RECOMMENDATION ITU-R RA.1513-1

Levels of data loss to radio astronomy observations and percentage-of-time criteria resulting from degradation by interference for frequency bands allocated to the radio astronomy on a primary basis

(Question ITU-R 227/7)

(2001-2003)

The ITU Radiocommunication Assembly,

considering

a) that research in radio astronomy depends critically upon the ability to make observations at the extreme limits of sensitivity and/or precision, and that the growing use of the radio spectrum increases the possibility of interference detrimental to the radio astronomy service (RAS);

b) that for some radio astronomy observations, such as those involving the passage of a comet, an occultation by the moon, or a supernova explosion, a high probability of success is desirable because of the difficulty or impossibility of repeating them;

c) that since interference to radio astronomy can result from unwanted emissions of services in adjacent, nearby, or harmonically related bands, interference from several services or systems may occur in any single radio astronomy band;

d) that burden sharing may be necessary to facilitate the efficient use of the radio spectrum;

e) that mitigation techniques may be used, and more advanced techniques are being developed for future implementation, to allow more efficient use of the radio spectrum;

f) that threshold levels of interference (assuming 0 dBi antenna gain) detrimental to the RAS for 2 000 s integration times are given in Recommendation ITU-R RA.769, but that no acceptable percentage of time has been established for interference from services with transmissions randomly distributed in time and either sharing a frequency band with the RAS, or producing unwanted emissions that fall within a radio astronomy band;

g) that administrations may require criteria for evaluation of interference between the RAS and other services in shared, adjacent, nearby, or harmonically related bands;

h) that methods (e.g. the Monte Carlo method) are currently being developed to determine the appropriate separation distance between radio astronomy sites and an aggregate of mobile earth stations, and that these methods require the specification of an acceptable percentage of time during which the aggregate interference power exceeds the threshold levels detrimental to the RAS;

j) that studies of sharing scenarios and experience gained from long practice have led to values of tolerable time loss due to degradation of sensitivity, on time scales of a single observation, which are explained in more detail in the Annex 1,

recommends

1 that, for evaluation of interference, a criterion of 5% be used for the aggregate data loss to the RAS due to interference from all networks, in any frequency band allocated to the RAS on a primary basis, noting that further studies of the apportionment between different networks are required;

2 that, for evaluation of interference, a criterion of 2% be used for data loss to the RAS due to interference from any one network, in any frequency band which is allocated to the RAS on a primary basis;

3 that the percentage of data loss, in frequency bands allocated to the RAS on a primary basis, be determined as the percentage of integration periods of 2 000 s in which the average spectral pfd at the radio telescope exceeds the levels defined (assuming 0 dBi antenna gain) in Recommendation ITU-R RA.769. The effect of interference that is periodic on time scales of the order of seconds or less, such as radar pulses, requires further study;

4 that the criteria described in section 3.3.2 of Annex 1 be used for evaluation of interference, in any frequency band allocated to the RAS on a primary basis, from unwanted emissions produced by any non-GSO satellite system at radio astronomy sites.

Annex 1

Data loss resulting from interference

1 Introduction

An important parameter for all radiocommunication services is the percentage of time lost to interference. Administrations may need quantitative criteria relative to radio astronomy operations with active services operating in the same, adjacent, nearby, or harmonically related bands. For example, Recommendation ITU-R M.1316 uses this percentage of time lost to interference in the calculation of the separation distance by default between stations operating in the MSS (Earth-to-space) and a radio astronomy observatory, by using the Monte Carlo methodology.

Existing limits to the aggregate time losses tolerated by various other «science» services are given in Table 1, for comparison.

TABLE 1

Example of criteria for aggregate percentage of time of data loss use for other science services

Earth exploration-satellite service (EESS) (passive sensors) (%) (Recommendation ITU-R SA.1029): – 3-D atmospheric sounding – All other sensors	 0.01 1.0-5.0
EESS (near-Earth spacecraft) (%) (Recommendation ITU-R SA.514)	0.1
Meteorological-satellite service (%) (Recommendation ITU-R SA.1161)	0.1
Space operations systems *S*/*N* > 20 dB for > 99% of time (%) (Recommendation ITU-R SA.363)	1.0
EESS (active sensors) (%) (Recommendation ITU-R SA.1166)	1.0-5.0

Radio telescopes are designed to operate continuously, following a schedule of observing programs requested by astronomers. As a rule, access to radio telescopes is on a competitive basis, with research proposals often exceeding available telescope time by a factor of 2-3. Virtually all radio astronomy installations are operated out of public funds, and must be used very efficiently. Some loss of observing time resulting from maintenance or upgrading of hardware or software, however, cannot be avoided. Experience over many years of operation with major instruments by one administration shows that such losses need not exceed 5% of time, for example one 8 h day per week. Considerations of overall efficiency and cost of operation indicate that the additional aggregate time loss due to interference should be limited to a similar 5% figure.

