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Recommendation ITU-R M.1748

(03/2006)

Protection of the radio astronomy service in the band 1 400-1 427 MHz from unwanted emissions of MSS feeder links that may operate in the bands 1 390-1 392 MHz (Earth-to-space) and 1 430-1 432 MHz (space-to-Earth)

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

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RECOMMENDATION ITU-R M.1748*

Protection of the radio astronomy service in the band 1 400-1 427 MHz from unwanted emissions of MSS feeder links that may operate in the bands 1 390-1 392 MHz (Earth-to-space) and 1 430-1 432 MHz (space-to-Earth)

(2006)

Scope

This Recommendation provides epfd values for the protection of radio astronomy stations operating in the band 1 400-1 427 MHz from MSS feeder links (space-to-Earth) that may operate in the band 1 430-1 432 MHz, as well as a methodology to determine separation distances between radio astronomy stations operating in the band 1 330-1 427 MHz and MSS feeder links (Earth-to-space) that may operate in the band 1 390-1 392 MHz.

The ITU Radiocommunication Assembly,

considering

a) that WRC-03 allocated the bands 1 390-1 392 MHz and 1 430-1 432 MHz provisionally on a secondary basis to the fixed-satellite service (FSS) for feeder links for non-geostationary mobile-satellite systems (MSS) operating below 1 GHz in the Earth-to-space and space-to-Earth directions, respectively (see No. 5.339A of the Radio Regulations (RR)) and that Resolution 745 (WRC-03) applies;

b) that Resolution 745 (WRC-03) calls for studies, including the measurement of emissions from equipment that would be employed in operational systems, to validate that these systems meet all requirements for the protection of passive services in the band 1 400-1 427 MHz from unwanted emissions from MSS feeder links;

c) that the band 1 400-1 427 MHz is allocated to the Earth exploration-satellite service (EESS) (passive), radio astronomy (RAS) and space research (passive) services on a primary basis in all Regions, and that No. 5.340 of the RR applies to this band;

d) that the 1 400-1 427 MHz band is extensively used by radio astronomers worldwide for observations of the neutral hydrogen spectral line, as well as for continuum observations;

e) that the threshold levels of interference detrimental to the radio astronomical observations are given in Tables 1 and 2 of Annex 1 to Recommendation ITU-R RA.769;

f) that Recommendation ITU-R RA.1513 provides criteria for recommended levels of data loss to the RAS from any one network and that both the uplink and downlink associated with a network may contribute to data loss to the RAS in the 1 400-1 427 MHz band;

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* This Recommendation was jointly prepared by Radiocommunication Study Groups 7 and 8 and any future revision will also be undertaken jointly.

g) that data losses from earth stations operating in the 1 390-1 392 MHz band to the RAS operating in the 1 400-1 427 MHz band may be minimized using relatively modest separation distances, of the order of 100 km or less;

h) that Recommendation ITU-R RA.1631 describes the radio astronomy antenna pattern to be used in compatibility studies involving satellite constellations, Recommendation ITU-R M.1184 provides technical characteristics of mobile-satellite systems in frequency bands below 3 GHz for use in developing criteria for sharing between the MSS and other services, and Recommendation ITU-R M.1583 describes the methodology to be used in interference calculations between non-geostationary mobile-satellite service or radionavigation-satellite service systems and radio astronomy sites,

noting

a) that, for typical combinations of data rates and modulation techniques, it is feasible to reduce unwanted emissions in the 1 400-1 427 MHz band to the interference levels detrimental to the RAS given in Recommendation ITU-R RA.769, without a specific post-amplifier filter, by employing baseband processing techniques;

b) that when the baseband processing referred to under *noting* a) is not sufficient by itself to meet the required unwanted emission levels an additional post-amplifier filter can be used;

c) that the band 1 330-1 400 MHz, which is used to observe the red-shifted neutral hydrogen spectral line, is also included in No. 5.149 of the RR,

recommends

1 that unwanted emissions of non-GSO MSS feeder links (space-to-Earth) of a single network that may operate in the band 1 430-1 432 MHz should be less than:

– an epfd of −259 dB(W/m^2) in any 20 kHz bandwidth of the band 1 400-1 427 MHz for more than 98% of integration periods of 2 000 seconds for spectral line observations; and

– an epfd of −243 dB(W/m^2) in the entire 1 400-1 427 MHz band for more than 98% of integration periods of 2 000 seconds for continuum (broadband) observations;

2 that the methodology contained in Recommendation ITU-R M.1583 should be used to derive a pfd limit per satellite from the epfd limits given for MSS networks in *recommends* 1 above;

3 that earth stations that may operate in the band 1 390-1 392 MHz in conjunction with a given non-GSO MSS network should be separated from radio astronomy stations which conduct observations in the band 1 400-1 427 MHz, so that the total data loss due to uplink and downlink does not exceed 2%;

4 that the methodology described in Annex 2 should be used to derive the separation distance between the radio astronomy station and the MSS feeder-link earth station on a case-by-case basis.

