

RECOMMENDATION ITU-R F.1403

**POWER FLUX-DENSITY CRITERIA IN ITU-R RECOMMENDATIONS FOR
PROTECTION OF SYSTEMS IN THE FIXED SERVICE SHARED
WITH SPACE STATIONS OF VARIOUS SPACE SERVICES**

(Questions ITU-R 111/9, ITU-R 113/9, ITU-R 115/9, ITU-R 116/9, ITU-R 118/9 and ITU-R 201/9)

(1999)

The ITU Radiocommunication Assembly,

considering

- a) that the fixed service (FS) shares many frequency bands on a co-primary basis with space radiocommunication services such as the fixed-satellite, broadcasting-satellite, mobile-satellite and space science services;
- b) that criteria for the power flux-density (pfd) at the surface of the Earth produced by space stations of space services have been developed in order to control the interference into systems in the FS in the frequency bands shared with the space-to-Earth direction of these space services;
- c) that these criteria are mainly expressed as hard limits on pfd produced by space stations but when it is not practicable, as coordination thresholds;
- d) that in some cases of interference assessment from non-geostationary (non-GSO) satellites into digital systems in the FS in the 1-3 GHz range, coordination thresholds have been expressed in terms of fractional degradation in performance (FDP);
- e) that various pfd criteria have been established since 1963 when certain frequency bands were allocated for the first time on a shared basis to the FS and the fixed-satellite service (FSS);
- f) that a number of methodologies for interference assessment have been developed in order to derive appropriate pfd criteria;
- g) that it is important to review the principles and advice which were incorporated in these methodologies,

recommends

- 1 that Recommendations ITU-R SF.358, ITU-R SF.1005 and ITU-R SF.1008 should be referred to for the pfd limits on space stations (mainly GSO) in the FSS;
- 2 that Recommendation ITU-R SF.1320 should be referred to for the pfd limits on non-GSO space stations in the FSS used for feeder links of systems in the mobile-satellite service (MSS);
- 3 that Recommendation ITU-R SA.1273 should be referred to for pfd limits on space stations in space science services in the 2 GHz bands;
- 4 that Recommendations ITU-R M.1141, ITU-R M.1142, ITU-R M.1143 and ITU-R F.1246 should be referred to for coordination thresholds for frequency assignments to GSO and non-GSO space stations in the MSS in the 1-3 GHz frequency range;
- 5 that Recommendation ITU-R F.1338 should be referred to for coordination thresholds for frequency assignments to space stations in the broadcasting-satellite service (BSS) (sound) in the band 1 452-1 492 MHz;
- 6 that Recommendations ITU-R F.1107 and ITU-R F.1108 should be referred to for the methodology for assessment of interference from GSO and non-GSO space stations into systems in the FS;
- 7 that Annex 1 should be referred to for the historical evolution of pfd criteria in ITU-R Recommendations for protection of systems in the FS shared with space stations of various space services, which might be used as guidance for future studies on pfd criteria in various sharing situations.

Historical evolution of pfd criteria in ITU-R Recommendations for protection of systems in the FS

1 Introduction

Power flux-density at the Earth's surface produced by space stations is an important factor for consideration in order to protect systems in the FS from emissions of space stations sharing the same frequency bands. Numerous ITU-R Recommendations have been established since 1963 dealing with this matter.

Some Recommendations give hard limits on pfd. This facilitates frequency sharing, because individual coordination is not required. But in some cases, it is difficult to establish hard limits, because no such limits can be found which adequately protect the FS and, at the same time, do not place undue constraints on system design of space services. In such cases, Recommendations present coordination thresholds and, if the pfd exceeds the coordination threshold, individual coordination is required with the affected administrations.

In addition to the pfd, a concept of FDP was introduced in Recommendation ITU-R F.1108 in order to assess the effects of interference from non-GSO satellites into the FS.

This Annex presents a historical evolution of pfd criteria adopted in various ITU-R Recommendations, many of which have been incorporated into the Radio Regulations (RR).

