RECOMMENDATION ITU-R F.1509*

Technical and operational requirements that facilitate sharing between point-to-multipoint 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 163/9)

(2001)

The ITU Radiocommunication Assembly,

considering

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

b) that in addition to point-to-point fixed service (FS) systems, point-to-multipoint (P-MP) FS systems are planned to operate in the 25.25-27.5 GHz band;

c) that P-MP FS systems offer business and home users the possibility of economical wireless access to voice, video and data services;

d) that space-to-space radiocommunication links in the inter-satellite service are established or planned for the 25.25-27.5 GHz band;

e) that space-to-space links are established between low-orbiting user satellites and geostationary data relay satellites (DRS) and also proximity operations communication system (POCS) between users in proximity of low-orbiting space stations (see Recommendation ITU-R SA.1415);

f) that these links, particularly the space-to-space links of a DRS network, are designed to operate with margins on the order of 2 dB to 4 dB;

g) that the protection criteria for POCS links may be found in Recommendation ITU-R SA.609, and the protection criteria for DRS links may be found in Recommendation ITU-R SA.1155;

h) that satellite links are susceptible to interference from the emissions of fixed service systems within a field-of-view that is of large geographical extent;

j) that a limited number of DRS networks, as described in Recommendation ITU-R SA.1018, are either operating or planned for operation in the geostationary orbit, at orbital locations given in Recommendation ITU-R SA.1276;

k) that specifying particular orbital locations to be protected rather than the orbital arc will impose less burden on the FS for band sharing, particularly for those stations located at high latitudes,

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

recommends

1 that for each transmitter of a hub station of a P-MP FS network operating in the 25.25-27.5 GHz band (see Annex 1 for the background of the e.i.r.p. limits):

1.1 the e.i.r.p. spectral density of the emission in the direction of any geostationary-satellite orbit (GSO) location specified in Recommendation ITU-R SA.1276 should not exceed the following values in any 1 MHz band for the elevation angle θ above the local horizontal plane (see Notes 1, 2, 3 and 4):

$$+8 \qquad\qquad \text{dBW} \qquad\qquad \text{for } 0° \leq \theta \leq 20°$$

$$+14 - 10 \log(\theta/5) \qquad \text{dBW} \qquad\qquad \text{for } 20° < \theta \leq 90°$$

1.2 the e.i.r.p. spectral density of the emission should not exceed the following values in any 1 MHz band for the elevation angle θ above the local horizontal plane (see Note 3):

$$+14 \qquad\qquad \text{dBW} \qquad\qquad \text{for } 0° \leq \theta \leq 5°$$

$$+14 - 10 \log(\theta/5) \qquad \text{dBW} \qquad\qquad \text{for } 5° < \theta \leq 90°$$

1.3 during conditions when precipitation attenuation is experienced between the FS hub transmitting and receiving stations, the transmitting hub station may use automatic transmit power control (ATPC) to increase its transmitted power, by an amount not exceeding the precipitation attenuation such that its e.i.r.p. spectral density in the direction of any GSO location specified in Recommendation ITU-R SA.1276 does not exceed +17 dBW in any 1 MHz band;

2 that the e.i.r.p. spectral density of the emission of each subscriber station of a P-MP FS network operating in the band 25.25-27.5 GHz should comply with *recommends* 3 and 4 of Recommendation ITU-R F.1249;

NOTE 1 – Recommendation ITU-R SA.1276 identifies the following geostationary DRS orbital positions: 16.4° E, 21.5° E, 47° E, 59° E, 85° E, 90° E, 95° E, 113° E, 121° E, 160° E, 177.5° E, 16° W, 32° W, 41° W, 44° W, 46° W, 49° W, 62° W, 139° W, 160° W, 170° W, 171° W, and 174° W.

NOTE 2 – The e.i.r.p. spectral density radiated towards a geostationary DRS location should be calculated as the product of the transmitted power spectral density and the gain of the omnidirectional or sectoral antenna in the direction of the DRS. In the absence of a radiation pattern for the hub-station antenna, the reference radiation pattern of Recommendation ITU-R F.1336 should be used. The calculation should take into account the effects of atmospheric refraction and the local horizon. A method for calculating the separation angles is given in Annex 2.

NOTE 3 – At elevation angles below the local horizontal plane no e.i.r.p. limitations are required, other than those specified in Radio Regulations (RR) Article S21.

NOTE 4 – In the case of a hub-station employing single frequency operation in which the same frequency is used for both transmission and reception on a time-division basis, the e.i.r.p. spectral density limit in *recommends* 1.1 can be relaxed by $7 \log (1/\delta)$ dB, where δ $(0 < \delta < 1)$ is the proportion of time when a hub-station is transmitting signals. However, this relaxation should not exceed 3 dB even for a small δ.

ANNEX 1

**An assessment of the spatial and temporal distribution of interference
to DRS systems and POCS from the emissions of P-MP
hub stations in the FS in the band 25.25-27.5 GHz**

1 Introduction

This Annex provides an assessment obtained by computer simulation, of the spatial and temporal distribution of interference to DRS at specific orbital locations, and POCS from the emissions of a global deployment of hub stations of P-MP FS systems in the band 25.25-27.5 GHz. These P-MP FS systems are frequently referred to as local multipoint distribution service (LMDS) systems. For this analysis, the peak-of-beam e.i.r.p. spectral density at each hub station is assumed to be +8 dB(W/MHz) in accordance with Recommendation ITU-R F.758. A single LMDS transmitting station operating with an e.i.r.p. spectral density of +8 dB(W/MHz) does not exceed the protection level given in Recommendation ITU-R SA.1155 regardless of its geographic location with respect to the orbital location of a DRS. The protection level of −148 dB(W/MHz) is not to be exceeded for more than 0.1% of an orbital period. However, the aggregate effect of multiple co-channel LMDS transmitting stations within an urban population centre can, under some geometric conditions, cause interference in excess of the DRS protection level.

Section 2 describes the approach used and the assumptions made to evaluate the spatial and temporal distribution of the interference to DRS. In this Annex, two studies, Study A and Study B, are presented in § 3 and § 4, respectively. In Study A, an e.i.r.p. spectral density of +8 dB(W/MHz) was assumed, whereas in Study B, an e.i.r.p. spectral density of +14 dB(W/MHz) was used. Section 3 presents the spatial distribution of the interference to DRS at specific orbital locations. It shows that when the e.i.r.p. spectral density of the emissions in the local horizontal plane from a service area containing 29 hub stations visible to the DRS and operating at +8 dB(W/MHz), the interference to DRS can be as high as 9 dB in excess of the recommended interference level. Also in § 3 are the results of dynamic simulations to determine the temporal characteristics of interference to DRS while tracking a low-orbiting user satellite with the orbital characteristics of the international space station. It is shown that, for a small number of orbits with ascending nodes that result in the user satellite being aligned with urban population centres that appear on or near the Earth's limb, the duration of the interference can exceed a period of time that is greater than 0.1% of an orbital period of the user satellite. Section 4 presents the result of Study B. Section 5 describes a simple means to extend the results of this study to LMDS deployments that use smaller cells. Section 6 discusses interference into POCS. The results show that, based on an e.i.r.p. spectral density of +14 dB(W/MHz), the aggregate interference from LMDS hub stations into the receiver antennas of the POCS fall well below the protection criterion of −147 dB(W/MHz) at all times. Section 7 gives the conclusions of the study and proposes characteristics to facilitate sharing between space science services, inter-satellite service systems and P-MP FS systems.

2   Approach

Computer simulations have been used to evaluate the spatial and temporal distribution of interference to DRS systems from the emissions of a potentially large number of high density P-MP FS systems assumed to be operated in the 25.25-27.5 GHz band. The basic approach embodied in the simulation is to deploy a number of LMDS hub stations in urban population centres and to then determine the spatial and temporal interference resulting from this deployment. To determine the spatial distribution, the aggregate interference to a DRS at a specified orbital location is computed as the high-gain receiving antenna of the DRS is scanned in roll and pitch. The approach is described in § 2.1. The approach used to determine the temporal characteristics of the interference are described in § 2.2. In both cases, the simulation takes into account: the e.i.r.p. spectral density and gain of the LMDS transmitting station in the direction of the DRS; atmospheric absorption; path loss; and, the gain of the DRS receiving antenna in the direction of the interfering LMDS station.

2.1   Spatial distribution

LMDS stations are expected to be deployed in a cellular configuration in urban population centres to serve businesses, government and homes with moderate to high capacity interactive or broadcast type digital communications services. These services might include Internet access, voice, data and video. For the purpose of this analysis, it is assumed that the aggregate co-channel emissions from an LMDS service area may be modelled as a single station that uses a transmitter with the power spectral density equal to the sum of the power spectral density at the input to each LMDS hub station in the service area, and that a single transmitting antenna provides an acceptable representation of the distribution of the e.i.r.p. spectral density above the local horizontal plane.

It has been assumed for these simulations that the e.i.r.p. spectral density of the emissions of each hub station is +8 dB(W/MHz)[1] and that the aggregate LMDS emission from a single service area is proportional to the number of hub stations in the urban population centre.

The specific model used for the simulation is as follows. The power received from a distant transmitting station can be written as:

$$P_r = \frac{P_t G_t G_r}{l_1 l_2 l_3} \qquad (1)$$

where:

> P_r: received power spectral density at the output of an antenna in a specified frequency band (stated as a power spectral density for the purpose of this analysis (W/MHz))

> P_t: transmitted power at the input to an antenna in the same frequency band specified for received power (stated as a spectral density for the purpose of this analysis (W/MHz))

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[1]   For this analysis, a peak of beam hub emission of +8 dB(W/MHz) is assumed at 0° elevation angle and in all azimuths from the hub. It is also assumed that the adjacent antenna sectors operate at the same frequency employing orthogonal linear polarizations.

G_t : gain of the transmitting antenna in the direction of the receiving station relative to an isotropic radiator (numeric)

G_r : gain of the receiving antenna in the direction of the transmitting station relative to an isotropic radiator (numeric)

l_1 : free-space propagation loss (numeric)

l_2 : loss in excess of free-space due to several stationary and time-dependent atmospheric effects (numeric)

l_3 : polarization coupling loss (numeric), equal to unity if the transmitting and receiving antennas are co-polarized[2].

The free-space propagation loss is:

$$l_1 = \left(\frac{4\pi d}{\lambda} \right)^2 \tag{2}$$

where

d : distance between the transmitting and receiving stations (m)

λ : wavelength (m).

Each co-frequency transmitting station forms a radio link to the receiver. The received power from each of the n links, which are assumed to be transmitting uncorrelated signals, adds to form an aggregate received power given by:

$$P_r = \sum_{i=1}^{n} \frac{P_{ti} G_{ti} G_{ri}}{l_{1i} l_{2i} l_{3i}} \tag{3}$$

where the terms are as previously defined with the addition of a subscript, i, to denote each link.

The aggregate interference is the sum of the interference from each transmitting station. The interference from each station is determined based on the transmitting and receiving antenna gains, taking into account the off-axis angle of the respective antennas.