Annex 1

Example calculation of the pfd per satellite required to respect epfd limits for the protection of the radio astronomy service operating in the band 1 400-1 427 MHz from unwanted emissions of MSS feeder links that may operate in the band 1 430-1 432 MHz

1 Methodology

Recommendation ITU-R S.1586 (or Recommendation ITU-R M.1583) provides a methodology to evaluate the levels of unwanted emissions produced by a non-geostationary satellite system at a radio astronomy site. It is based on a division of the sky into cells of nearly equal size and a statistical analysis where the pointing direction of the RAS antenna and the starting time of the satellite constellation are the random variables. For each trial, the unwanted emission level (expressed in terms of epfd) is averaged over a 2 000 s period.

Moreover, Annex 1 to Recommendation ITU-R RA.769 provides the threshold levels for interference detrimental to the RAS and Recommendation ITU-R RA.1513 provides a criterion of 2% for maximum allowable data loss to the RAS due to interference from any one network, which is determined as the percentage of integration periods of 2 000 s in which the average spectral power flux-density (pfd) at the radio telescope exceeds the levels defined in Recommendation ITU-R RA.769.

The purpose of the present study is to determine the maximum pfd level required for unwanted emissions of non-GSO MSS system feeder links in the band 1 430-1 432 MHz to comply with the criteria for the protection of radio astronomical observations in the band 1 400-1 427 MHz as given in Recommendations ITU-R RA.769 and ITU-R RA.1513, using the methodology of Recommendation ITU-R S.1586, which is designed to take into account the non-geostationary nature of these systems when assessing their unwanted emission levels at radio telescope sites.

2 MSS system characteristics

The characteristics of the MSS system are summarized in Table 1. It is assumed that the satellites are outfitted with an isoflux antenna, capable of producing a constant pfd on the ground.

TABLE 1

MSS system characteristics

Orbital altitude	1 000 km
Orbital inclination	50° (and 83° for polar coverage)
Number of planes	6 (+ one more for polar coverage)
Number of satellites per plane	4

3 RAS station characteristics and protection criteria

The Effelsberg radio telescope in Germany was chosen for this analysis. Its geographical coordinates are: latitude: N 50.7°, longitude: E 7.0°.

The antenna pattern and peak gain at boresight used are given in Recommendation ITU-R RA.1631.

TABLE 2

pfd levels detrimental to the RAS

Frequency band (MHz)	Interference level (dB(W/m^2))	Reference bandwidth (MHz)	Type of observation
1 330-1 400	−196[(1)]	0.02	Spectral line
1 400-1 427	−180	27	Continuum
1 400-1 427	−196	0.02	Spectral line

(1) There is no detrimental threshold level defined in Recommendation ITU-R RA.769 for the band 1 330-1 400 MHz (see RR No. 5.149). The protection criterion listed above for this band was derived from the one used in the band 1 400-1 427 MHz in case of for spectral line observations.

The simulations were performed considering minimum telescope elevation angles of 0° and 3°.

In terms of an epfd level, the detrimental pfd threshold level corresponds to:

$$epfd_{lim} = pfd_{lim} - G_{max}$$

TABLE 3

epfd levels detrimental to the RAS

Frequency band (MHz)	epfd interference level (dB(W/m^2))	Reference bandwidth (MHz)	Type of observation
1 330-1 400	−259	0.02	Spectral line
1 400-1 427	−243	27	Continuum
1 400-1 427	−259	0.02	Spectral line

4 Determination of the required maximum pfd per satellite level for the protection of the radio astronomy service

4.1 Procedure

The following approach is used (see Recommendation ITU-R S.1586):

Step 1: Select a pfd value per satellite. In a first approximation (and as a worst-case scenario) this value may be considered constant for all elevation angles.

In the particular example under consideration, the satellite is assumed to be equipped with an isoflux antenna.

Step 2: Select a radio astronomy station.

Step 3: Division of the sky into 2 334 cells of about 9 square degrees solid angle each (see Table 1 in Annex 3 to Recommendation ITU-R S.1586).