In order to achieve the figures shown in Table 1, individual services should design their systems and control their operations to an appropriate fraction of these figures. Prudence dictates that individual systems be allowed only a fraction of the interference budget, depending on factors related to the actual allocation situation, such as band sharing and the interference potential due to unwanted emissions from other services.

It should be noted that the concept of aggregate data loss is not fully developed at present. Simulation tools, such as the one described in Recommendation ITU-R M.1316, allow the case of interference resulting from a single system to be considered. Other methodologies for single systems are also being developed. At this time there is no similar tool for the case of aggregate data loss resulting from several systems. A method that takes into account the characteristics of several systems may be difficult to develop. A particular difficulty is the apportionment of the aggregate data loss among the various systems. Further studies of these problems are needed.

The advent of radio services using space stations and high-altitude platform stations requires reassessment of the measures by which the RAS is protected from interference. Frequency sharing with such services is normally impossible, but potentially negative effects upon the RAS by services in nearby bands arise through two factors:

a) unwanted emissions falling in bands allocated to the RAS;

b) intermodulation and departures from linearity in radio telescope systems due to strong signals in adjacent bands.

It is assumed that the satellite operators will use all practical means to minimize unwanted emissions, and radio astronomers all practical methods to minimize sensitivity to signals in adjacent or nearby bands. Nevertheless, item b) should be an important consideration when operating systems in bands adjacent or close to bands allocated to the RAS.

2 Data loss and sky blockage

Whenever data loss is mentioned in this Recommendation, it refers to data that have to be discarded because they are contaminated by the aggregate interference, from one or more sources that exceeds the levels of Recommendation ITU-R RA.769, under the assumptions stated therein. The term blockage is used here to indicate antenna directions in which the level of interference received exceed those given for detrimental interference in Recommendation ITU-R RA.769. In the presence of such interference, data useful for research at the frontiers of knowledge is generally not obtainable. Data loss may result from loss of part of the observing band, part of the observing time or from blockage of part of the sky. All of these can be expressed as loss of effective observing time.

It is stated in Recommendation ITU-R RA.1031 that many radio astronomy measurements can tolerate interference from a shared service which exceeds the thresholds given in Recommendation ITU-R RA.769, for 10% of time. It should be noted that such observations, which can tolerate enhanced measurement errors, represent observations such as solar radio flare patrols. Observations of significance in radio astronomy are those which result in new knowledge of astronomical phenomena, which either require making observations of objects not previously studied, or observing known objects with increased precision. Both such cases call for observations at the highest achievable sensitivity. As radio astronomy has matured, the usefulness of data which is limited in accuracy by the presence of interference has declined, and it is the usual practice of astronomers to delete data for which there is any evidence of interference. Thus it is a matter of practical reality that interference occurring at any identifiable level results in loss of the contaminated data.

The 0 dBi contour of the pattern for large antennas between 2 GHz and about 30 GHz defined in Recommendation ITU-R SA.509 has a radius of 19°. When a radio telescope points less than 19° from a transmitter, emitting in a radio astronomy band at the detrimental level defined in Recommendation ITU-R RA.769, interference results. This effectively blocks radio astronomy observation within a region of the sky 19° in angular radius. Fractional sky blockage is the ratio of sky blockage (above the horizon), as defined above, to the solid angle of the visible hemisphere.