2 Power flux-density limits on FSS space stations

Power flux-density limits on space stations in the FSS are recommended in Recommendation ITU-R SF.358. It was in 1963 that the first version of this Recommendation was developed. It took more than twenty years before this Recommendation was almost finalized. It is applicable to both GSO and non-GSO space stations. However, it should be noted that only a limited number of non-GSO space stations were assumed in confirming the applicability of this Recommendation. Therefore, Recommendation ITU-R SF.358 should be regarded as applicable mainly to GSO space stations and, if a large number of non-GSO space stations are involved, a separate consideration is necessary (see, for example, Recommendation ITU-R SF.1320).

A detailed history about Recommendation ITU-R SF. 358 is given in Appendix 1 to Annex 1.

3 FSS in bidirectional band usage and use by FSS space stations of orbits slightly inclined with respect to the GSO

The coexistence of the FS with the FSS was planned by the 1963 Extraordinary Administrative Radio Conference (1963 EARC) for unidirectional FSS transmissions and for GSO space stations. As a result, the permissible interference from the FSS was nearly invariant with time, except for propagation anomalies, and was generated from transmitting space stations or from transmitting earth stations.

However, in order to increase the capacity of the FSS and to increase the longevity of the space segment, the use of bidirectional transmission was considered for additional frequencies, and the use of slightly inclined orbits was also studied to save fuel and increase the useful life of the space stations.

The benefits to the FSS of additional frequencies through the use of bidirectional transmission comes at the expense of more interference sources for both the FS and the FSS, and the use of slightly inclined orbits comes at the risk of increasing the number of fixed receivers exposed to near direct interference from transmitting space stations.

3.1 Recommendation ITU-R SF.1005 (Geneva, 1993)

The sharing criteria that were established by the 1963 EARC assumed that the aggregate permissible interference into the model hypothetical reference circuit was small in comparison to the total noise of the system, and in fact, it could be accommodated within the total noise budget of existing systems without making any changes to systems already deployed throughout the world. Specifically, the permissible interference into fixed receivers from transmitting space stations could effectively be limited by controlling the pfd at the surface of the Earth, and the interference from transmitting earth stations could be controlled by limiting the e.i.r.p. at the horizon. The limits on the pfd and the e.i.r.p. could satisfy the assumption of small permissible interference, but allow the effective development of the FSS for the benefit of satellite technology throughout the world.

The use of bidirectional transmission by the FSS increases the interference sources; as a result, the assumption that the permissible interference from the FSS should be small could not be maintained without additional restrictions on the FSS. The additional restrictions, that were developed in Recommendation ITU-R SF.1005 – Sharing between the fixed service and the fixed-satellite service with bidirectional usage in bands above 10 GHz currently unidirectionally allocated (which is based on ex-CCIR Report 1005 developed in 1986), were that bidirectional operation would be limited for frequencies above 10 GHz; the pfd for angles of arrival within 5° above the horizon and the interference from transmitting earth stations should be lowered by 7 dB, 5 dB, and 3 dB for frequency bands, 10-15.4 GHz, 15.4-20 GHz, and above 20 GHz respectively; and for angles of arrival above 25° the pfd limits of Table 1 of Recommendation ITU-R SF.358 should continue to apply.

The application of bidirectional usage can be introduced with less interference impact on the FS provided that the FSS uses transmitting earth stations with high elevation angles (>40°), spot beams of approximately 2°, and does not extensively use the GSO.

3.2 Recommendation ITU-R SF.1008 (Geneva, 1994)

The coexistence of the FSS and the FS has taken place successfully for the last three decades mostly for space stations located in their nominal GSO locations. The probability that a FS receiver will intersect the GSO is low, and the probability that a transmitting space station will be located at that orbital location is significantly lower. As a result, the aggregate interference that the model radio-relay system is expected to receive is mostly from a single near, direct exposure and side-lobe interference from the rest of the visible space stations in the GSO.

However, in order to keep the space stations in their nominal orbital positions fuel needs to be expanded, and particularly, significant fuel needs to be used for north-south station-keeping. In fact, the lifetime of the space segment may be determined by the availability of fuel. If the north-south station-keeping was to be relaxed, the longevity of space stations can be extended, but the resulting inclination of the orbit would result in more terrestrial receivers exposed to near direct interference even though the duration of the exposure would be a fraction of the 24 h period, and the total average interference of the model hypothetical reference circuit may not increase.