Step 4: For each cell *t* the radio astronomy station may observe (taking into account the minimum elevation angle θ_{min} at which the radio astronomy station is capable of conducting observations in the frequency band, as defined in Appendix 4 of the RR), point the radio telescope towards a randomly chosen direction within the cell, and start the satellite transmissions at a randomly chosen point in time. The epfd is then evaluated for each time sample over a 2 000 s integration time, with a time Step of 1 s. The average epfd corresponding to this trial is then calculated.

Step 5: If the epfd level averaged over the 2 000 s integration interval of the trial exceeds the interference threshold level, that particular 2 000 s observation is considered to be affected.

Step 6: Repeat Steps 4 and 5 to get a representative number of trials (100 trials were found to be statistically sufficient).

Step 7: Determine the percentage of affected integration periods of 2 000 s over the whole sky accessible to the radiotelescope as defined in Step 4.

Step 8: Change the pfd level of the non-GSO MSS system until this percentage is below 2%.

4.2 Results

The simulation leads to the required pfd limits per MSS satellite given in Table 4.

TABLE 4

Maximum pfd levels per MSS satellite to protect a radio astronomy station

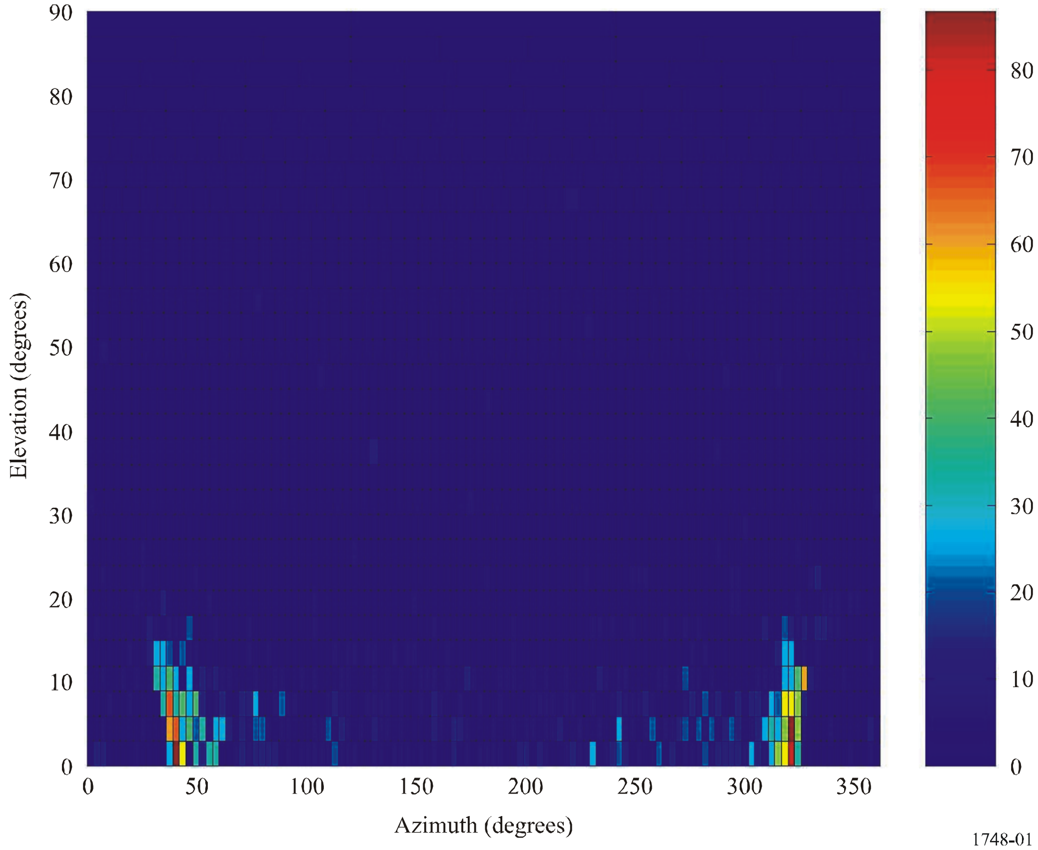
Band and type of observation	pfd limit per satellite ($dB(W/m^2)$)	Reference bandwidth (MHz)
1 330-1 400 MHz (spectral line)	−201	0.02
1 400-1 427 MHz (continuum)	−185	27
1 400-1 427 MHz (spectral line)	−201	0.02

The total amount of data loss is 2.07% when considering the minimum elevation angle of 0°, and 1.65% when considering a minimum elevation angle of 3°.

