RECOMMENDATION ITU-R IS.1141*

SHARING IN THE FREQUENCY BANDS IN THE 1-3 GHz FREQUENCY RANGE BETWEEN THE NON-GEOSTATIONARY SPACE STATIONS OPERATING IN THE MOBILE-SATELLITE SERVICE AND THE FIXED SERVICE

(Question ITU-R 202/2)

(1995)

Coordination threshold criteria for sharing between the mobile-satellite (space-to-Earth) non-GSO systems and the fixed service in the 1-3 GHz frequency band

The ITU Radiocommunication Assembly,

considering

a) that Resolution Nos. 46, 113, 703, and Recommendation No. 717 of the World Administrative Radio Conference for Dealing with Frequency Allocations in Certain Parts of the Spectrum (WARC-92) (Malaga-Torremolinos, 1992) invite the ITU-R (ex-CCIR) to study criteria for sharing and coordination between systems in the mobile-satellite service (MSS) and the fixed and mobile services;

b) that the bands 2 170-2 200 MHz, 2 483.5-2 500 MHz and 2 500-2 535 MHz are allocated to the MSS (space-to-Earth) and fixed service (FS) on a co-primary basis;

c) that the bands 1 492-1 525 MHz, 1 525-1 530 MHz and 2 160-2 170 MHz are allocated to the MSS (space-to-Earth) and FS in some regions or by some administrations, on a co-primary basis;

d) that for certain bands that are subject to the coordination procedure of Resolution No. 46 (WARC-92), WARC-92 adopted and applied the power flux-density (pfd) levels of Radio Regulation (RR) No. 2566 as a coordination threshold for protection of receiving stations in the FS from transmitting space stations in the MSS;

e) that for several decades, systems in the FS have been operated by many administrations in the bands newly allocated to the MSS;

f) that broadcasters in many countries operate ancillary services which have both fixed and mobile characteristics in certain bands shared with the MSS;

g) that the performance of FS systems (analogue point-to-point, digital point-to-point, digital point-to-multipoint including local access systems) need to be considered for sharing in the 1-3 GHz band;

h) that the performance of non-GSO MSS systems need to be considered for sharing in the 1-3 GHz band;

j) that a specific value of pfd produced by different non-GSO MSS satellite constellations gives rise to different values of fractional degradation of performance (FDP) (Recommendation ITU-R F.1108);

k) that multiple non-GSO MSS systems employing CDMA techniques have been proposed to share the frequency spectrum in the space-to-Earth direction, in the 2 483.5-2 500 MHz band, on a co-frequency basis;

l) that analyses performed with the methodology outlined in Recommendation ITU-R F.1108 indicate that it is feasible for non-GSO MSS systems to share the spectrum with analogue radio-relay systems in the 2 483.5-2 500 MHz band (see Annex 1) and 2 160-2 200 MHz band even when using higher pfd values for coordination threshold than those in RR No. 2566;

* This Recommendation applies only for sharing in the space-Earth direction. No Recommendation was produced for Earth-to-space direction.

m) that analyses performed with the methodology outlined in Recommendation ITU-R F.1108 for currently designed digital radio-relay systems indicate that the FDP protection criteria would be exceeded in the 2 483.5-2 500 MHz band where non-GSO MSS systems use pfd values as set forth in RR No. 2566 (see Annex 1);

n) that the presence of interference from ISM and RLAN in the band 2 483.5-2 500 MHz makes this band unattractive in many countries for digital radio-relay systems,

recommends

1 that the following criteria, presented in Table 1, should be used as coordination threshold values between non-GSO MSS (space-to-Earth) and FS systems in the bands listed. Pfd values are provided to designate protection for analogue systems, and FDP values are provided to designate protection for digital systems, except as noted in § 2;

2 that in order to accommodate non-GSO MSS systems in the 2 483.5-2 500 MHz band, new digital point-to-point and point-to-multipoint radio-relay systems may need to be designed and operated to be compatible with the pfd values given in § 1.

TABLE 1

Coordination threshold values for specific bands used for non-GSO MSS (space-to-Earth) and FS systems

Frequency band (MHz)	Power flux-density (pfd) per space station at angle of arrival δ (degrees) (dB(W/(m²·4 kHz)))	Fractional degradation of performance, FDP (%) (1)
1 492-1 525	(2)	25
1 525-1 530	(2)	25
2 160-2 170	–147 for 0° < δ < 5° –147 + 0.5(δ – 5) for 5° < δ < 25° –137 for 25° < δ < 90°	25
2 170-2 200	–147 for 0° < δ < 5° –147 + 0.5(δ – 5) for 5° < δ < 25° –137 for 25° < δ < 90° (3)	25
2 483.5-2 500	–150 for 0° < δ < 5° –150 + 0.65(δ – 5) for 5° < δ < 25° –137 for 25° < δ < 90° (4)	pfd values in the preceding column apply to digital radio-relay systems in this band (4)
2 500-2 535	(2)	25

(1) The method for calculating the FDP for a fixed service network is contained in Recommendation ITU-R F.1108.