The portion of the 24 h period during which the terrestrial receiver is exposed to main lobe interference will result in significant decrease in the thermal noise fade margin, and during these periods the receiver will be susceptible to slowly varying, non-dispersive, shallow fades. These fades can occur sufficiently frequently to make the affected receiver unavailable for an unacceptable amount of time. Recommendation ITU-R SF.615 provides the objectives for network unavailabilities from all sources of interference, and the contribution of the expected unavailability from even a few exposed receivers will exceed the aforementioned objectives by an order of magnitude. As a result, the receivers susceptible to main-lobe interference will have to be relocated in order to preserve the performance of the system.

Recommendation ITU-R SF.1008 – Possible use by space stations in the FSS of orbits slightly inclined with respect to the GSO in bands shared with the fixed service, limits the amount of inclination to less than 5° without imposing any additional restrictions on the FSS. The slight inclination of the orbit limits the additional terrestrial receivers that are exposed to main-lobe interference, and even though the number of affected stations increases with latitude, the number of susceptible receivers for latitudes as high as 60° is less than a few for a 50-hop system. However, for inclinations greater than 5°, the number of affected stations increases linearly, and a back-off on the pfd is recommended which increases linearly between five and ten degrees inclination, and reaches a maximum of 20 dB back-off at an inclination of 10°.

Finally, the inclination of the orbit may be designed at the planning stage of the satellite, and a satellite may be injected into an inclined orbit such that the lifetime of the satellite is maximized while minimizing the amount of the inclination, and thus, the impact on the FS and the need for tracking is reduced.

4 Power flux-density limits on BSS space stations in the 12 GHz band

The 1977 World Broadcasting-Satellite Administrative Radio Conference (WARC SAT-77) established the Regions 1 and 3 Plan for the BSS in the bands 11.7-12.2 GHz (in Region 3) and 11.7-12.5 GHz (in Region 1). The 1983 Regional Administrative Radio Conference (RARC-83) established the Region 2 Plan for the BSS in the band 12.2-12.7 GHz. Various parameters of BSS space stations were stipulated in the Plan. These frequency bands are shared with the FS. Therefore, it is necessary in the planning of FS systems to take due account of the BSS Plan and not to cause any harmful interference to BSS receiving earth stations.

When any change is made to the BSS Plan, there is a risk that a BSS space station in a new orbital location or at a new frequency assignment may cause unacceptable interference to existing FS systems. For this purpose, Annex 1 to RR Appendix S30 stipulates limits on the pfd to protect the terrestrial services in all three Regions.

5 New allocations to various space radiocommunication services by WARC-92

The World Administrative Radio Conference (WARC-92) was held in 1992 in Malaga-Torremolinos for dealing with frequency allocations in certain parts of the spectrum. This Conference allocated many frequency bands to various space radiocommunication services on a shared basis with the FS. It made the frequency sharing situations very much complicated and invited the ITU-R to carry out urgent studies to establish appropriate sharing criteria.

5.1 Allocation to BSS for HDTV near 20 GHz

WARC-92 allocated the band 21.4-22 GHz to the BSS in Regions 1 and 3 on a shared basis with the FS and the band 17.3-17.8 GHz to the BSS in Region 2, out of which the band 17.7-17.8 GHz is shared with the FS. These allocations to the BSS shall come into effect on 1 April 2007 (see RR Nos. S5.517 and S5.530).

Resolution 525 (WARC-92) specifies the conditions for the use of the band 21.4- 22 GHz in Regions 1 and 3 by the BSS after that date and on an interim basis prior to that date. This Resolution gives the values of pfd at the Earth's surface produced by emissions from a space station of an operational BSS (HDTV) system before 1 April 2007, as coordination thresholds. These values are identical to the values which were given in Recommendation ITU-R F.760 that had been developed by Radiocommunication Study Group 9 just prior to the WARC-92.