Figure 1 shows, for the radio astronomy site of Effelsberg, for each cell over the whole sky, the percentage of observations where the epfd criterion has been exceeded. The total number of trials per cell is 100. The intensity scale represents the number of trials for which the epfd criterion has been exceeded.

FIGURE 1

Simulation results for Effelsberg



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5 Conclusions

The study shows that a pfd limit of −185 dB(W/m^2) (for continuum observations) per MSS satellite in the whole band 1 400-1 427 MHz and −201 dB(W/m^2) (for spectral line observation) per MSS satellite in any 20 kHz bandwidth of the band 1 400-1 427 MHz is sufficient for the protection of the radio astronomy service for the system considered.

The spectral line pfd limit is also applicable to the band 1 330-1 400 MHz.

Annex 2

Separation distance between radio astronomy stations operating in the band 1 400-1 427 MHz and MSS feeder-link earth stations that may operate in the band 1 390-1 392 MHz

1 Introduction

The purpose of this Annex is to determine the separation distance between a radio astronomy station that may operate in the band 1 400-1 427 MHz and an MSS feeder-link earth station operating in the band 1 390-1 392 MHz, to avoid interference detrimental to the radio astronomy station.

Recommendation ITU-R RA.1513 deals with the issues of maximum levels of data loss and percentage-of-time criteria acceptable for radio astronomy observations that are central to sharing studies. The threshold levels of interference detrimental to radio astronomical observations are given in Recommendation ITU-R RA.769.

2 Methodology

For radio astronomy, the power received is integrated over a period of time in order to reach a better sensitivity. The result of this integration is called an observation in the following paragraphs.

The power received from an interferer during an observation may be expressed as follows:

$$I = \frac{1}{\mathrm{N}} \sum_{i=1}^{\mathrm{N}} \frac{P_t(i) \cdot G_t(i) \cdot G_r(i)}{L_b(i)} \tag{1}$$

where:

- $L_b(i)$: propagation loss at instant i
- $P_t(i)$: transmitting power level (W) in the RAS bandwidth at the input to the antenna at instant i
- $G_t(i)$: gain of the transmitting antenna in the direction of the radio astronomy antenna at instant i
- $G_r(i)$: gain of the radio astronomy antenna in the direction of the transmitter at instant i
- N: number of samples
- I: interference power (W) in the reference bandwidth at the receiver input averaged over the observation period T.

Usually (and to be consistent with the detrimental threshold levels given in Recommendation ITU-R RA.769) the calculation is performed over an integration period T of 2 000 s. During this period of time, some of the parameters may vary. For this particular application, P_t is considered constant. As the transmitter is an earth station following a satellite or a constellation of satellites, G_t varies during the integration time and also from one observation to the next. We assume that the radio astronomy antenna properties are fixed during the integration time (e.g. that G_r does not vary in the 2 000 s period), but that the RAS antenna pointing direction varies from one observation to the next.

Observations performed over a given integration time are considered lost when the interference power received, I, averaged over T exceeds the threshold value given in Recommendation ITU-R RA.769.

Therefore:

$$L_b = \frac{P_t}{\Delta P_H} \cdot \frac{1}{\mathrm{N}} \sum_{i=1}^{\mathrm{N}} G_t(i) \cdot G_r(i) \tag{2}$$

where:

- P_t: transmitting power level (W) in the RAS bandwidth at the input to the antenna (including feeder loss)
- $G_t(i)$: gain of the transmitting antenna in the direction of the radio astronomy antenna at instant i
- $G_r(i)$: gain of the radio astronomy antenna in the direction of the transmitter at instant i
- N: number of samples
- ΔP_H: interference power (W) threshold given in Recommendation ITU-R RA.769.

It is necessary to perform the calculation over several periods of time in order to verify that the percentage of observations lost is lower than the 2% criterion given in Recommendation ITU-R RA.1513.

3 Radio astronomy station antenna gain towards the MSS feeder-link earth station

It is possible to apply the methodology in Annex 3 to § 1 of Recommendation ITU-R M.1583 to derive statistics on the antenna gain of the radio astronomy station. The sky is divided into 2 334 cells of approximately 9 square degrees of solid angle each. For each cell it is possible to consider a random pointing direction of the radiotelescope antenna, and, from that and the antenna pattern, to calculate the antenna gain in the direction of an earth station viewed under an elevation angle of 0°.