(2) The value of pfd to protect analogue systems, per Recommendation ITU-R SF.357, is to be determined for this band for each non-GSO MSS satellite constellation proposed. Until such time as the new values are available, the pfd values given in RR No. 2566 will apply.

(3) The pfd values specified for the 2 160-2 200 MHz band provide full protection for analogue radio-relay systems using the sharing criteria established by Recommendation ITU-R F.357, for operation with a non-GSO MSS system employing narrow-band TDMA/FDMA techniques.

(4) The pfd values specified for the 2 483.5-2 500 MHz band provide full protection for analogue radio-relay systems using the sharing criteria established by Recommendation ITU-R F.357, for operation with multiple non-GSO MSS systems employing CDMA techniques (see Annex 1). The pfd values specified will not provide full protection for existing digital fixed systems in all cases. However, these pfd values are considered to provide adequate protection for digital fixed systems designed to operate in this band, where high power ISM and possible low power applications are expected to produce a relatively high interference environment.

ANNEX 1

Sharing methodology and interference criteria used for the determination of coordination threshold criteria

1 Description of methodology

The methodology for determining the coordination threshold between non-GSO MSS downlinks and the FS is based on Recommendation ITU-R F.1108. This Recommendation provides:

– a method to determine the visibility statistics of non-GSO satellites as seen by terrestrial stations. The method takes into account the orbital parameters of the non-GSO system, the motion of the Earth and the relevant geometrical factors. It is a sufficiently complex method that a computer program is required to determine the visibility statistics;

– a method of relating the interference to a FDP for digital FS networks;

– a method of relating the interference to a degradation in performance for analogue FS networks.

For the digital FS case, the interference objective is a degradation to the availability objective (increase in outage) and it is a single value (e.g. 10%).

For the analogue FS case, a two point interference objective mask, consisting of a long-term and a short-term interference objective, is used.

1.1 Simulation methodology

A computer program was used to simulate the interference into the FS network from the non-GSO satellite constellation(s) operating in the 2 483.5-2 500 MHz band. The program calculates the satellite orbital positions at each time instance and the aggregate interference from all satellites visible to the FS station(s) is determined using the following equation:

$$I = \sum_{i=1}^{N} \sum_{j=1}^{M} \rho(\delta_{ij}) \; A_{iso} \; G(\theta_{ij}) \tag{1}$$

where:

i : 1 of N visible satellites

j : 1 of M stations on a route

$\rho(\delta_{ij})$: power flux-density received at station j from the i^{th} satellite

δ_{ij} : elevation angle from station j to the i^{th} satellite

A_{iso} : area of an isotropic antenna

= $\lambda^2/4\pi$

$G(\theta_{ij})$: j^{th} station's antenna gain in the direction of the i^{th} satellite

θ_{ij} : angle between the j^{th} station's antenna pointing vector and the range vector from the j^{th} station and the i^{th} satellite.

The pfd incident on the station's receiving antenna as a function of the elevation angle can be assumed to be of the form:

$$\rho(\delta) = \begin{cases} \rho(5) & \text{for } 0° \le \delta < 5° \quad (2a) \\ \dfrac{\rho(25) - \rho(5)}{20}(\delta - 5) + \rho(5) & \text{for } 5° \le \delta < 25° \quad (2b) \\ \rho(25) & \text{for } 25° \le \delta < 90° \quad (2c) \end{cases}$$

where:

δ: elevation angle (degrees)

ρ: pfd (dB(W/(m^2))) in a reference bandwidth

$\rho(5)$: pfd value at $\delta \le 5°$

$\rho(25)$: pfd value at $\delta \ge 25°$.

Alternatively, satellite beam parameters can be assumed and the associated pfd values at various angles of arrival can be derived.

The point-to-point FS station antenna gain conforms to the antenna pattern having averaged side-lobe levels as defined in Note 6 of Recommendation ITU-R F.699. A suitable antenna radiation pattern for point-to-multipoint systems can also be used.