To speed the computation and taking into account that some terms are nearly constant for a single deployment area, equation (3) is further refined as:

$$P_r = \sum_{i=1}^{m} \frac{G_{ti} G_{ri} \sum_{j=1}^{q} P_{tij}}{l_{1i} l_{2i} l_{3i}} \tag{4}$$

where:

q : number of hubs in a specific deployment area

m : number of deployment areas.

Subsequent analysis showed that for the interference scenarios being simulated that the error introduced by the simplification in equation (4) is less than 1 dB.

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[2] For main-beam alignment between a linearly polarized transmit antenna (as normally used in the FS) and circularly polarized satellite receiver antennas, l_3 is assumed to be 2.

The deployment of LMDS systems is assumed to correspond to the locations of 431 urban population centres with a population estimated by the United Nations to exceed 750 000 people by 2015 (see Urban Agglomerations, 1950-2015 (the 1996 revision), United Nations Population Division, New York, United States of America, 1996 (available on diskette)).

An empirical relationship between the radius R_p (km) of an equivalent circular area containing a total population P is given by:

$$R_p = \alpha \times P^\beta \tag{5}$$

For the United States of America, $\alpha = 0.035$ and $\beta = 0.44$ have been found to provide satisfactory results. For other areas of the world, $\alpha = 0.0155$ and $\beta = 0.44$ were found to provide a satisfactory estimate.

Equation (5) was used in the estimate of the number of hub stations required to serve an area encompassing the total population in an urban agglomeration. Assuming that each hub serves a circular area of radius R_h, the number of hubs N will be:

$$N = \text{Int}\left(\eta\left(\frac{R_p}{R_h}\right)^2 + 0.5\right) \tag{6}$$

where:

> N :   number of hubs for the assumed radius of the cell
>
> Int() :   indicates the integer value of the argument
>
> R_p :   equivalent radius of the urban area (km)
>
> R_h :   radius of a typical LMDS cell (km)
>
> η :   deployment factor ($0 < \eta \leq 1$).

For the simulations, it was assumed that the radius of a cell was 5 km and that the deployment factor was 0.30. This value of the deployment factor takes into account economic, demographic and geographic factors and that some administrations may adopt a policy that the relevant band be not used for P-MP FS systems. The largest calculated number of hub stations obtained using the UN population database and equations (5) and (6) are 35 for New York City, United States of America and 11 for Tokyo, Japan. The methodology yields a total worldwide deployment of 944 co-frequency hub stations. Note that worldwide deployment of only co-frequency hubs is considered in this Annex.

The reference radiation pattern for the hub station antennas is based on Recommendation ITU-R F.1336. The omnidirectional pattern is obtained by using four sectoral antennas, each with gain of 15 dBi and a 90° 3 dB beamwidth in the horizontal plane. Additionally, a 3 dB polarization

discrimination has been assumed to account for the linearly polarized hub station transmitting antenna and the circularly polarized DRS receiving antenna for boresight-to-boresight coupling. The reference radiation pattern of the transmitting antenna, ignoring any down-tilt, conformed to the following pattern in the vertical plane:

$$G(\theta) = G_0 - 12\left(\frac{\theta}{\varphi_3}\right)^2 \qquad \text{for } |\theta| \le \varphi_3 \qquad (7a)$$

$$G(\theta) = G_0 - 12 - 10\log\left(\frac{\theta}{\varphi_3}\right) \qquad \text{for } |\theta| > \varphi_3 \qquad (7b)$$

where:

$G(\theta)$: gain relative to an isotropic antenna (dBi)

G_0 : maximum gain in the horizontal plane (dBi)

θ : elevation angle measured in the vertical plane (degrees)

φ_3 : 3 dB beamwidth in the vertical plane (degrees).

$$\varphi_3 = \frac{31\,000 \times 10^{-0.1G_0}}{90} \qquad (7c)$$

Atmospheric absorption along the LMDS-DRS path was accounted for by using the following equations which apply to 27.5 GHz in accordance with Recommendation ITU-R F.1404:

$$A_{LowLat} = 22.73 \;/\; \left[1 + 0.9463\theta + 0.03455\theta^2 + h(0.3232 + 0.4519\theta) + h^2(0.2486 + 0.1317\theta)\right] \quad (8a)$$

$$A_{MidLat} = 11.96 \;/\; \left[1 + 0.8121\theta + 0.03055\,\theta^2 + h(0.2619 + 0.4728\,\theta) + 0.1409\,h^2\right] \qquad (8b)$$

$$A_{HiLat} = 8.77 \;/\; \left[1 + 0.8259\theta + h(0.2163 + 0.3037\,\theta) + 0.1067\,h\right] \qquad (8c)$$

where:

A_{LowLat} : atmospheric absorption for low latitude areas (latitude between $\pm22.5°$) (dB)

A_{MidLat} : atmospheric absorption for mid latitude areas (latitude between 22.5° and 45°) (dB)

A_{HiLat} : atmospheric absorption for high latitude areas (latitude greater than 45°) (dB)

θ : elevation angle (degrees), $0 \le \theta \le 90°$

h : height of the transmitting antenna above mean sea level (amsl) (km), $h \le 3$ km.

The height of the transmitting antenna for each LMDS station was assumed to be 0.50 km above mean sea level.

The DRS satellites use high-gain steerable receiving antennas to track low-orbiting user satellites. For the spatial analysis, the independent variables are the orbital location of the geostationary DRS (it is assumed that the orbital inclination is zero), and the roll and pitch angles of the steerable antennas. The roll and pitch angles are defined in a spherical coordinate system centred on the

DRS. The x-axis is directed towards the centre of the Earth, the y-axis points in the direction of the satellite velocity vector, and the z-axis is parallel to the Earth's axis of rotation. Defining the local coordinate system in this way, rotation about the x-axis is called yaw, rotation about the y-axis is called roll, and rotation about the z-axis is called pitch.

The spatial distribution of the interference environment is determined by scanning the DRS receiving antenna in roll and pitch in increments of 0.2°. At each DRS antenna pointing position, the aggregate interference from the emissions of each LMDS station within view of the DRS is calculated taking into account the elevation angle to the DRS, the e.i.r.p. spectral density of the LMDS emissions in the direction of the DRS, atmospheric absorption, the range, and the gain of the DRS receiving antenna in the direction of the LMDS station. The boresight gain of the DRS receiving antenna was assumed to be 58 dBi with radiation pattern that conformed to the reference radiation pattern given in Recommendation ITU-R S.672 for an antenna with circular symmetry and a –20 dB first sidelobe level.

$$G(\varphi) = G_0 - 12\left(\frac{\varphi}{\varphi_3}\right)^2 \qquad \text{for} \quad 0 \quad \leq \varphi \leq 1.29\ \varphi_3 \qquad (9\text{a})$$

$$G(\varphi) = G_0 - 20 \qquad \text{for} \quad 1{,}29\ \varphi_3 < \varphi \leq 3.16\ \varphi_3 \qquad (9\text{b})$$

$$G(\varphi) = G_0 - 20 - 25\log\left(\frac{\varphi}{3.16\varphi_3}\right) \qquad \text{for} \quad 3.16\ \varphi_3 < \varphi \text{ and } G(\varphi) \geq 0 \qquad (9\text{c})$$

$$G(\varphi) = 0 \qquad \text{otherwise} \qquad (9\text{d})$$

where:

G_0 : maximum on-axis gain (dBi)

$G(\varphi)$: off-axis gain (dBi)

φ : off-axis angle (degrees)

φ_3 : 3 dB beamwidth (degrees)

$$\varphi_3 = \sqrt{27\,000 \times 10^{-0.1G_0}} \qquad (9\text{e})$$

2.2   Temporal distribution

The temporal characteristics of interference to a DRS receiving system are also determined by computer simulation, but in this case, a dynamic simulation is used. The technical and operating characteristics of LMDS hub stations and their assumed deployment are as described in § 2.1. A DRS satellite with the receiving system characteristics as described in § 2.1, is assumed to be located at a prescribed geostationary orbital location and to be tracking a low-orbiting satellite that is transmitting to the DRS. The low-orbiting satellite is in an orbit with an altitude of 400 km and inclined by 51.6° with respect to the equatorial plane – orbital characteristics that are typical of the international space station. In § 4, an orbit of Earth observing satellite (EOS) with an altitude of 800 km and an inclination angle of 98.6° will also be considered. The DRS receiving antenna is

assumed to track, without error, the low-orbiting satellite in 1 s increments along its orbit. At each location along its orbit, the interference to the DRS receiving system from the aggregate emissions of all LMDS hub stations within the field of view is determined for each orbital period over a period of 10 days. The orbital period is defined as the elapsed time between consecutive crossing of the equatorial plane in the south-to-north direction.

3 Results of Study A

The global distribution of the 431 deployment areas is shown in Fig. 1. Results for the spatial distribution have been obtained for two sets of DRS orbital locations and are presented in § 3.1. The temporal characteristics of interference are presented in § 3.2.

FIGURE 1

Assumed locations of LMDS systems
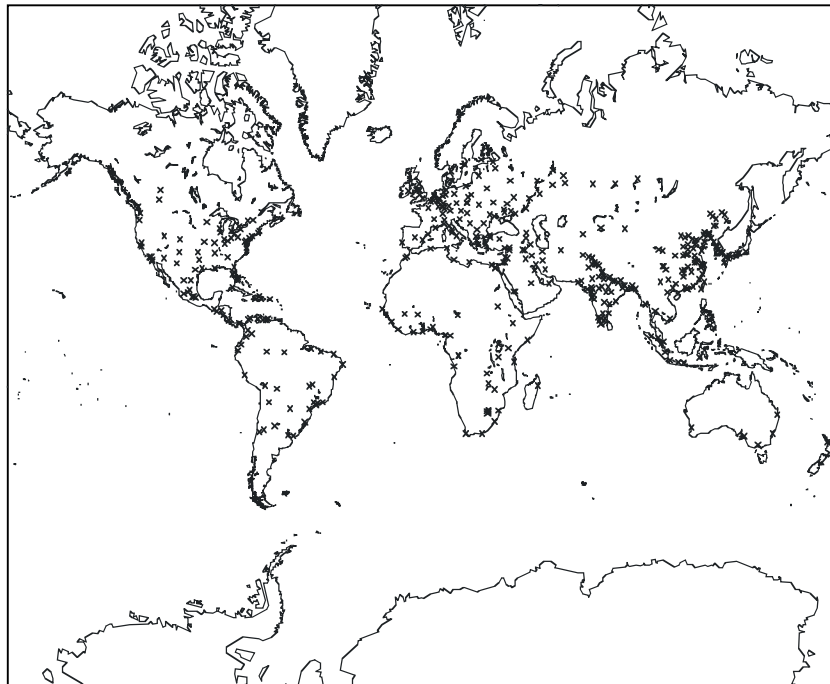
1509-01