The curves in Fig. 2 were obtained for a frequency of 1.4 GHz for the antenna pattern of Recommendation ITU-R SA.509 and an antenna diameter of 100 m. The elevation angle of the transmitter as seen from the radiotelescope has been taken as 0°. These curves do not change when considering other frequency bands or antenna diameters because the Recommendation ITU-R SA.509 antenna pattern does not depend on frequency or maximum antenna gain.

4 MSS feeder-link earth station antenna gain towards the radio astronomy station

The antenna gain cumulative distribution (cdf) curve shown in Fig. 3 was obtained for an MSS feeder-link earth station tracking a constellation of 24 satellites at an altitude of 1 000 km, with an antenna pattern conforming to Annex III of Appendix 8 of the RR and a maximum antenna gain of 30 dBi.

5 Derivation of propagation losses with the Monte-Carlo methodology

A Monte-Carlo simulation taking into account the variation of the transmitter antenna gain during the 2 000 seconds period, an emission power of −60 dBW in the 1 400-1 427 MHz band, and an RAS protection threshold of −205 dBW leads to the cdf curve for the propagation loss shown in Fig. 4.

FIGURE 2

RAS antenna gain towards a transmitter at an elevation angle of 0°

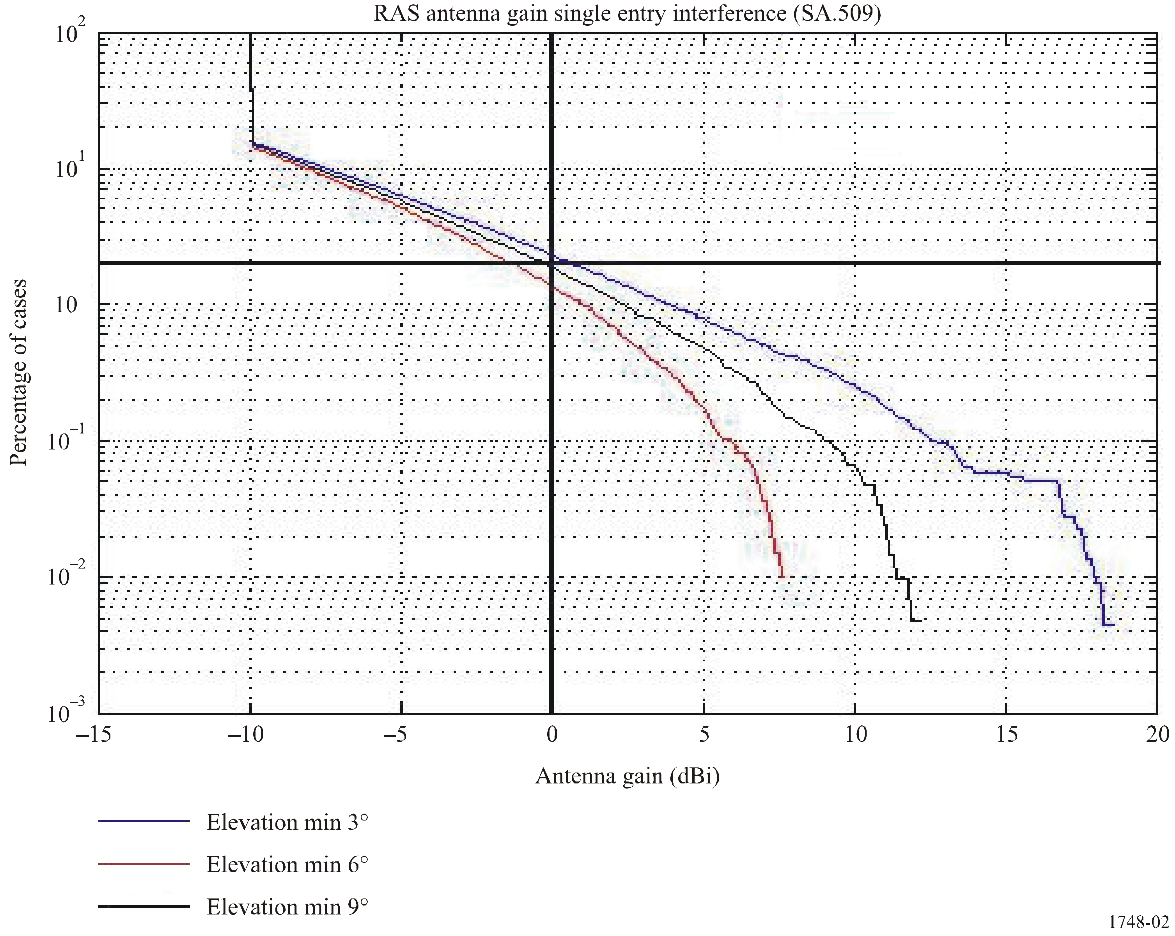


FIGURE 3

MSS feeder-link earth station antenna gain towards an RAS station at an elevation angle of 0°