1.2 Analogue FS systems

It was assumed that there are 51 analogue stations on a route centred at a given latitude. The routes span a distance of 2 500 km with stations spaced exactly 50 km apart. The azimuth angle for each station is specified by a given trendline angle and a variable angle that is uniformly distributed between ±12.5°. The analysis considers trendline angles that vary between 10° and 170° in 20° steps. Each station is assumed to use a high gain antenna pointed at the next station at an elevation angle of 0°.

The program calculates the interference statistics based on the aggregate interference noise power calculated at each sample point. The interference statistics show the probability that the aggregate received interference noise power exceeds a given interference level. The interference interval is then mapped to the interference noise power in a 4 kHz telephony channel by:

$$N_{ch} = \frac{N_T}{k\,T\,B}\,I \quad (3)$$

where:

N_T: thermal noise power introduced in a 4 kHz telephony channel at a station = 25 pW psophometrically weighted at a point of zero relative level (pW0p)

k: Boltzmann's constant

T: station receiving system noise temperature

B: reference bandwidth = 4 kHz

I: aggregate received interference noise power in the reference bandwidth.

1.3 Digital FS system

Only one digital FS receiver is required for the analysis as opposed to a complete route. The FS station is positioned at a certain latitude and its pointing azimuth is varied between 0° and 180°, each station is assumed to use a high gain antenna at an elevation angle of 0°.

At each time instance the program calculates the aggregate interference received at the FS station.

It then calculates the fractional degradation in performance FDP for the digital station as:

$$FDP = \sum_{I_i = min}^{max} \frac{I_i \ f_i}{N_T} \qquad (4)$$

where:

I_i: interference noise power level

f_i: fractional period of time that the interference power equals I_i

N_T: station receiving system noise power level = $k\ T\ B$

k: Boltzmann's constant

T: station receiving system effective noise temperature

B: reference bandwidth = 1 MHz.

The fade margin loss (FML) is given by:

$$FML = 10 \log (1 + FDP) \qquad \text{dB}$$

A 10% fractional degradation in performance equates to about a 0.4 dB loss in fade margin, 25% FDP equates to about 1 dB loss in fade margin, while a 100% fractional degradation in performance corresponds to a 3 dB loss in fade margin.

1.4 Multiple non-GSO constellations

1.4.1 Analogue FS systems

When analysing the impact on the FS from multiple non-GSO constellations, the computer program generates the discrete probability density function of the interference noise power into an FS channel for each non-GSO MSS system. If the interference intervals are small enough, the discrete probability density function (pdf) will closely approximate the continuous pdf for interference to line-of-sight radio-relay systems from a particular type non-GSO MSS system. Specifically, the pdf of the interference power I_j from the j^{th} non-GSO MSS system may be written as:

$$p_j(I_j) \qquad (5)$$

The next step is to obtain the pdf of the interference noise power for two or more non-GSO MSS systems. The pdf of the sum of two uncorrelated random variables may be obtained as the convolution of the individual pdfs. In general, if:

$$z = x + y \qquad (6)$$

where x and y are uncorrelated random variables, and the pdfs of x and y are given by $p_x(x)$ and $p_y(y)$, then the pdf of z is given by the convolution integral:

$$p_z(z) = \int_{-\infty}^{\infty} p_x(z - y) \ p_y(y) \ \mathrm{d}y \qquad (7)$$

The key assumption associated with the convolution integral is that the random variables x and y are uncorrelated. It is asserted that this is the case for non-GSO MSS systems because of the differences in the orbital parameters of the different systems although this should be confirmed. Thus, the convolution integral may be used to obtain the pdf of the total interference $p(I)$ to line-of-sight radio-relay systems caused by two non-GSO MSS systems j and k:

$$p(I) = \int_{-\infty}^{\infty} p_j(I - I_k)\ p_k(I_k)\ \mathrm{d}I_k \tag{8}$$

Equation (8) may be used iteratively (the n-fold convolution) to obtain the pdf of the total interference for n independent non-GSO MSS systems.

The cdf is obtained from:

$$P(I > x) = \int_{x}^{\infty} p(I)\ \mathrm{d}I = \sum_{x}^{\infty} p(I) \tag{9}$$

where:

$P(I > x)$: cdf of the interference power in the telephony channel

$p(I)$: either the discrete or continuous pdf.

1.4.2 Digital systems

The calculation of the fractional degradation in performance described in § 1.3 is equal to the first moment of the interference power normalized to the noise at the receiver input in the reference bandwidth. Thus, the FDP due to interference from several independent constellations is the sum of the degradations produced by each.