3.1 Spatial distributions

Two sets have been determined. The first set contains the orbital locations of DRS satellites to be operated by the United States of America. The spatial distribution of interference to DRS located at these orbital locations is determined in 0.2° increments of roll and pitch. The second set contains all the DRS orbital locations indicated in Recommendation ITU-R SA.1276 as orbital locations to be protected from the emissions of FS systems.
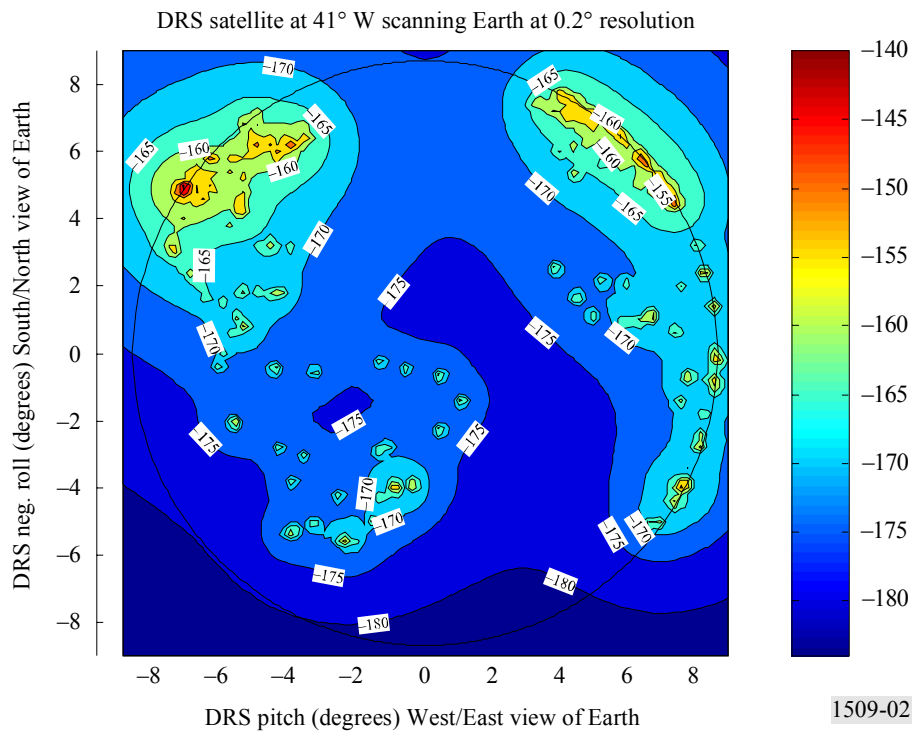
3.1.1 DRS orbital locations at 41° W, 174° W and 85° E longitude

Figure 2 shows a contour plot of the spatial distribution of interference to a geostationary DRS satellite located at 41° W. The plot is based on an e.i.r.p. spectral density of +8 dB(W/MHz) in the local horizontal plane from each LMDS hub station in view of the DRS satellite. An increase of 1 dB in the e.i.r.p. spectral density of all hub stations will result in a 1 dB increase in the

interference to a DRS. The maximum interference level of −139 dB(W/MHz) occurs at a DRS antenna pointing angle of 5° in roll and −7.2° in pitch, the minimum interference level of less than −180 dB(W/MHz) occurs when the DRS receiving antenna is pointed towards the South Pole. These levels are in the range from 9 dB greater than to 32 dB less than the protection level given in Recommendation ITU-R SA.1155. Assuming the e.i.r.p. spectral density of all the hub stations is +8 dB(W/MHz), then the interference to DRS will primarily occur when tracking low-orbiting satellites near the Earth's limb in the Northern Hemisphere. Note that the area exceeding the DRS protection level is relatively small and that for most scan positions, the DRS protection level is met.

FIGURE 2

Spatial distribution of interference (dB(W/MHz)) to DRS located at 41° W longitude assuming 944 hubs operating at +8 dB(W/MHz) from 431 cities worldwide. The large circle is the Earth's disk. Note the two areas in North America and one area in Europe from which interference exceeds the DRS protection level

Figures 3 and 4 show the spatial distribution of the interference to the DRS orbital locations of 174° W and 85° E, respectively. These are similar to the results at 41° W. For the DRS orbital location of 174° W, the peak total interference is −144.9 dB(W/MHz). For the DRS orbital location at 85° E, the maximum interference is −146.0 dB(W/MHz). As was the case for the DRS orbital location of 41° W, the maximum interference levels occur when the DRS receiving antenna is pointed towards urban population centres that appear on or near the Earth's limb.

FIGURE 3

Spatial distribution of interference (dB(W/MHz)) to DRS located at 174° W longitude assuming 944 hubs operating at +8 dB(W/MHz) e.i.r.p. from 431 cities worldwide. The large circle is the Earth's disk
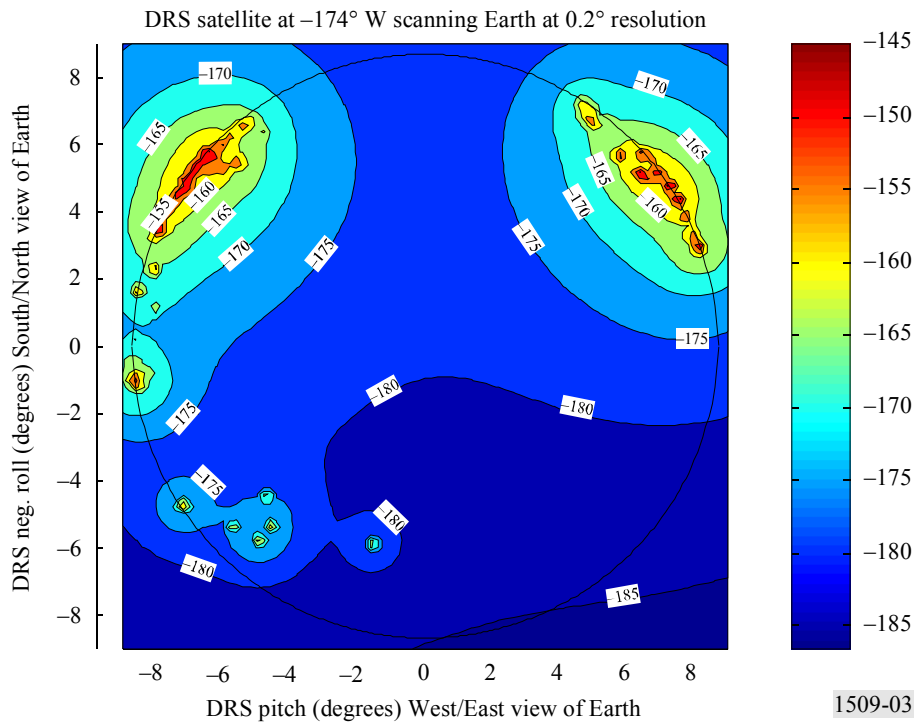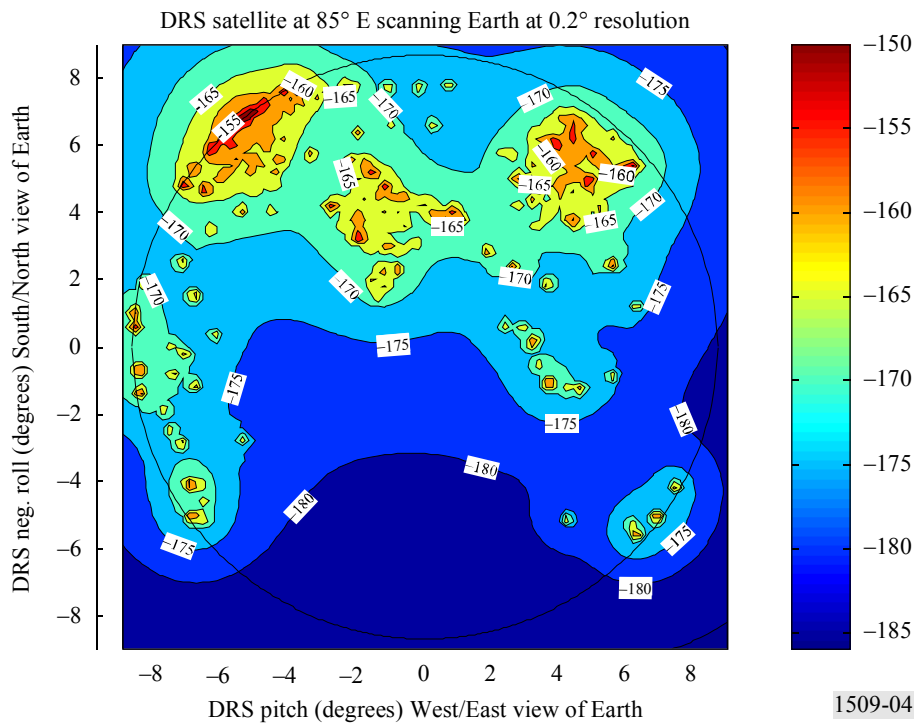

DRS satellite at −174° W scanning Earth at 0.2° resolution

1509-03

FIGURE 4

Example of interference (dB(W/MHz)) to DRS located at 85° E longitude assuming 944 hubs operating at +8 dB(W/MHz) from 431 cities worldwide. The large circle is the Earth's disk

DRS satellite at 85° E scanning Earth at 0.2° resolution

1509-04

3.1.2   DRS orbital locations indicated in Recommendation ITU-R SA.1276

Recommendation ITU-R SA.1276 lists 23 DRS orbital locations that are to be protected, to the extent possible (Recommendation ITU-R F.1249), from interference in excess of the DRS protection level by FS systems operating in the 25.25-27.5 GHz band. Table 1 summarizes the peak interference results of simulations for each of the orbital locations identified in Recommendation ITU-R SA.1276. A scan resolution of 0.2° in roll and pitch was used. Table 1 also indicates that variability of the peak interference levels as measured by standard deviation is less than 4 dB from all the orbital locations. This observation implies that the variation in peak interference from orbital location to orbital location is relatively small.

Table 1 shows a summary of the peak interference from the scan direction with peak total interference for each satellite orbital location. The peak total interference averages –144.3 dB(W/MHz). The maximum total interference received at any orbital location and any scan direction was –139 dB(W/MHz). The interference contribution from the deployment area contributing the most to the peak total interference is also listed.

The simulations show that the peak interference from widespread deployment of LMDS systems is about 3 dB more than the interference caused by a single deployment area. An aggregation gain factor, defined here as the difference in dB between the total peak interference and the interference from the dominant contributor, is also shown in Table 1. The average aggregation gain is 2.5 dB. The simulation suggests that on average, the peak total aggregate interference is within 2.5 dB of the interference from the urban population centre contributing the most interference. It is concluded that the aggregated e.i.r.p. of an urban population centre, i.e. the sum of the individual hub e.i.r.p. toward a specific DRS orbital location, can be used to predict the peak interference that is likely to occur at most DRS locations by adding 2.5 dB to the aggregate e.i.r.p. of the city.

From Table 1, the average elevation angle toward the satellite of the dominant interference contributor is about 7°. In no case was the peak interference caused by a deployment area with an observed elevation angle less the 1.5°.

From Table 1, it is also concluded that if the LMDS hub station transmitting antenna exhibited additional loss for elevation angles above about 5°, the total interference received at several orbital locations would be reduced by about the value of the additional antenna loss. Thus, shaping in the elevation plane of the LMDS transmitting antenna may be a useful approach, for some deployment areas, to reduce interference toward specific DRS orbital locations.