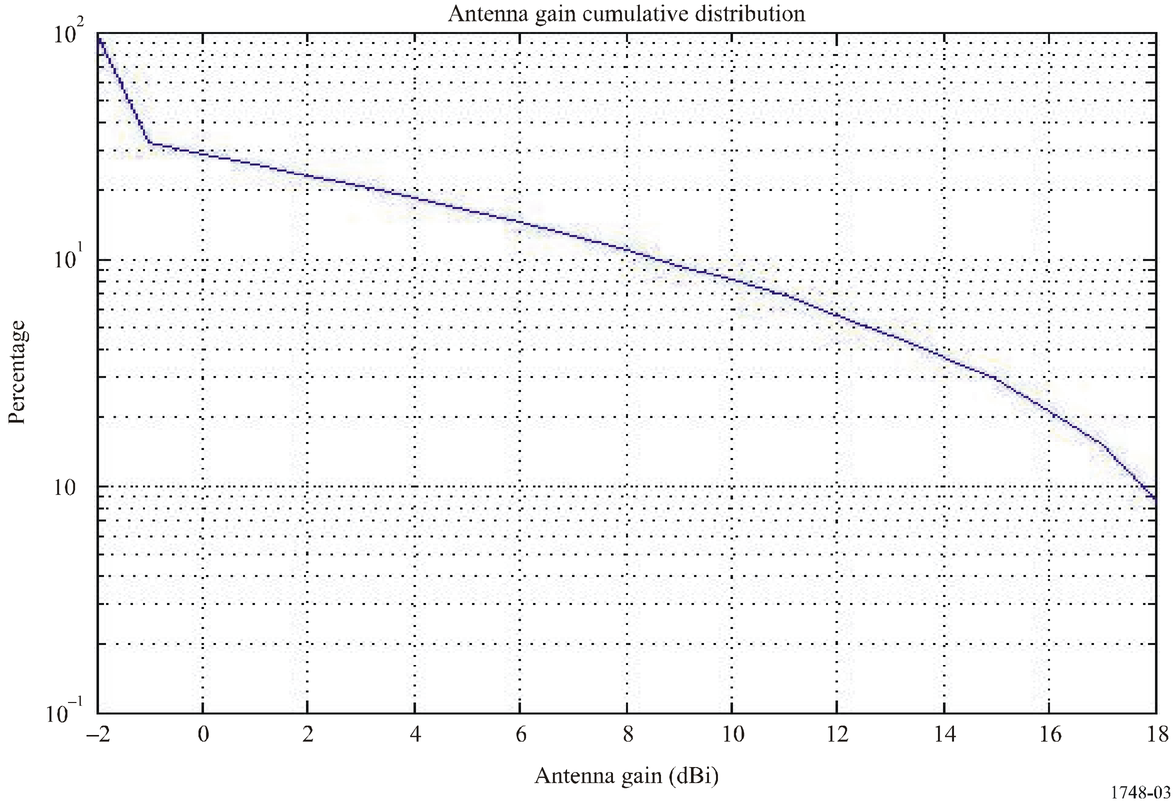
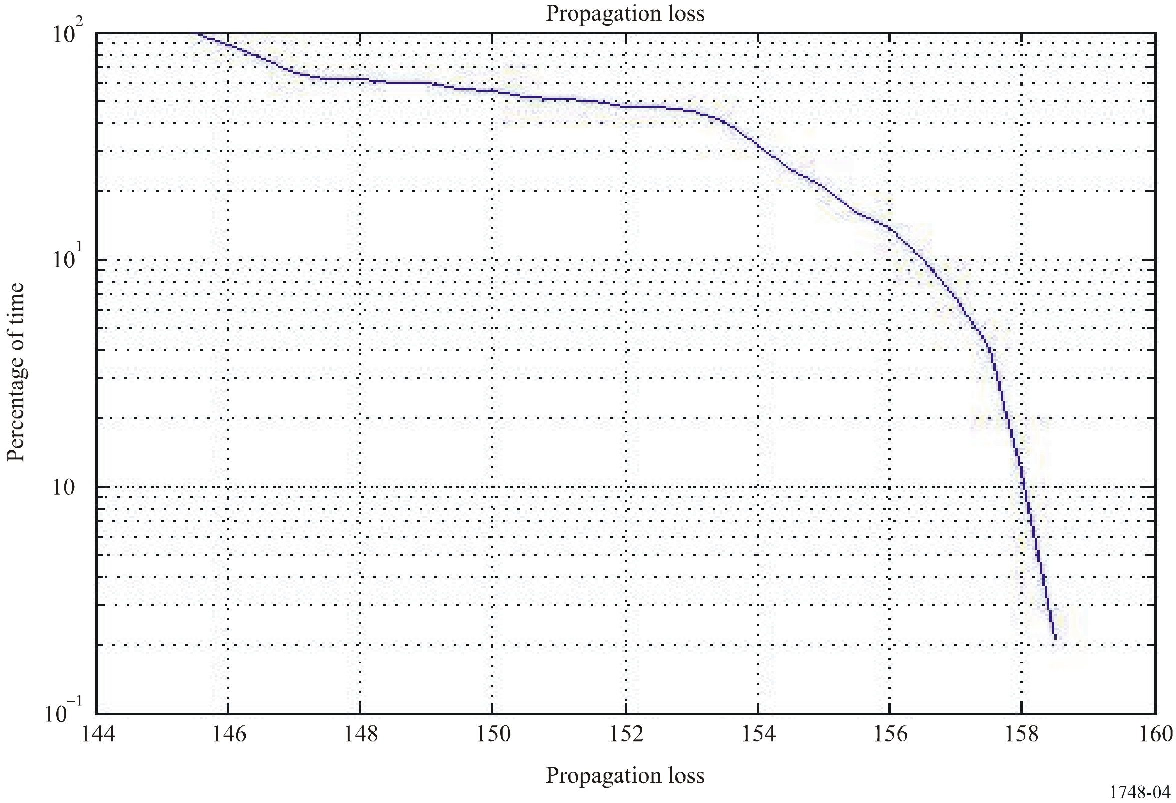