Figure 1 shows the effect of a hypothetical transmitter on the horizon at the origin of the azimuth scale, which just meets the spectral pfd level of Recommendation ITU-R RA.769 at a radio astronomy station. The contours in the Figure show the decibel level by which the received power from the transmitter exceeds the level at which it is detrimental to radio astronomy, as a function of the pointing angle of the radio astronomy antenna. The received transmission causes detrimental interference when it is received in sidelobes of the radio astronomy antenna with gain greater than 0 dBi. Table 2 shows the percentage of sky receiving such detrimental interference, for pointing angles of the antenna at elevations above 5°. Since radio astronomy antennas are rarely pointed below 5°, this is the lowest elevation considered. For a source of interference above an elevation angle of 19° (such as an airborne or space transmitter) for which the spectral pfd at a radio astronomy station just meets the level in Recommendation ITU-R RA.769, a circular area of sky, with a radius of 19° centred on the source of interference, is blocked from radio astronomy observation at useful levels of sensitivity. This area subtends a solid angle of 0.344 sr, which is 5.5% of the 2π sr of sky above the horizon.

The application of the concept of sky blockage in a non-stationary environment (e.g. non-GSO satellite systems or mobiles) requires further study.

3 Sharing situations

In assessing interference it is useful to distinguish between transmissions of terrestrial origin, particularly in cases where there is no line-of-sight (LoS) path, and those coming from aircraft, high-altitude platforms and space-based transmitters in LoS of the affected radio telescope. Concerning the percentage of observing time lost one should distinguish between interference from distant transmitters due to variable propagation conditions (i.e. beyond human control) and interference from active applications where the emission is effectively random with respect to the power level and the angle of arrival at a radio telescope (see § 3.1).

FIGURE 1

The effect of a source of interference at the detrimental level for the RAS, on the horizon at zero azimuth. The curves show the decibel level by which the interference received by the radio astronomy receiver exceeds the detrimental level for different pointing angles of the radio astronomy antenna. Note that radio astronomy observations are generally made with pointing angles above 5° elevation

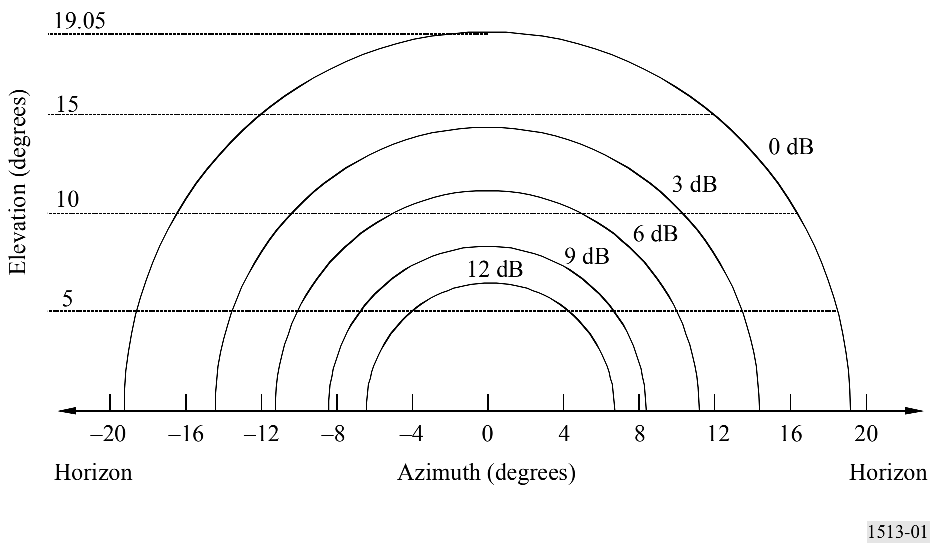


TABLE 2

Percentage of sky in which sensitive observations are precluded by interference received above the detrimental level, as a function of pointing elevation of the radio telescope, for the interfering source in Fig. 1

Minimum elevation (degrees)	**Blockage (%)**
5	2.0
10	1.3
15	0.6
20	0

3.1 Interference due to variable propagation conditions

3.1.1 Terrestrial applications

In cases where the strength of an interfering signal varies as a result of time-varying propagation conditions, a percentage of time must be specified for propagation calculations. A number of 10% is given in Recommendation ITU-R RA.1031. However, this does not automatically lead to a 10% data loss for radio astronomy observations. Propagation conditions vary episodically, typically over periods of a few days. It should therefore be noted that over periods of weeks at a time, the period for which data are contaminated by interference may be only a few days. These effects occur primarily at longer wavelengths, i.e. below about 1 GHz. Periods of data loss can be reduced by dynamic rescheduling of radio astronomy observations.