Table 1 also includes the rain climate regions (rain-zone), as defined in Recommendation ITU-R P.837, of the dominant interference contributor. The operating power of the hub station is expected to depend on the link availability objectives, link distance, and the rain climate zone in which the system is located. Recommendation ITU-R F.758 contains specific remarks for equipment in the 25.25-27.5 GHz band. In Table 17 of Recommendation ITU-R F.758, Note 8 indicates that systems operating at a range of 5 km and at an e.i.r.p. spectral density of +8 dB(W/MHz) per hub provide a link margin capability of 37 dB. Recommendation ITU-R. F.755, specifically Table 8, indicates that 37 dB of link margin at 5 km is sufficient to provide 0.9999 link

availability in rain-zone K. A link margin of 37 dB is insufficient for 0.9999 link availability in rain-zones which exhibit a rain-rate greater than that exhibited in rain-zone K. It is tentatively concluded that LMDS systems in rain-zones with a rain-rate less than that exhibited in rain-zone K can operate at 5 km range with less than 8 dB(W/MHz) hub e.i.r.p. and interference to the DRS could be reduced. It is also concluded that systems in rain zones with a rain-rate greater than that found in rain-zone K could be operationally constrained, for some deployments, if the hub e.i.r.p. density were limited to 8 dB(W/MHz) in order to facilitate sharing with the DRS.

TABLE 1

Summary f peak interference over the DRS field of view at the DRS orbital locations given in Recommendation ITU-R SA.1279 assuming 944 hub stations operating at +8 dB(W/MHz) from 431 cities worldwide

Sat. orbital loc. E. long. (degrees)	Dominant interferer N. lat. (degrees)	Dominant interferer E. long. (degrees)	Dominant interferer hubs/rain-zone		Dominant interferer area e.i.r.p. toward DRS (dB(W/MHz))	Dominant interferer observed el. angle toward DRS (degrees)	Interference from dominant interferer (dB(W/MHz))	Peak total interference when pointed at dominant interferer (dB(W/MHz))	Aggregation gain (dB)
−174	32.833	−96.833	10	M	17.7	2.4	−144.6	−144.3	0.3
−171	32.833	−96.833	10	M	16.8	4.8	−143.0	−142.8	0.2
−170	39.133	117.200	5	H	13.8	4.8	−146.0	−142.0	4.0
−160	41.830	−87.750	16	K	18.9	4.6	−143.1	−141.1	2.0
−139	40.750	−74.000	35	K	17.9	10.2	−143.1	−140.9	2.2
−62	51.467	6.983	3	E	11.7	4.4	−148.3	−142.7	5.6
−49	34.000	−118.167	29	E	18.6	8.6	−140.2	−139.3	0.9
−46	34.000	−118.167	29	E	20.6	6.2	−140.3	−139.0	1.3
−44	34.000	−118.167	29	E	21.5	4.6	−140.2	−139.3	0.9
−41	34.000	−118.167	29	E	22.4	2.2	−140.3	−139.0	1.3
−32	40.750	−74.000	35	K	13.0	26.5	−145.7	−145.4	0.3
−16	42.330	−83.080	10	K	14.4	8.2	−145.7	−140.8	4.9
16.4	23.700	90.367	7	N	14.4	6.1	−146.6	−145.0	1.6
21.5	23.700	90.367	7	N	10.2	10.8	−149.3	−147.7	1.6
47	31.250	121.500	7	M	15.3	4.7	−145.6	−143.4	2.2
59	34.400	135.270	4	M	13.6	2.9	−151.1	−145.6	5.5
85	48.130	16.220	1	K	6.4	5.5	−153.9	−146.7	7.3
90	52.250	18.983	2	H	10.3	3.6	−150.2	−147.8	2.4
95	41.033	28.950	5	K	10.3	9.3	−151.6	−149.3	2.3
113	36.200	44.017	2	K	7.3	8.3	−154.9	−150.1	4.8
121	36.200	44.017	2	K	10.8	2.1	−151.4	−148.4	3.0
160	37.750	−122.500	10	D	17.9	1.5	−145.3	−143.8	1.5
177.5	34.000	−118.167	29	E	14.2	12.6	−146.4	−145.3	1.1
Maximum					14.2	26.5	−140.2	−139.0	7.2
Mean					14.7	6.7	−146.4	−144.3	2.5
Std dev					4.4	5.3	4.4	3.4	1.9
Minimum					6.4	1.5	−154.9	−150.1	0.2

3.2   Temporal distribution

The temporal characteristics of interference to DRS while tracking a low-orbiting user satellite have been evaluated for three DRS orbital locations listed in Recommendation ITU-R SA.1276, i.e., 41° W, 174° W and 85° E. The international space station is the assumed low-orbiting user satellite, which operates at an altitude of 400 km, inclined 51.6° to the equatorial plane.

The dynamic simulation was run for 10 days of orbital time in 1 s increments. At each interval, the aggregate interference from the emissions of all LMDS hub stations within the field of view was calculated and used to determine the cumulative distribution function (CDF) of the interference for that particular orbital period. Since there were 145 orbits during the 10 day period, 145 CDFs were generated from each dynamic simulation. Figure 5 shows, for a DRS located at 41° W, a family of curves of exceedence probabilities of the interference for individual, consecutive orbits of the low-orbiting user satellite. The curves correspond to interference levels exceeded for 99%, 20% and 0.1% of an orbital period. This family of exceedence probabilities is plotted against the interference level on the abscissa and the start time of when the satellite is in view of the DRS satellite on the ordinate. Also shown on the Figure is a vertical line corresponding to an interference level of -148 dB(W/MHz). From the Figure, it is seen that there are 11 orbits that will experience interference levels in excess of −148 dB(W/MHz). In addition this Figure indicates that the time between orbits that the interference exceeds −148 dB(W/MHz) ranges from a minimum of 7.7 h to a maximum of 71 h. Figure 6 shows the individual time series of the interference for periods of time when the interference level exceeds −148 dB(W/MHz). As the Figure shows, the duration of the interference above the protection level extends from less than 10 s to less than 60 s.

FIGURE 5

**Temporal characteristics of the interference to a DRS located at 41° W
while tracking a low-orbiting user satellite in
an international space station type orbit**

Result for 41° W (10 days of orbit time, 1 s intervals)
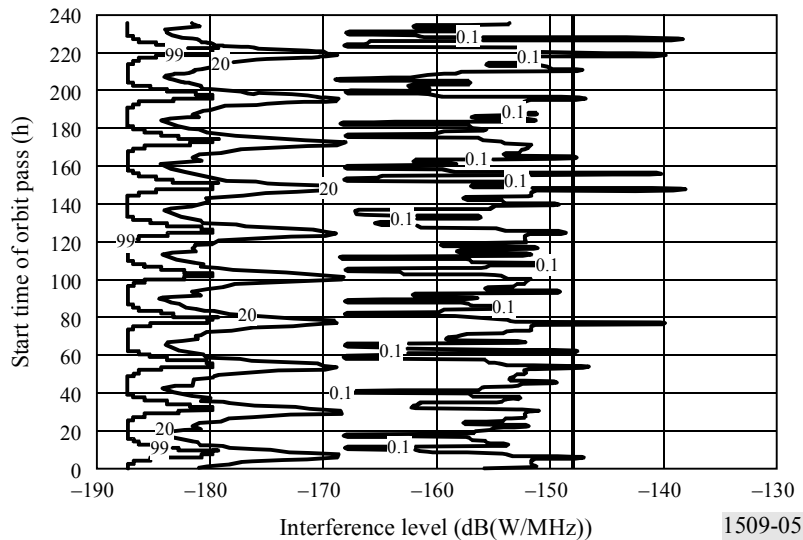
1509-05

FIGURE 6

**Examples of interference to a DRS located at 41° W while tracking
a low-orbiting user satellite in an international space station type orbit
(see § 3.2)**

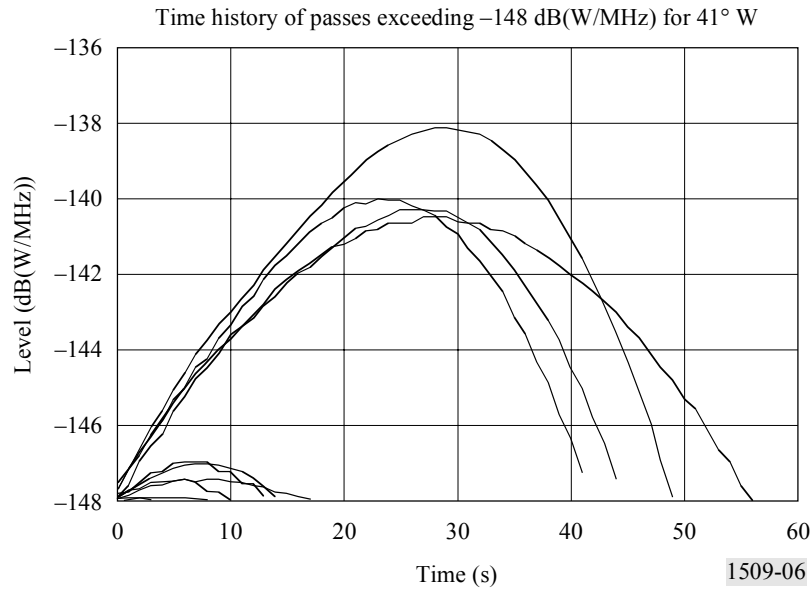Time history of passes exceeding −148 dB(W/MHz) for 41° W

1509-06

Figure 7 shows comparable results for the DRS orbital location of 174° W. For this location, there are 12 orbits that will experience interference in excess of the protection level for more than 0.1% of the orbit period. In addition, this Figure indicates that the time between orbits that the interference exceeds −148 dB(W/MHz) ranges from a minimum of 6.1 h to a maximum of 30.9 h. Figure 8 shows the time series of each period of interference. For this orbital location the duration of interference greater than the protection level of −148 dB(W/MHz) varies from about 5 s to 50 s.