Two types of antennas are used for the digital systems: relatively high gain circularly symmetric type antennas; and, low to moderate gain antennas with constant gain in the azimuth plane and directional pattern in the elevation plane. All digital line-of-sight radio-relay systems and local-access systems using sector antennas are assumed to use antennas that are circularly symmetric. The radiation pattern of this type of antenna is assumed to conform to the antenna pattern having averaged side-lobe levels as defined in Note 6 of Recommendation ITU-R F.699.

2 Results

Several computer simulations using a common methodology have been performed to determine pfd values which ensure the relevant FS interference objectives are met. This section contains the results of those simulations.

Analogue FS systems

Values of pfd to protect 2 500 km analogue radio-relay routes centred at 15°, 40° and 60° latitude from the emissions of non-GSO MSS systems were evaluated. Values were determined by assuming combinations of three non-GSO MSS constellations selected from four representative systems.

The analyses used a base pfd value of –150 dB(W/(m^2 · 4 kHz)) for elevation angles less than 5°, linearly increasing to –137 dB(W/(m^2 · 4 kHz)) at 25° and remaining at that level for elevation angles up to 90°. It was shown that, except for one or two route trend lines centred in the higher latitudes, the –150/–137 dB(W/(m^2 · 4 kHz)) template provided protection to analogue radio-relay systems consistent with the values contained in Recommendation ITU-R F.357.

It was assumed that the four non-GSO systems used CDMA techniques and that they were all designed such that they could share on a co-frequency, co-coverage basis.

Digital FS systems

For multiple non-GSO MSS systems interfering, with a digital point-to-point station employing a high-gain receiving antenna, it was shown that the pfd template needed to realize an average FDP on the order of 10% with peaks not much greater than 15% to 20% was –162 dB(W/(m^2 · 4 kHz)) in the 0-5° range of elevation angle, linearly escalating to

–149 dB(W/(m^2 · 4 kHz)) at 25° elevation angle and remaining at that value up to 90° of elevation angle. At values of pfd sufficient to protect the operation of analogue point-to-point radio-relay systems, i.e., –150 dB(W/(m^2 · 4 kHz)) escalating to –137 dB(W/(m^2 · 4 kHz)), digital point-to-point radio-relay stations would experience an average FDP on the order of 160%, with peaks to 240% and 320% and troughs as low as 80% depending on the latitude of the station. An FDP of 160% is equivalent to a decrease in fade margin of about 4 dB.

2.1 Trends

Several trends arising from the results can be observed.

The received interference can vary rapidly with the FS pointing azimuth for some non-GSO constellations. Constellations with polar or near polar orbits also impact various FS pointing azimuths differently, but the effect is much less pronounced.

FS stations at higher latitudes generally experience more interference over time than FS stations located at lower latitudes. This is more true for constellations with polar orbits, however actual operational requirements may include turning off outer beams due to coverage overlap and hence the interference effect will be reduced.

Satellite constellations operating at lower altitudes require different pfd masks to protect the FS than those constellations operating at higher altitudes.

As a first order estimate, the levels of interference over time decrease inversely with the square of the operating frequency.

2.2 Conclusions

The selection of a single pfd mask which ensures protection of the FS and which does not simultaneously penalize other non-GSO constellations, is difficult. Selection of a particular pfd mask based on one constellation can result in inadequate protection to the FS, as another constellation which could meet those pfd levels could still exceed the FS interference objectives. In other words, two different non-GSO constellations can operate with different pfd masks which both protect the FS equally. The above does not hold true for a pfd mask derived from several non-GSO constellations which have been designed to share on a co-frequency, co-coverage basis and which use CDMA techniques.

The pfd required to protect 2 500 km hypothetical reference circuit (HRC) analogue FS systems from the simultaneous emissions of three non-GSO MSS constellations was found to be –150 dB(W/(m^2 · 4 kHz)) at elevation angles between 0° and 5°, linearly escalating to –137 dB(W/(m^2 · 4 kHz)) at an elevation angle of 25°. The pfd remained constant at this value for elevation angles above 25°. Interference to the HRC was consistent with the values given in Recommendation ITU-R SF.357.

The pfd required to ensure that the fractional degradation of performance (FDP) as defined in Recommendation ITU-R F.1108, of digital FS systems, did not exceed about 10% was found to be some 9 dB to 10 dB more stringent than the values of pfd required to protect the performance of analogue FS systems. These lower values, if adopted, will inhibit the introduction of viable non-GSO MSS systems.

It was concluded that sharing with these systems would be most readily accomplished by establishing pfd values that, while resulting in an FDP in excess of the value given in Recommendation ITU-R F.1108, would not unduly penalize the design and operation of either FS or non-GSO MSS systems in the 2 483.5-2 500 MHz band.