3.1.2 Space-based applications

Time variable tropospheric propagation conditions need not be considered under LoS conditions.

3.2 In-band sharing, where the transmission is variable in time and location

3.2.1 Terrestrial applications

To maximize the efficiency with which radio telescopes are used, loss of observing time due to interference by other users of the spectrum should be avoided. However, some small loss may be inevitable. An example is unwanted emissions from mobile (earth) stations in the MSS. An acceptable practical level of data loss from such a system is 2%. Recommendation ITU-R M.1316 provides an example of coordination between the RAS and the MSS (Earth-to-space). In this Recommendation, the percentage of observing time loss is used in the calculation of the separation distance by default between mobile earth stations in the MSS (Earth-to-space) and the radio astronomy station, using the Monte Carlo methodology.

3.2.2 Space-based applications

Sharing with satellite downlinks is not possible in bands where the RAS has a primary allocation.

3.2.3 Space-based radio astronomy applications

Space-based radio astronomy requires individual analysis appropriate to the application.

3.3 Unwanted emissions into a radio astronomy frequency band, where the transmission is variable in time and/or direction of arrival

3.3.1 Terrestrial applications

Time-sharing between terrestrial applications and radio astronomy is not usually considered operationally feasible. Filtering of transmitters and geographical separation are employed to suppress unwanted emission levels into the radio astronomical band to below the Recommendation ITU-R RA.769 threshold values at the location of a radio telescope. There is a potential for interference when the radio astronomy beam is pointed closer than 19° to a terrestrial source (see Fig. 1). The levels in Recommendation ITU-R RA.769 are based on the assumption that the interference source is at the isotropic contour. As shown in Fig. 1, a terrestrial source on the horizon (elevation = 0°) can cause detrimental interference in up to 2% of the visible hemisphere for a telescope that can point within 5° of the horizon. However, as a rule, radio telescopes are pointed within 5° of the horizon for only a portion of their total observing time. Some sources of interference are known and can be avoided. In practice, a level of up to 2% data loss could be tolerated from one interfering system. It should be noted that as a radio telescope is pointed at very low elevation angles the system noise increases which reduces the sensitivity. This is not taken into account in Recommendation ITU-R RA.769, since the usual elevation limit of 5°-10° results in very little time being spent in the region of degraded sensitivity.

The methodology described in Recommendation ITU-R M.1316 may also be used to evaluate the effect of terrestrial unwanted emissions into a radio astronomy band.

3.3.2 Space-based applications

Protection of radio astronomy in the presence of GSO satellites is covered by Recommendation ITU-R RA.769.

Two Recommendations were developed by the ITU-R: Recommendation ITU-R S.1586 – Calculation of unwanted emission levels produced by a non-geostationary fixed-satellite service system at radio astronomy sites and Recommendation ITU-R M.1583 – Interference calculations between non-geostationary mobile-satellite service or radionavigation-satellite service systems and radio astronomy telescope sites; to address the compatibility between non-GSO constellations and RAS sites. These Recommendations provide a methodology to evaluate the levels of unwanted emissions produced by a non-GSO constellation at radio astronomy sites. The first step of this approach is to divide the sky into cells. First, a random choice is made for a pointing direction of the RAS antenna, which will lie within a specific cell on the sky. Then, the starting time of the constellation is randomly chosen. The average epfd corresponding to this trial is then calculated for the chosen pointing direction and starting time of the constellation using the following equation to determine epfd corresponding to each time sample:

$$epfd_{G_r = 0\,\mathrm{dBi}} = 10 \log_{10}\left[\sum_{i=1}^{N_a} 10^{\frac{P_i}{10}} \cdot \frac{G_t(\theta_i)}{4\pi d_i^2} \cdot G_r(\varphi_i)\right] \tag{1}$$