FIGURE 7

**Temporal characteristics of the interference to a DRS located at 174° W while tracking
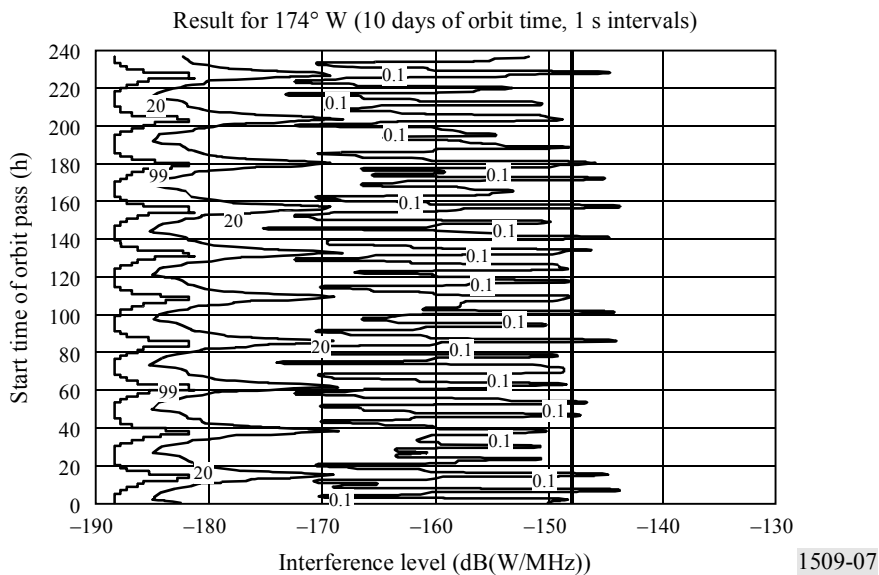a low-orbiting user satellite in an international space station type orbit**

Result for 174° W (10 days of orbit time, 1 s intervals)

1509-07

FIGURE 8

Examples interference to a DRS located at 174° W while tracking a low-orbiting user satellite in an international space station type orbit (see § 3.2)

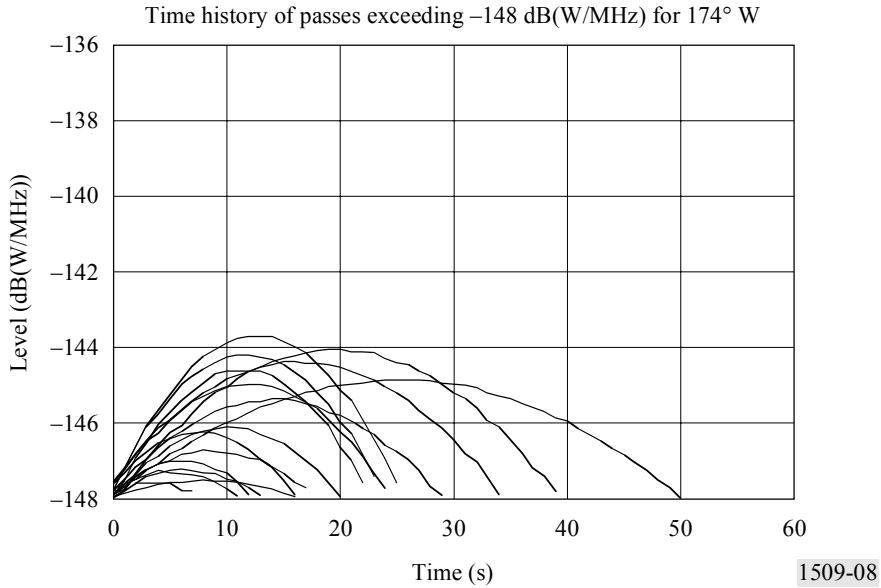Time history of passes exceeding −148 dB(W/MHz) for 174° W

1509-08

Figure 9 shows the temporal characteristics of the interference for the DRS orbital location of 85° E. The Figure shows that the protection criteria of Recommendation ITU-R SA.1155 are satisfied for each orbit of a satellite in an international space station type orbit.

FIGURE 9

Temporal characteristics of the interference to a DRS located at 85° E while tracking a low-orbiting user satellite in an international space station type orbit
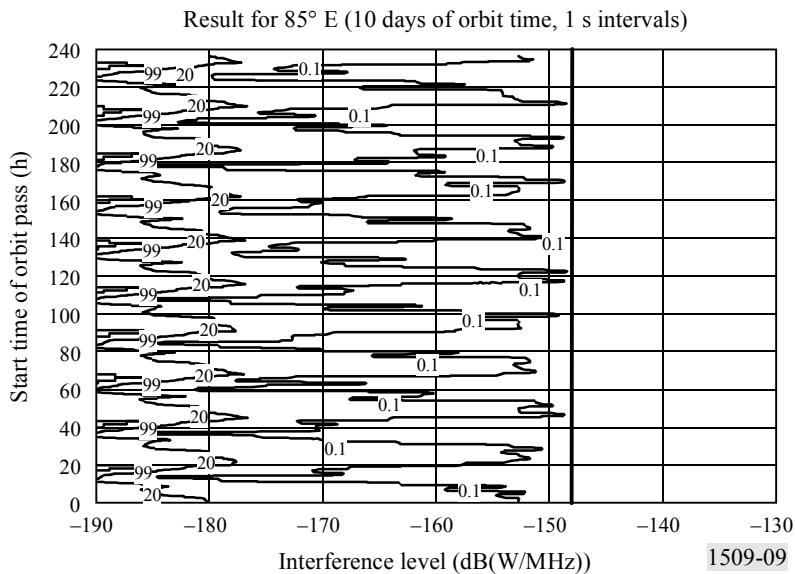
Result for 85° E (10 days of orbit time, 1 s intervals)

1509-09

Table 2 summarizes the temporal results.

TABLE 2

Summary of temporal interference, *I,* results

DRS orbital location	Total number of satellite orbits (~1.6 h/orbit)	Duration between orbits where $I < -148$ dB(W/MHz) (h)	Number of satellite orbits where $I > -148$ dB(W/MHz)	For orbits in which $I > -148$ dB(W/MHz)		
				Duration $I > -148$ dB(W/MHz) (s)	Percentage of orbit $I > -148$ dB(W/MHz)	Peak $I^{(1)}$ (dB(W/MHz))
174° W	145	6.1 to 30.9	12	5 to 50	0.1 to 0.8	−143.8
41° W	145	7.7 to 71	11	10 to 60	0.2 to 1.0	−137.8
85° E	145	N/A	0	N/A	N/A	−148.3

[1] The small differences in the peak levels found by the temporal and spatial analysis are due to: sampling effects between a spatial and temporal analysis, small model differences in hub antenna elevation pattern 3 dB beamwidth, upper elevation side-lobe contribution differences, operating frequency, and the inclusion of atmospheric bending effects (Recommendation ITU-R F.1333) in the spatial model.

It is concluded that during the few orbits in which the interference level exceeds −148 dB(W/MHz), the protection level is exceeded by slightly more than 0.1% up to a worst case of about 1% of the time for a DRS located at 41° W and 174° W. For a DRS located at 85° E, the protection criteria of Recommendation ITU-R SA.1155 is satisfied.

4 Results of Study B

The following sections present the results of the temporal and spatial analysis based on another study. In this study, an e.i.r.p. spectral density of +14 dB(W/MHz) per hub station will be assumed, in view of a need that certain systems may require an e.i.r.p. density larger than +8 dB(W/MHz). Two user satellites will be considered, international space station (orbital altitude of 400 km and inclination angle of 51.6°) and EOS (orbital altitude of 800 km and inclination angle of 98.6°). Sharing criterion of −142 dB(W/MHz) will be assumed instead of a protection criterion of −148 dB(W/MHz).

4.1 Results – Temporal analysis

For the purpose of this analysis, the worst-case interference scenario is presented, which is the 41° W DRS. Figure 10 illustrates the aggregate emissions from LMDS hubs received by the DRS as it tracks the international space station over a period of 30 days in 5 s increments. Figure 11 presents a similar graph for the DRS tracking the EOS.
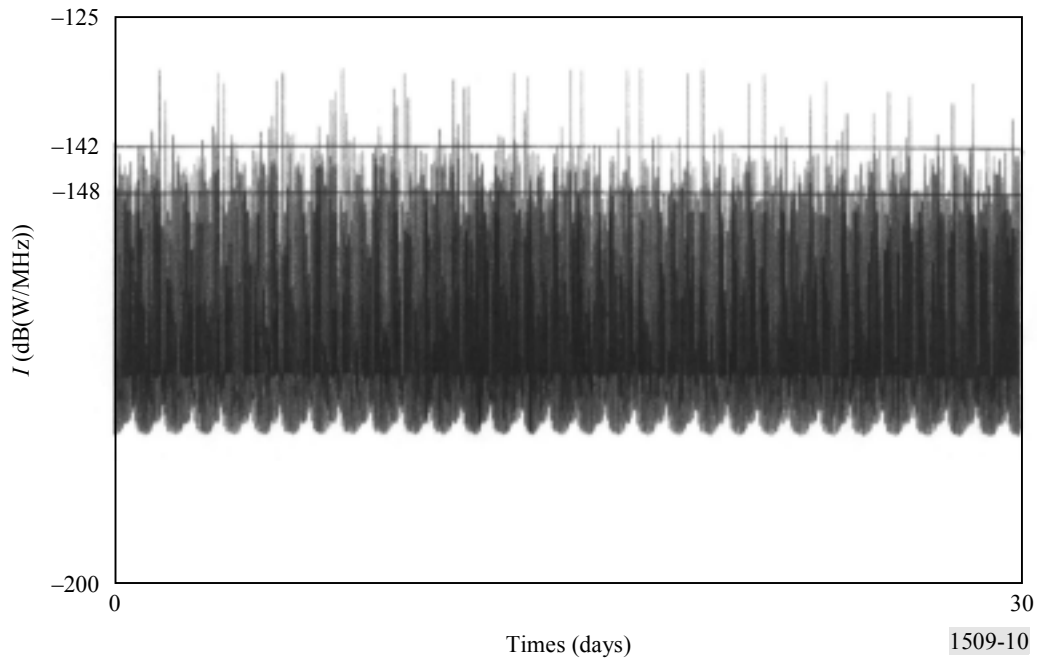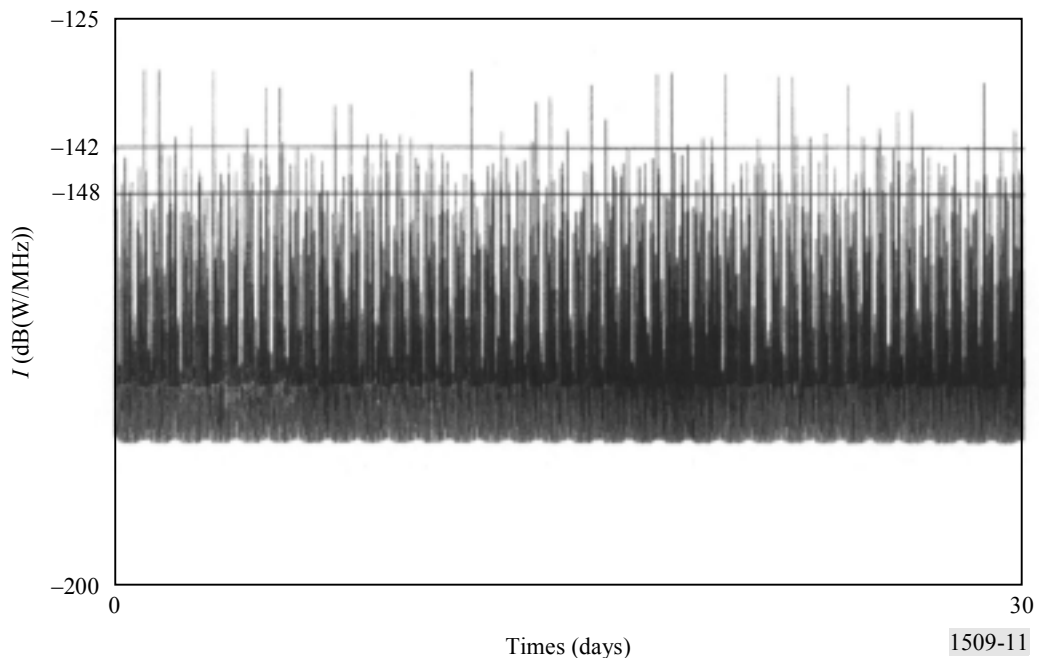
FIGURE 10

Interference into 41° W DRS while tracking the international space station

Times (days)

1509-10

FIGURE 11

Interference into 41° W DRS while tracking the EOS

Times (days)

1509-11

As shown in both Figures, the emissions from the LMDS deployments, operating at an e.i.r.p. of +14 dB(W/MHz) per hub station fall predominantly below the sharing criterion of −142 dB(W/MHz). For the DRS tracking the international space station, the cumulative emissions exceeding the sharing criterion account for only approximately 0.1% of the time over the full

30 day period. This is illustrated in Fig. 12. As illustrated in Fig. 13, the cumulative emissions received by the DRS tracking the EOS exceed the sharing criteria by approximately 0.06% of the time. It should be noted that these events originate from known predictable locations on Earth, which can be easily identified through simulation.