ANNEX 2

Sharing of frequency bands in the 1-3 GHz range between transmitting stations in the fixed service and non-geostationary space stations operating in the mobile-satellite (Earth-to-space) service

1 Introduction

Studies were required for the sharing scenario between transmitting stations in the FS and non-GSO MSS space station receivers in the MSS Earth-to-space frequency bands between 1-3 GHz, i.e. 1 610-1 626.5 MHz, 1 675-1 710 MHz, 1 970-2 010 MHz and 2 655-2 690 MHz. However, the sharing studies were limited to the 1 610-1 626.5 MHz and 1 970-2 010 MHz bands, since these bands are of immediate interest for the implementation of non-GSO MSS systems. No inputs were received for the other bands. A study on the specific sharing scenario of FS troposcatter links with non-GSO systems was also considered. In addition to the sharing studies, the possible regulatory options for FS systems are discussed.

Sharing studies have shown that co-channel operation of the transmitting stations of the new FS and receivers of non-GSO MSS space stations in the 1 980-2 010 MHz band would not in general be possible.

Sharing studies in the band 1 610-1 626.5 MHz band (see RR No. 730) found that the loss of traffic capacity may be acceptable in the case of very low FS density (e.g. one in 230 000 km^2).

One option to improve the sharing conditions would be to reduce considerably the permissible e.i.r.p. limits in RR Article 27 for FS transmitters. Any such limits are highly dependent on the assumptions regarding new FS transmitter density and would be based on the assumption of a high FS density. This would lead to extremely stringent limits on new FS stations which may not be practical for their operation.

In view of the above, no Recommendation to facilitate sharing from a technical viewpoint was developed. The present Annex discusses difficulties in sharing.

2 Simulation of interference from FS links into MSS satellite receiver

2.1 Point-to-point FS links

Studies on the interference from typical multiple FS transmitters (circa 6 000 worldwide) into non-GSO/MSS (medium-Earth orbit) space stations receivers in the band 1 980-2 010 MHz found that unacceptable interference to non-GSO/MSS space station receivers would occur. The assumed target equivalent interference C/I criterion was not met for close to 100% of the time. Based on this study, it can be concluded that co-channel sharing of MSS uplinks to non-GSO MSS satellites in frequency band segments in the 1 980-2 010 MHz band which are or remain heavily used by the FS would not be possible. It is noted that a preliminary assessment based on interpolations of actual FS utilisation data in a number of countries has indicated that the number of point to point FS transmitters could be greater than that assumed in the above study and would only further increase the level of interference.

Further studies on the interference from typical multiple FS transmitters (between 700 and 3 000 worldwide) into non-GSO/MSS (low-Earth orbit) space stations receivers in the band 1 610-1 626.5 MHz found that the loss of traffic capacity may be acceptable only in the case of very low FS density (e.g. one in 230 000 km^2).

2.2 Troposcatter FS links

In the case of sharing between FS troposcatter systems and the non-GSO MSS (medium-Earth orbit) system, a study considered showed that co-channel sharing would not be feasible. In the main beam of a troposcatter transmitter operating at its maximum output power, the MSS satellite receiver could experience interference levels of up to 60 dB higher than is tolerable. In the side lobe region tolerable interference levels are still exceeded. Thus it would be necessary to phase out these systems if the non-GSO MSS is to be implemented in portions of the bands where troposcatter systems operate.

2.3 Point-to-multipoint FS links

Certain point-to-multipoint FS systems operate with lower e.i.r.p. than point-to-point FS systems, although in general non-directive antennas are used. The potential for a given number of point-to-multipoint FS systems to cause interference to non-GSO MSS satellites receivers may be significantly less than that caused by the same number of FS point-to-point FS stations. However the aggregate interference at the non-GSO satellite from a large number of point-to-multipoint FS systems could conceivably cause a similarly high level of interference as a smaller number of conventional point-to-point FS systems. Further studies are needed.

3 Conclusions

3.1 Co-channel operation of the transmitting stations of the FS in the band 1 980-2 010 MHz will cause unacceptable interference to the non-GSO MSS space station receivers.

3.2 For systems in FS in the band 1 610-1 626.5 MHz (RR No. 730), loss of traffic capacity for a non-GSO MSS system may be acceptable only in the case of very low FS density (e.g. one in 230 000 km^2).

3.3 In view of the sharing difficulties noted above, no Recommendations to facilitate sharing from a technical viewpoint were developed.