxation of e.i.r.p. spectral density limits on the emissions of point-to-point FS stations toward DRS orbital locations, has exemplified diurnal variations of diffraction attenuation and their dependence on the nominal location of the DRS, relative to the line connecting the FS transmitting and receiving antennas. For the examples considered, the nominal level could be commensurate with the free space value or it could be as much as 16.5 dB below free space value. This shows that the permissible level of e.i.r.p. for FS stations exhibiting Fresnel zone blockage should be determined on a site-by-site basis taking into account the geographical and geometrical factors affecting the FS station to DRS path.

It should be noted that where the DRS orbit station is within the main beam of the point-to-point FS transmitting antenna but is obstructed by a building or other topographical feature, it is probable that another part of the geostationary arc will be visible within the FS antenna main beam without any obstruction, so that the point-to-point FS station would be constrained by the requirements of *recommends* 3.