FIGURE 12

**Cumulative interference into DRS 41° W while tracking
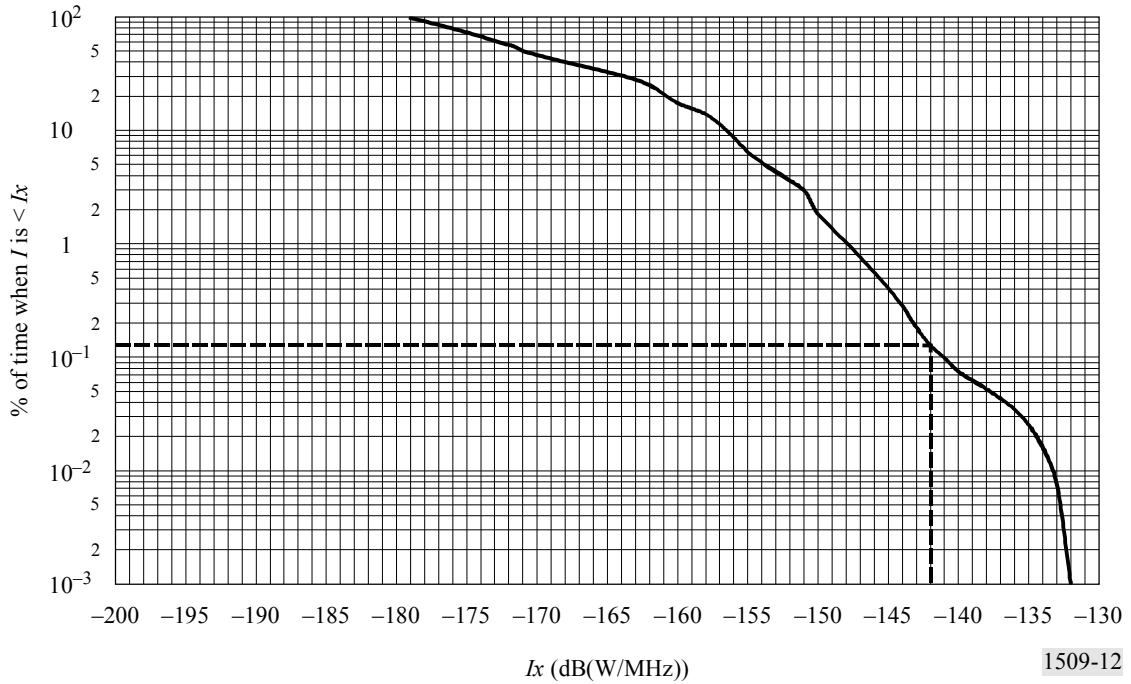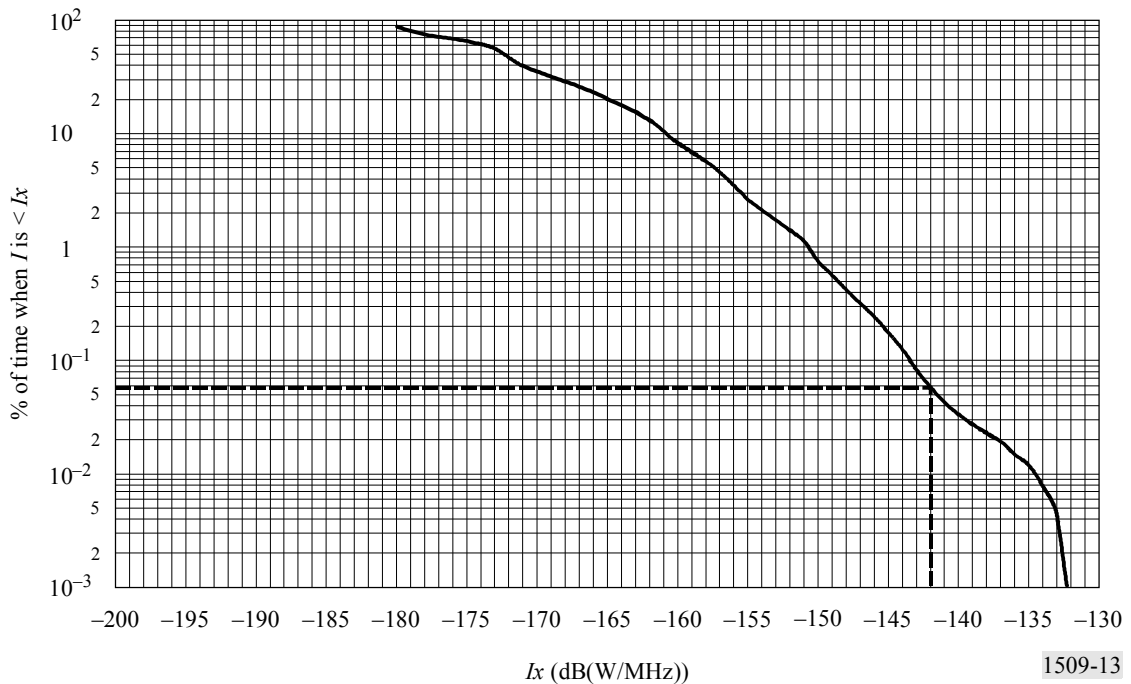the international space station over 30 days**

Ix (dB(W/MHz))

1509-12

FIGURE 13

**Cumulative interference into DRS 41° W while tracking
EOS over 30 days**

Ix (dB(W/MHz))

1509-13

The above results are consistent with the outcome of the spatial analysis discussed below.

4.2 Results – Spatial analysis

The results of the spatial analysis are given for three DRS orbital positions including 41° W, 174° W, and 85° E. The 41° W and 174° W represent the worst-case scenario, and 85° E is a typical case where interference exists. It should be noted that for many orbital slots, the sharing criterion is not exceeded at all.

Figure 14 illustrates the spatial interference profile of LMDS emissions into the 41° W DRS. As shown, the emissions exceeding the –142 dB(W/MHz) sharing criterion are concentrated around specific predictable locations. Figures 15 and 16 depict similar graphs for the 174° W and 85° E orbital positions.

FIGURE 14

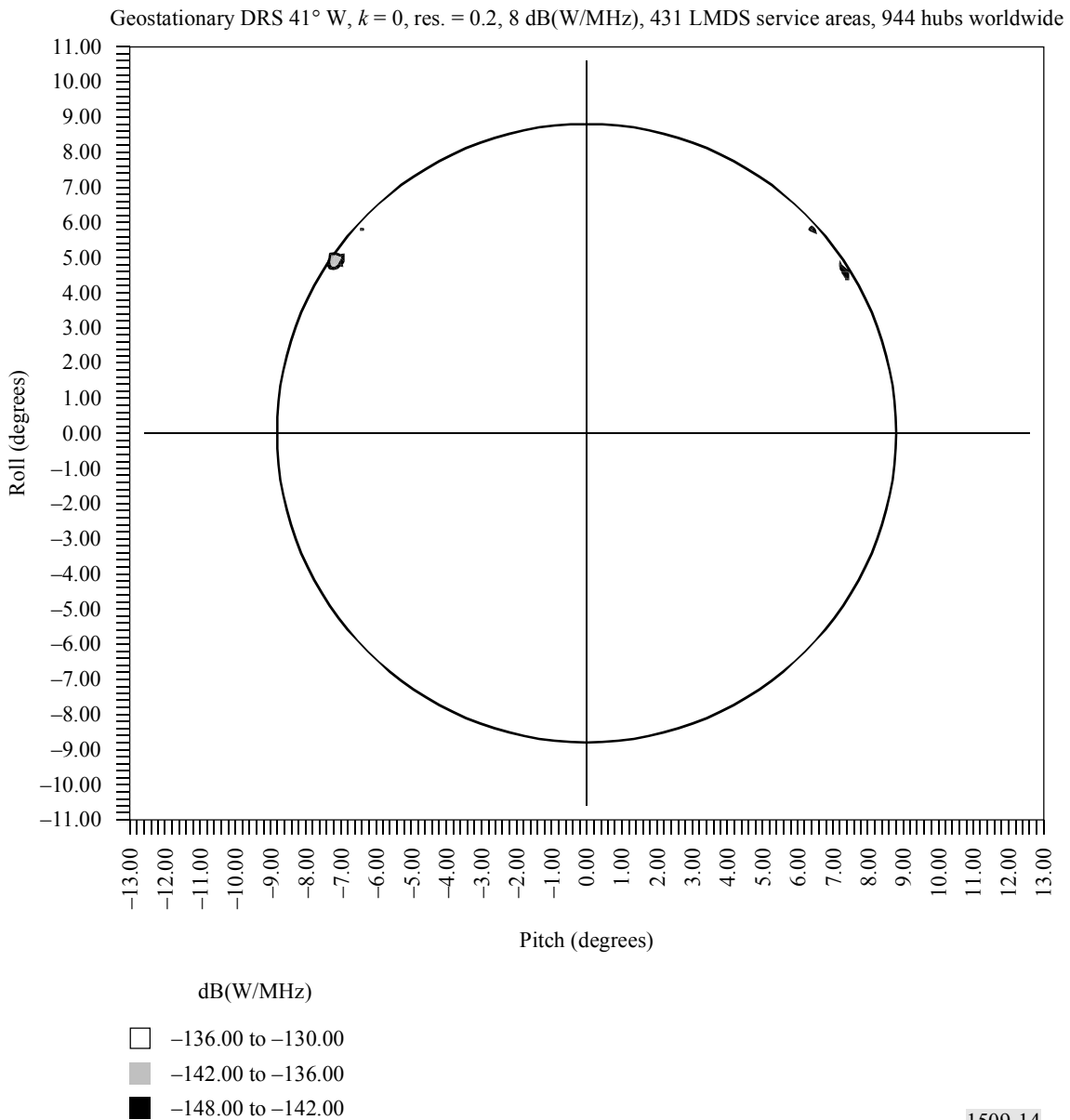**Spatial interference profile for 41° W DRS**

Geostationary DRS 41° W, $k = 0$, res. = 0.2, 8 dB(W/MHz), 431 LMDS service areas, 944 hubs worldwide

Pitch (degrees)

Roll (degrees)

dB(W/MHz)