Recommendation ITU-R F.760 examines the in-beam interference at low angles of arrival and off-beam interference at high angles of arrival to a 64-QAM FS receiver. After considering correlation of rain fading between wanted and interfering signals, the Recommendation arrives at the proposed pfd values. This was the first case in which the values in an ITU-R Recommendation were incorporated into a Resolution attached to the RR as coordination thresholds.

5.2 Allocation to BSS (sound) in the 1-3 GHz range

WARC-92 allocated the band 1 452-1 492 MHz to the BSS (sound) on a worldwide basis (except for one administration, see RR No. S5.344). In addition, the bands 2 310-2 360 MHz and 2 535-2 655 MHz were also allocated to the BSS (sound) for use in certain countries (see RR Nos. S5.393 and S5.418). These bands are shared with the FS.

WARC-92 did not adopt any coordination thresholds for pfd values produced by BSS (sound) space stations to be used in coordination with the FS. Resolution 522 (WARC-92) invited the ITU-R to study the appropriate sharing criteria between BSS (sound) systems and the systems of other services sharing the bands.

5.3 Allocation to MSS in the 1-3 GHz range

WARC-92 allocated a number of frequency bands in the 1-3 GHz range to the MSS (Earth-to-space and space-to-Earth) on a shared basis with the FS. WARC-92 considered what pfd values are appropriate in the bands allocated to the MSS (space-to-Earth) in order to protect the FS. It was recognized that it was not possible to find an appropriate pfd limit that will adequately protect the FS and, at the same time, will not cause undue constraint on the design of MSS systems. Therefore, WARC-92 decided to establish coordination thresholds instead of pfd limits.

In the absence of any ITU-R Recommendation on this issue, WARC-92 was faced with the difficulty of arriving at appropriate coordination thresholds. After long debates, WARC-92 reached a provisional conclusion that in the bands allocated to the MSS (space-to-Earth), coordination of MSS space stations with respect to terrestrial services is required only if the pfd produced at the Earth's surface exceeds limits in RR No. 2566 (edition of 1994). Here, RR No. 2566 means the pfd limits on FSS space stations in the band 3-8 GHz (-152 dB(W/m²) and -142 dB(W/m²)) in a 4 kHz band for low and high arrival angles, respectively).

At the same time, Recommendation 717 (WARC-92) invited the ITU-R to carry out further studies on frequency sharing criteria between the MSS and the FS and other terrestrial services.

5.4 Allocation to space science services

Before WARC-92, the bands 2 025-2 110 MHz and 2 200-2 290 MHz had been allocated to the space science services by a footnote to the Frequency Allocation Table in the RR. The allocation was subject to agreement being reached using the procedure given in RR Article 14 (edition of 1994). WARC-92 removed the Article 14 requirement and changed this footnote allocation to a primary allocation in the Table of Allocations. In the revised allocation table, the band 2 025-2 110 MHz is allocated to space operation, Earth exploration-satellite and space research services (Earth-to-space and space-to-space) and the band 2 200-2 290 MHz is allocated to space operation, Earth exploration-satellite and space research services (for space-to-Earth and space-to-space). Both bands are shared with the FS.

WARC-92 allocated additional bands to space science services. They included the band 25.25-27.5 GHz allocated to the inter-satellite service shared with the FS.

WARC-92 retained pre-WARC-92 pfd limits on space stations in the bands 2 025-2 110 MHz and 2 200-2 290 MHz to protect the FS (-154 dB(W/m²) and -144 dB(W/m²) in a 4 kHz band for low and high arrival angles, respectively). For the band 25.25-27.5 GHz, the same pfd limit as that on FSS space stations in the band 17.7-19.7 GHz (-115 dB(W/m²) and -105 dB(W/m²) in a 1 MHz band for low and high arrival angles, respectively) was applied.

6 Methodology for interference assessment

Various new frequency allocations to space services decided by WARC-92 made it necessary to establish sharing criteria to protect FS stations from emissions of space stations sharing the same frequency bands. Recommendations ITU-R F.1107 and ITU-R F.1108 were developed in order to present the methodology for assessment of interference into the FS from geostationary and non-geostationary space stations, respectively.