FIGURE 4

Propagation loss required for the protection of RAS stations from MSS feeder-link earth station emissions in nearby frequency bands for a minimum telescope elevation angle of 0°



The 2% data loss to a radio astronomy station from the MSS system needs to be apportioned between the uplink and the downlink. As an example, if the RAS suffers no data loss from the downlink, the corresponding propagation loss for the uplink (averaged over 2 000 s) should be 157.9 dB. If the data loss from the downlink is 1.8%, then the propagation loss corresponding to 0.2% data loss from the uplink should be 158.5 dB, only 0.6 dB higher.

The same propagation loss may be derived easily from this value for other emission power values or detrimental threshold levels, by using the following equation:

$$L_2 = L_1 + (P_{t2} - P_{t1}) - (P_{r2} - P_{r1})$$

Table 5 gives the values obtained for different MSS feeder-link earth station emission powers, and RAS observation types and bands.

TABLE 5

Propagation loss required to reach the detrimental threshold

Observation type	Frequency band	Bandwidth	P_t (dBW)	P_r (dBW)	L_b (dB)	Comment
Continuum	1 400-1 427 MHz	27 MHz	−60	−205	158	Hypothesis for the calculation above
Continuum	1 400-1 427 MHz	27 MHz	−63	−205	155	New power limit for protection of EESS
Continuum	1 400-1 427 MHz	27 MHz	−107.5	−205	111	Actual unwanted emission power of one MSS system
Spectral line	1 400-1 427 MHz	20 kHz	−94	−220	139	Assuming a flat spectrum in the passive band
Spectral line	1 400-1 427 MHz	20 kHz	−127	−220	106	Actual unwanted emission power of one MSS system
Spectral line	1 330-1 400 MHz	20 kHz	3	−220	236	Emission power of the MSS earth station in 20 kHz

It has to be noted that taking into account a percentage of data loss of 0.2% instead of 2% would result in attenuation losses 0.6 dB higher than those provided in Table 5.

6 Derivation of the protection distance from the propagation attenuation

The actual protection distance or protection zone radius depends on the RAS site and its surrounding area (including relief, vegetation and buildings). The following Figure shows an application of Recommendation ITU-R P.452 to the Jodrell Bank RAS site in the United Kingdom (as an example), and shows that such a protection zone is easily achievable.

Several locations for MSS feeder-link earth stations were considered around the Jodrell Bank radio astronomy station, in concentric circles. For each location the propagation loss was calculated using Recommendation ITU-R P.452. The squares represent the locations where this propagation loss exceeds 158 dB.