☐ –136.00 to –130.00
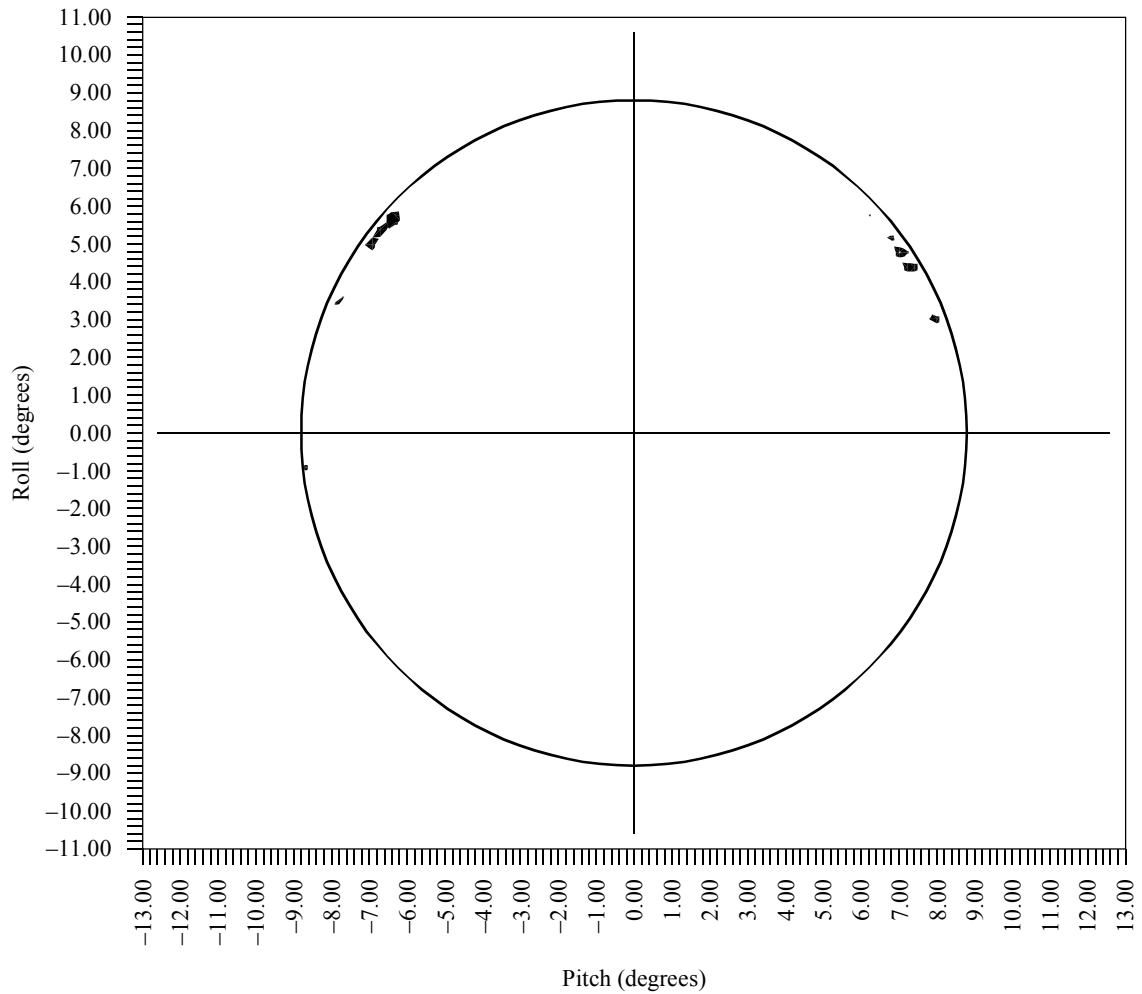
▨ –142.00 to –136.00

■ –148.00 to –142.00

1509-14

FIGURE 15

Spatial interference profile for 174° W DRS

Geostationary DRS 174° W, $k = 0$, res. = 0.2, 8 dB(W/MHz), 431 LMDS service areas, 944 hubs worldwide

dB(W/MHz)

☐ −136.00 to −130.00

▨ −142.00 to −136.00

■ −148.00 to −142.00

1509-15

FIGURE 16

Spatial interference profile for 85° E DRS

Geostationary DRS 85° E, $k = 0$, res. = 0.2, 8 dB(W/MHz), 431 LMDS service areas, 944 hubs worldwide

dB(W/MHz)

☐ −136.00 to −130.00
▨ −142.00 to −136.00
■ −148.00 to −142.00
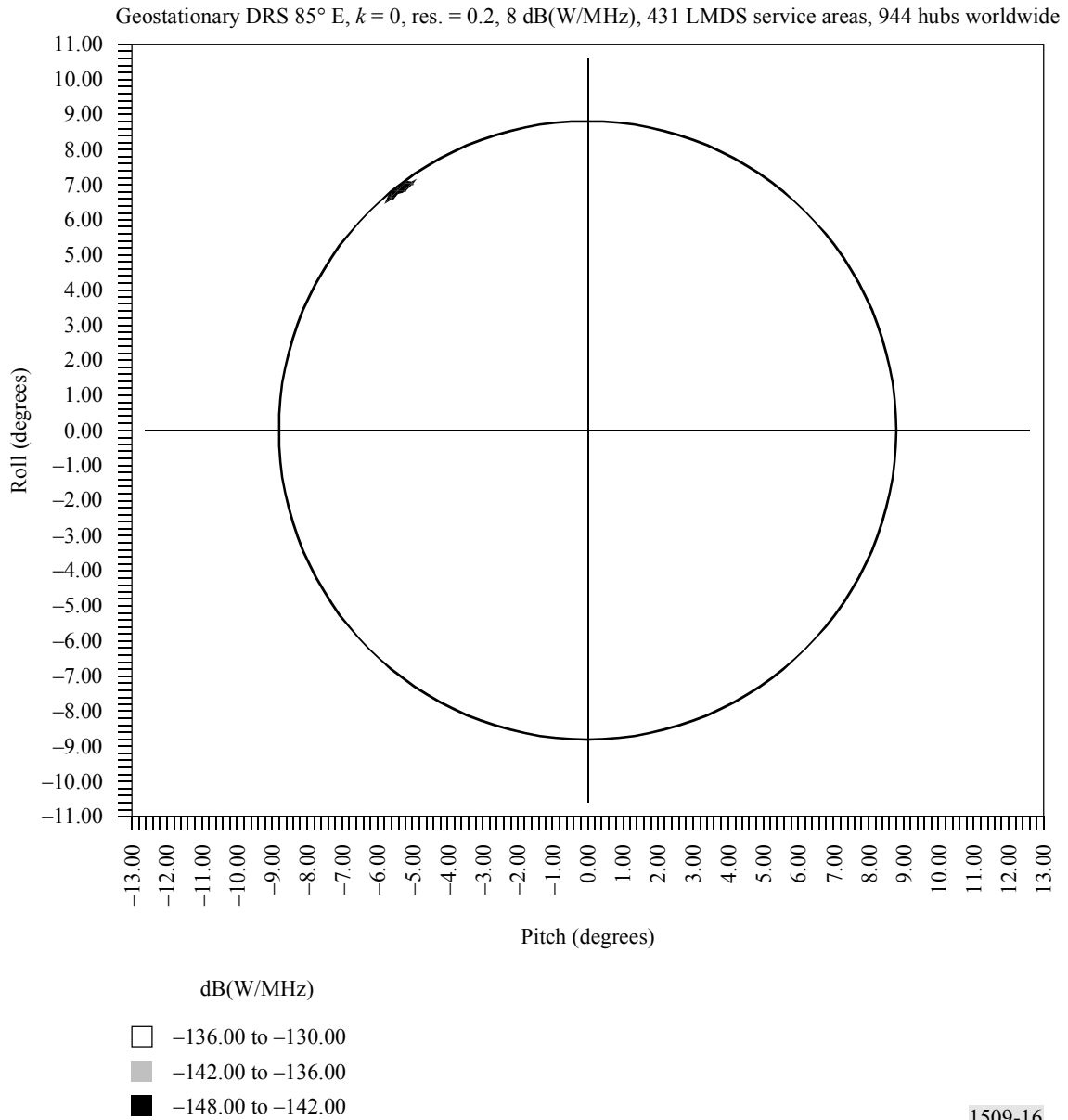
1509-16

It should be noted that the above graphs are based on simulation runs using $k = 0$ for the antenna radiation patterns in Recommendation ITU-R F.1336. Simulation runs were also performed using $k = 1$ (higher side-lobes), and it was observed the overall interference profile remained relatively constant, suggesting the sidelobe contributions are negligible.

4.3 Discussion of results (§ 4)

As indicated from the above analysis, a sharing criterion of −142 dB(W/MHz) allows sharing between the two services without overly constraining either service. Sharing criteria, unlike protection criteria, must recognize the specific nature of the services in the band and reflect the need to accommodate those services. In the case of DRS sharing the 25.25-27.5 GHz band with P-MP FS systems there are a number of mitigating factors which would support a sharing criterion of −142 dB(W/MHz), for example:

–   As discussed, the use of sectorized antenna systems with downtilt will be common place in P-MP deployments. Systems will require a significant level of sectorization to control intra-systems interference and to achieve frequency reuse levels that support business cases.

–   The emissions that do exceed the sharing criterion originate from predictable locations on Earth, allowing *a priori* measures to be taken to avoid interference.

–   The use of the band 25.25-27.5 GHz by the fixed service varies from administration to administration. In some countries, operators are authorized for point-to multipoint systems, in other countries, operators use a mix of point-to-point and P-MP systems (some broadband operators use multiple point-to-point systems from a central site). In addition, current band plans support a range of point-to-point and P-MP systems. Consequently, the aggregate emission level from multipoint systems into DRS systems is likely to be much less than characterized in this study.

5 Extension to other LMDS deployments

The results described in § 3 and 4 are based on specific assumptions regarding the radius of the LMDS cell. This section describes a simple means to extend the results to LMDS deployments that use smaller cells.

In general, smaller cell sizes will lead to a larger number of cells in a mature deployment of LMDS systems in urban population centres. As a consequence of the smaller cell size, the hub station e.i.r.p. required to provide the same link margin to the outermost subscriber will decrease as the square of the distance, assuming line-of-sight propagation. Thus, the relative reduction in the e.i.r.p. spectral density for cells smaller than the reference cell is given by:

$$\Gamma_i = 20 \log\left(\frac{r_i}{r_0}\right) \tag{10}$$

where:

Γ_i: e.i.r.p. spectral density reduction factor for the i-th cell (dB)

r_i: radius of the i-th cell (km)

r_0:   radius of the reference cell, i.e., 5 km.

The application of the reduction factor is straightforward. For example, assume that the e.i.r.p. spectral density of the 5 km reference cell is +8 dB(W/MHz); were the cell size reduced to 2.5 km, the e.i.r.p. spectral density would be reduced to +2 dB(W/MHz).

It is noted that the application of this approach will tend to limit the aggregate e.i.r.p. spectral density from any urban population centre to a level that is independent of the cell size.