6.1 Recommendation ITU-R F.1107 (Geneva, 1994)

Recommendation ITU-R F.1107 presents geometric considerations and methods of calculating the total interference power received at FS receivers caused by geostationary space stations. The methodology is based on the approach adopted for many years for developing Recommendation ITU-R SF.358 which had established pfd limits on FSS space stations.

A number of satellites are assumed to be operating at the GSO with uniform spacing. They are assumed to produce the maximum pfd at the surface of the Earth allowed by an assumed pfd mask. The aggregate interference is evaluated through computer simulations using Monte Carlo methods for generating representative service implementations. The FS network is assumed to be composed of 50 hop routes randomly distributed over an approximately 65° by 22.5° longitude by latitude surface. All receivers have the same noise temperature, antenna characteristics and spacing.

Calculations over many FS routes result in an interference distribution. In the case of interference into analogue FS systems, the aggregate interference should not exceed 1 000 pW except for a small percentage (generally 10%). A computer program is attached to this Recommendation.

6.2 Recommendation ITU-R F.1108-2 (Geneva, 1994)

Recommendation ITU-R F.1108-2 gives a method for determining the criteria to protect FS receivers from the emissions of space stations operating in non-GSO orbits in shared frequency bands. Geometric considerations are given for non-GSO satellites employing circular orbits. Satellite orbit parameters are orbit altitude, number of satellite orbital planes, longitude of ascending node for each plane, orbit inclination and number of satellites per plane. Interference into FS routes are assessed by computer simulations using Monte Carlo methods.

In the case of simulation of interference into analogue FS routes, the FS system model is 50 hops, 2 500 km routes, with hop directions being selected by Monte Carlo methods. Recommendation ITU-R SF.357 is used as a short- and long-term limit of interference that is allowed into an analogue FS system.

A new concept, called FDP, was introduced in order to assess interference from non-GSO space stations into digital FS systems. The FDP is an average of interference-to-thermal noise ratio, where summation is taken over all interference events. The Recommendation establishes the equivalence of this average with the FDP of digital systems in cases where the performance is dominated by multipath fading. For determining the effect of interference on digital receivers employing diversity, a different formula was introduced for evaluating FDP. This formula was first introduced in the process of developing Recommendation ITU-R SF.1320 dealing with pfd limits on space stations in non-GSO MSS feeder link networks. The formula was later incorporated into Annex 4 to Recommendation ITU-R F.1108-2.

7 Coordination thresholds for MSS in the 1-3 GHz frequency range

Frequency sharing between MSS and FS in the 1-3 GHz frequency range was studied by Study Group 2 (Task Group 2/2) during 1992 and 1995. It resulted in the establishment of Recommendations ITU-R IS.1141, ITU-R IS.1142 and ITU-R IS.1143, approved in 1995. After Study Group 2 was disbanded in 1995, a joint rapporteur group of Radiocommunication Study Groups 8 and 9 continued the study, which resulted in the revised Recommendations ITU-R M.1141, ITU-R M.1142 and ITU-R M.1143 and the new Recommendation ITU-R F.1246 in 1997.

7.1 Recommendation ITU-R M.1141

The methodology of Recommendation ITU-R F.1108-2 was applied to the assessment of interference from non-GSO MSS space stations to FS systems in various frequency bands in the 1-3 GHz range. As a result, the coordination thresholds provisionally adopted by the WARC-92 were confirmed as applicable to certain frequency bands with respect to sharing with analogue FS systems. Somewhat higher coordination thresholds were adopted for other frequency bands.

On the other hand, FDP of 25% was mainly adopted as coordination thresholds with respect to sharing with digital FS systems.

Several trends arising from the analysis were observed as follows:

- the average received interference can be strongly dependent on the FS pointing azimuth for some non-GSO constellations. For constellations with polar or near polar orbits, the effect of FS pointing azimuths 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 significant for constellations with polar orbits, however actual operational requirements may include reducing satellite emissions due to coverage overlap and hence the interference effect will be reduced.