FIGURE 5

Locations where the propagation loss of 158 dB is exceeded around Jodrell Bank

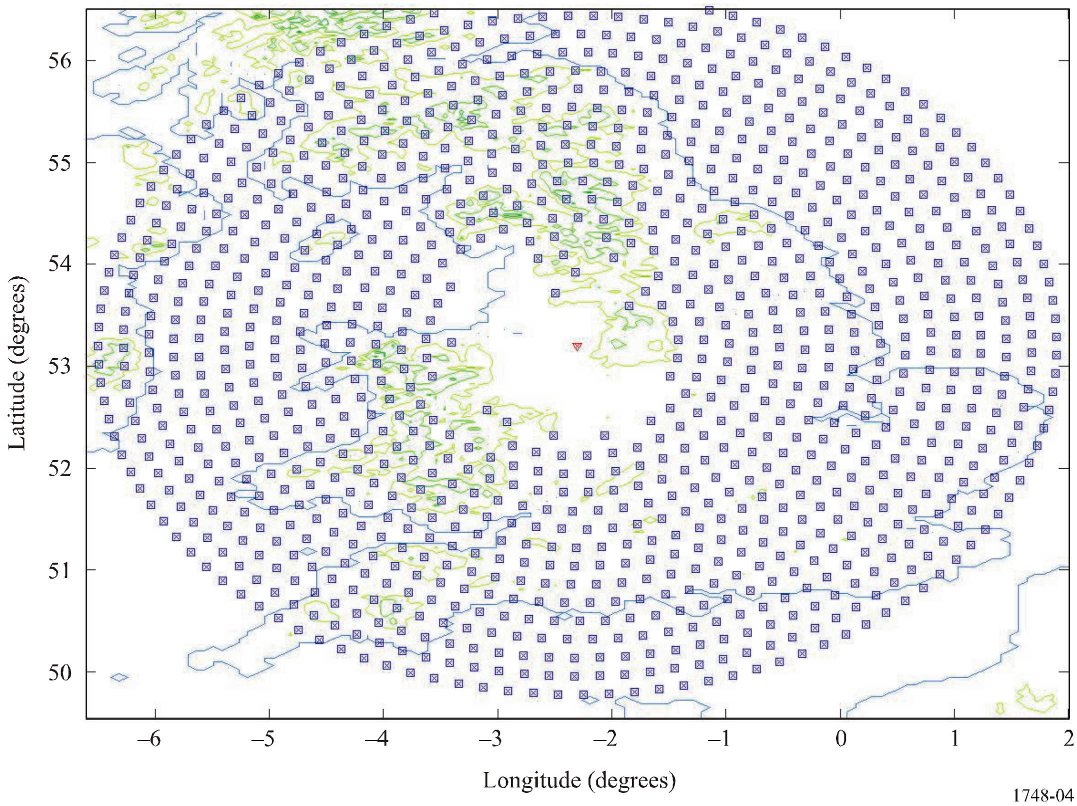


Table 6 gives the separation distances derived for Jodrell Bank using Recommendation ITU-R P.452 from the propagation losses given in Table 5.

TABLE 6

Approximate minimum separation distance

Observation type	Frequency band	Bandwidth	P_t (dBW)	Distance (km)
Continuum	1 400-1 427 MHz	27 MHz	−60	120
Continuum	1 400-1 427 MHz	27 MHz	−63	100
Continuum	1 400-1 427 MHz	27 MHz	−107.5	7
Spectral line	1 400-1 427 MHz	20 kHz	−94	50
Spectral line	1 400-1 427 MHz	20 kHz	−127	4.5
Spectral line	1 330-1 400 MHz	20 kHz	3	> 600

This calculation shows that, assuming an unwanted emission power limit of −63 dBW radiated in the band 1 400-1 427 MHz by MSS feeder-link earth stations that may operate in the band 1 390-1 392 MHz (imposed by the protection of the EESS) would require a separation distance of a radius of about 100 km. Such a separation distance is considered achievable.

However, for an actual MSS system, it has been shown that the minimum separation distance may be reduced to below 10 km. It is therefore necessary to calculate the minimum separation distance on a case-by-case basis around all radio astronomy stations performing observations in the band 1 400-1 427 MHz, taking into account the real MSS feeder link (Earth-to-space) system parameters.

The protection of radio astronomy stations performing observations in the 1 330-1 400 MHz band would require a separation radius greater than 600 km, which may prevent deployment of MSS feeder-link earth stations in very large areas surrounding those radio astronomy stations.