Note that the deployment objective for many fixed service deployments will be to maintain constant link availability as opposed to constant link margin as the distance to the outermost subscriber varies. Using the methods of Recommendation ITU-R P.530 and for a given link availability, the necessary link margin decreases as the link distance decreases. Thus, equation (10) provides a conservative estimate of the reduction of e.i.r.p. spectral density as a function of the cell size reduction.

6   Interference into POCS

The interference scenario for POCS is similar to that of the DRS in that co-channel LMDS emissions enter into the POCS receive antennas as the satellite orbits around the Earth.

6.1   Characteristics of LMDS systems

The same LMDS characteristics, described in § 2.1, were assumed for the POCS analysis.

However, an e.i.r.p. spectral density of +14 dB(W/MHz) was assumed.

6.2   Characteristics of POCS

Two POCS users were addressed in this analysis, including the international space station and space shuttle orbiter. Each POCS is assumed to employ two antennas, a high and low gain variant. Table 3 provides a summary of the POCS system characteristics.

TABLE 3

POCS characteristics

User	Orbit		Receiving Antenna	
	Altitude (km)	**Inclination (degrees)**	**Gain (dBi)**	**Pointing**
International space station	400	51.6	3.5	Nadir
			23.5	Along the velocity vector
Space shuttle orbiter	530	57	3.5	Nadir
			23.5	Along the velocity vector

For the low gain variant, an omni-directional antenna was assumed as opposed to a 244° full cone angle half-power beamwidth (HPBW), to represent a worst-case scenario. For the high gain antenna, a fixed 8° HPBW receiving antenna with a reference radiation pattern from Recommendation ITU-R S.672 ($L_S = -20$ dB) was used. Circular polarization is assumed for the POCS.

The protection criterion for the receiver is -147 dB(W/MHz) for no more than 0.1% of the time as specified in Recommendation ITU-R SA.609.

6.3 Methodology

Only the temporal analysis was performed for the POCS over a simulation period of 30 days. Data was collected every 5 s.

Similar to the DRS analysis, the atmospheric absorption was calculated based on Recommendation ITU-R P.676. As well, a 3 dB loss was included to account for the difference in polarization.

6.4 Results

The following Figures show the emission levels into the two receive antennae of both POCS from LMDS systems over a period of 30 days.

FIGURE 17

**Cumulative interference into an international space station
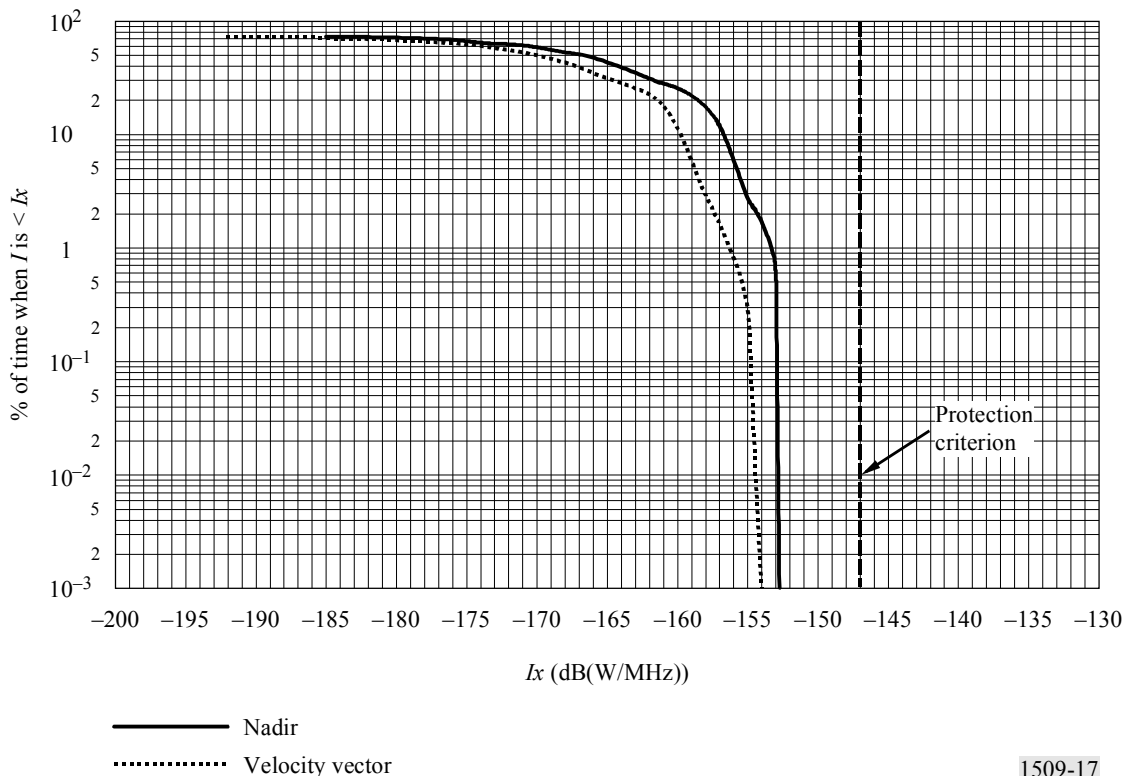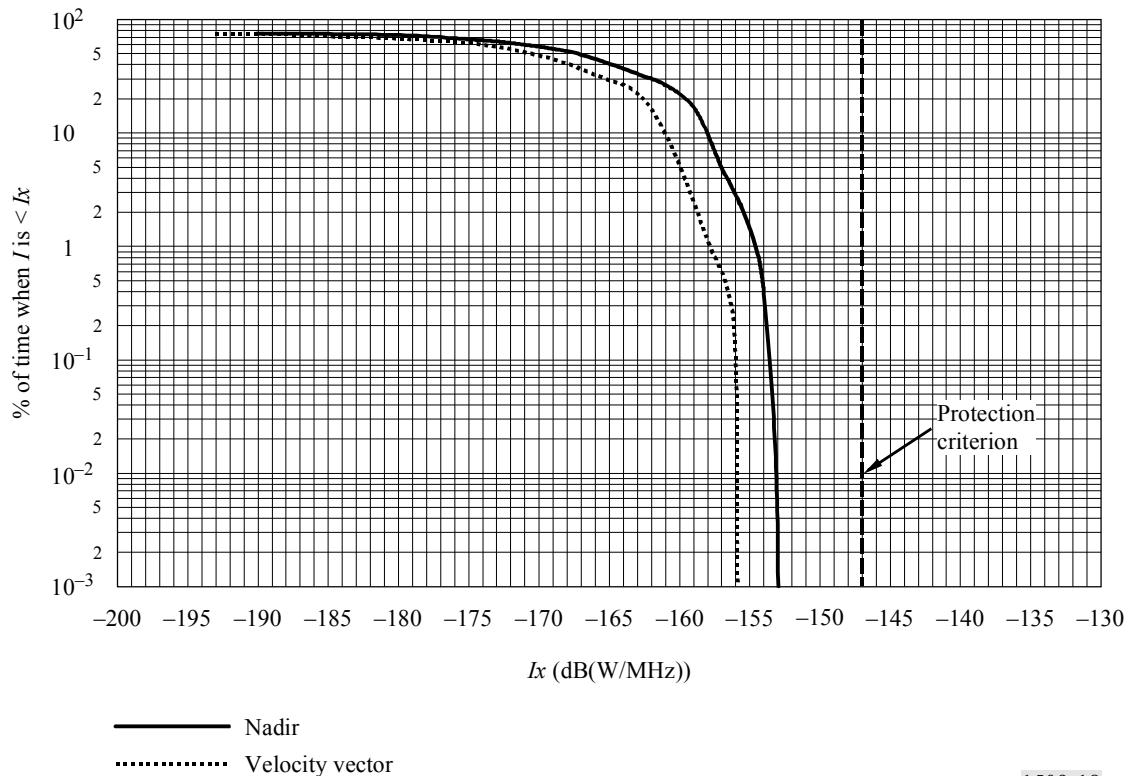POCS over 30 days**

1509-17

FIGURE 18

Cumulative interference into a space shuttle orbiter
POCS over 30 days

1509-18

As shown, the interference level into any of the receiver antennas of the POCS falls well below the protection criteria of –147 dB(W/MHz) at all times.

7   Summary and conclusions of Annex 1

From the results of Study A in § 3 it is predicted that most DRSs positioned at the orbital locations listed in Recommendation ITU-R SA.1276 will receive peak total interference that exceeds the protection level given in Recommendation ITU-R SA.1155 by an average of about 4 dB from a few LMDS deployment areas. This is based on the assumption that the e.i.r.p. spectral density of each hub station is operating at +8 dB(W/MHz) and that the service area of each hub has a radius of 5 km. The peak total interference for all orbital locations was –139 dB(W/MHz).

On a temporal basis the protection level given in Recommendation ITU-R SA.1155 is met for most of the orbits. For the few orbits in which the protection level is exceeded, it is exceeded by slightly more than 0.1% of the orbital period up to about 1% of the orbital period in the worst case for DRS satellites located at 41° W and 174° W. Furthermore, for these locations, the time between orbital periods in which the interference level exceeds –148 dB(W/MHz) ranges from 6.1 h to 71 h. For a DRS located at 85° E, the interference is such that the protection criteria given in Recommendation ITU-R SA.1155 is satisfied for all orbits of satellites in an international space station type orbit.

A reduction factor (see equation (10)) that assumes a constant link margin has been introduced to enable the determination of e.i.r.p. spectral density limits for cell sizes that are smaller than the reference cell size, i.e., 5 km in the case of this study.

As indicated in § 3 and by Figs. 2 to 4, urban population centres with several co-frequency hub stations that appear on or near the Earth's limb are the primary sources of interference to DRS. However, at the expected LMDS P-MP hub station deployment numbers derived using the methodology described in § 3 and operating at an e.i.r.p. spectral density of +8 dB(W/MHz) per hub sector, the protection level is exceeded from only a few geographic areas and sharing is practical.

The results of Study B in § 4 show that under an assumption of e.i.r.p. spectral density of +14 dB(W/MHz) per hub station, which is 6 dB higher than the assumption of Study A, the interference level is also about 6 dB higher than the results of Study A. Therefore, two studies have yielded almost equivalent results.

ANNEX 2

Method for calculating separation angles between hub-station antenna beams and the directions towards geostationary DRS

Annex 2 to Recommendation ITU-R F.1249 provides a method for calculating separation angles between point-to-point FS transmitting antenna beams and the directions towards geostationary DRS located at the positions specified in Note 1 of the main text of this Recommendation, taking into account the effects of atmospheric refraction and the local horizon. A hub station in a P-MP FS network adopts an omni-directional or sectoral antenna. In this case, the antenna gain should be regarded as independent of the azimuthal direction of the DRS. In Annex 2 to Recommendation ITU-R F.1249, ε_r is the elevation angle of the maximum gain (in the elevational plane) of the hub-station antenna (note that $\varepsilon_r = 0°$ if the beam tilting is not adopted and ε_r is negative if the downward beam tilting is adopted).

The elevation angle ε_s of the DRS is given by equations (8a), (8b) and (8c) of Annex 2 to Recommendation ITU-R F.1249. When the DRS is visible, the absolute value of $\varepsilon_s - \varepsilon_r$ is the separation angle between the hub-station antenna beam and the direction towards the DRS location.