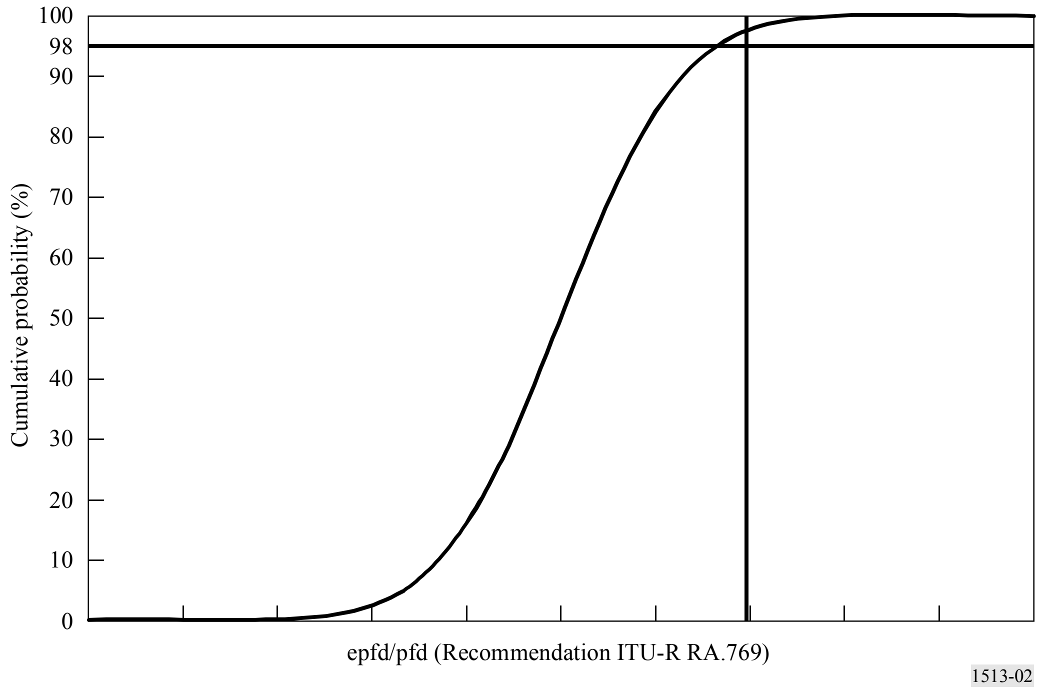
where:

- N_a: number of non-GSO space stations that are visible from the radio telescope
- i: index of the non-GSO space station considered
- P_i: RF power of the unwanted emission at the input of the antenna (or RF radiated power in the case of an active antenna) of the transmitting space station considered in the non-GSO satellite system (dBW) in the reference bandwidth
- θ_i: off-axis angle between the boresight of the transmitting space station considered in the non-GSO satellite system and the direction of the radio telescope
- $G_t(\theta_i)$: transmit antenna gain (as a ratio) of the space station considered in the non-GSO satellite system in the direction of the radio telescope
- d_i: distance (m) between the transmitting station considered in the non-GSO satellite system and the radio telescope
- φ_i: off-axis angle between the pointing direction of the radio telescope and the direction of the transmitting space station considered in the non-GSO satellite system
- $G_r(\varphi_i)$: receive antenna gain (as a ratio) of the radio telescope, in the direction of the transmitting space station considered in the non-GSO satellite system.

For each of these cells, a statistical distribution of the epfd is determined. Then, these epfd distributions may be compared with pfd levels given in Recommendation ITU-R RA.769 (defined assuming a 0 dBi receiving antenna gain in the direction of interference and given a 2 000 s integration time) so that the percentage of trials during which this criterion is met may be determined for each of the cells which were defined.

FIGURE 2

Comparison between the pfd levels given in Recommendation ITU-R RA.769 and the epfd distribution given for a cell



From the pfd threshold levels of interference detrimental to radio astronomy given in Recommendation ITU-R RA.769, epfd threshold levels can be derived taking into account the maximum radio astronomy antenna gain, G_{max}, assumed in the calculations, through the following equation:

$$epfd_{threshold} = pfd_{\mathrm{RA.769}} - G_{max}$$

Over the sky, for elevations higher than the minimum operating elevation angle of the radio telescope, the epfd threshold level defined above should not be exceeded for more than 2% of the time.

This methodology was initially developed to cover the case of non-GSO satellite systems, however it may also be used for some airborne systems, e.g. in the aeronautical MSS.

4 Conclusion

A practical criterion for the aggregate data loss resulting from interference to the RAS is considered to be 5% of time from all sources. The existence of multiple overlapping sources of interference is a practical aspect that should be accounted for. Further study of the apportionment of the aggregate interference between different networks is required.

The data loss from any one system should be significantly less than 5%. To comply with this requirement, 2% per system is a practical limit.