

RECOMMENDATION ITU-R RA.611-3*

**Protection of the radio astronomy service
from spurious emissions**

(Question ITU-R 145/7)

(1986-1990-1992-2003)

The ITU Radiocommunication Assembly,

considering

- a) that radio astronomy continues to be in the forefront of the expansion of scientific knowledge;
- b) that the radio astronomy service (RAS) requires frequency bands free of harmful interference in order that astronomical observations can be made;
- c) that the growing use of the radio spectrum, particularly in space, increases the possibility of harmful interference to radio astronomy from spurious emissions (see Annex 1 to this Recommendation);
- d) that the use of certain modulation techniques with inadequate filtering of spurious products can affect radio astronomy bands far removed from the wanted emission band;
- e) that Appendix 3 to the Radio Regulations (RR) establishes the maximum permitted levels of spurious emissions and provides for consideration of more stringent levels of spurious emissions for adequate protection of receiving stations in the RAS;
- f) that stations in the space services operating at frequencies above 960 MHz are excluded from the application of Appendix 3 to the RR;
- g) that in the case of radio systems using digital modulation techniques the spurious emission levels specified in Appendix 3 to the RR are not applicable but may be used as a guide. However, it may be noted that protection of the RAS from unwanted emissions resulting from applications of wideband digital modulation is considered in Recommendation ITU-R RA.1237;
- h) that radio astronomy observations are conducted in frequency bands up to 1 000 GHz;
- j) that the threshold levels of harmful interference to the RAS are given in Annex 1 to Recommendation ITU-R RA.769;
- k) that Recommendation ITU-R RA.1513 provides the acceptable levels of data loss to radio astronomy observations and percentage-of-time criteria resulting from degradation by interference for frequency bands allocated to the RAS on a primary basis;

* NOTE – The levels of the detrimental interference to the RAS referred to in Annex 1 to Recommendation ITU-R RA.769 are not accepted by the Arab Administrations, being unrealistic, as confirmed by previous Radiocommunication Conferences in 1995, 1997 and 2000 dealing with RR Recommendation 66.

- l) that the technical criteria for the case of harmful interference due to spurious emissions from transmitters in GSO space stations should, in respect of the RAS be those set out in Annex 1 to Recommendation ITU-R RA.769 enabling radio astronomy observations to be made at 5° or more from the GSO orbit;
- m) that progress has been made in meeting the requirements of the RAS without detrimental effects on other services;
- n) that there are continuing improvements in antenna design and in techniques for filtering spurious emissions,

recommends

- 1 that observatories in the RAS continue to be placed in locations which have good natural protection from harmful interference;
- 2 that all practicable efforts should be made to minimize the side-lobe gains of radio astronomy antennas;
- 3 that, in bringing stations into operation, administrations should take into account, to the maximum extent practicable, interference to radio astronomy observations due to spurious emissions from high-powered terrestrial stations or from space stations;
- 4 that, for the case of GSO space stations, administrations should take into account, to the maximum extent practicable, the objective of the RAS to be free of harmful interference (see Recommendation ITU-R RA.769) from spurious emissions when observing at 5° or more from the GSO orbit.

Annex 1

Interference to the RAS from spurious emissions

1 Protection criteria for the RAS

The sensitivity limit of most radio astronomy observations is at a pfd level far below that used for reception of radiocommunication signals. Annex 1 to Recommendation ITU-R RA.769 discusses detrimental interference and protection criteria for frequency sharing between RAS and other services; in Tables 1, 2 and 3 the sensitivity limits are listed for different frequencies. However, as a consequence of the low signal levels measured during radio astronomy observations, interference can occur from transmitters which do not share the same band. This may be classified as adjacent band interference (see Recommendation ITU-R RA.517) and interference from spurious emissions of transmitters in other bands. All other parameters being equal, the effect of spurious emission due to wideband digital modulation using spread-spectrum techniques in a transmitter will be more severe and is considered in Recommendation ITU-R RA.1237.

2 Harmonic and intermodulation interference

Interference from harmonic radiation or by the intermodulation of two or more signals may be caused by transmitters well separated in frequency from the radio astronomy band. Similarly, interference from inadequately filtered digitally modulated (e.g. spread-spectrum) signals can affect radio astronomy bands far removed from the carrier frequency.

Harmonic interference can occur in any band, and is generated mainly in the output power amplifier stages of the transmitters. The second and third harmonics of the carrier frequency may occur at a fairly high level but transmitters are normally provided with filters (tuned or low-pass) which attenuate all harmonics at the output of the transmitter to at least 60 dB below peak power. Carrier intermodulation will also occur when a proportion of the signal from one transmitter breaks through the combining filters to the output circuit of another transmitter feeding a common antenna. Relatively simple additional filters would attenuate these unwanted products, assuming they are not too close in frequency to the transmitter.

The levels discussed in the previous paragraph apply to interference generated in the output stages of the transmitter. In addition, harmonics and intermodulation products may be generated by non-linearity in the feeders and antennas.

Table 1 lists the services that could cause harmonic interference in a primary allocation to the RAS, from 13.36 MHz to 275 GHz, as per RR Article 5. The Table lists only cases where the second and third harmonic of a service frequency fall into the radio astronomy band.

TABLE 1

Services which could cause harmonic interference to the RAS

Band allocated to the RAS on primary basis	Regions of the World with a primary allocation	Interfering service	Harmonic of allocated frequency
13.36-13.41 MHz	1, 2, 3	AERONAUTICAL MOBILE MOBILE except aeronautical mobile	2nd 3rd
25.55-25.67 MHz	1, 2, 3	MARITIME MOBILE	2nd, 3rd
73-74.6 MHz	2	MOBILE LAND MOBILE	2nd 3rd
150.05-153 MHz	1	AERONAUTICAL RADIONAVIGATION MOBILE except aeronautical mobile BROADCASTING	2nd 2nd 3rd
322-328.6 MHz	1, 2, 3	MOBILE (Regions 2 and 3), MOBILE except aeronautical mobile (Region 1) BROADCASTING AERONAUTICAL RADIONAVIGATION	2nd 3rd 3rd
406.1-410 MHz	1, 2, 3	BROADCASTING, MOBILE (Region 3), Mobile (Region 2) SPACE OPERATION (space-to-Earth), METEOROLOGICAL-SATELLITE (space-to-Earth), SPACE RESEARCH (space-to-Earth) Mobile-satellite (space-to-Earth), MOBILE except aeronautical mobile	2nd 3rd 3rd

TABLE 1 (continued)

Band allocated to the RAS on primary basis	Regions of the World with a primary allocation	Interfering service	Harmonic of allocated frequency
608-614 MHz	2	MOBILE BROADCASTING, Mobile (Region 2)	2nd 3rd
1 400-1 427 MHz	1, 2, 3	BROADCASTING MOBILE (Region 3), Mobile (Region 2) MOBILE Meteorological-satellite (space-to-Earth)	2nd, 3rd 2nd 3rd 3rd
1 610.6- 1 613.8 MHz	1, 2, 3	BROADCASTING MOBILE	2nd, 3rd 2nd (Regions 2, 3), 3rd (Region 3)
1 660-1 670 MHz	1, 2, 3	BROADCASTING MOBILE (Regions 2 and 3)	2nd, 3rd 2nd, 3rd (Region 3)
2 690-2 700 MHz	1, 2, 3	AERONAUTICAL RADIONAVIGATION Radiolocation BROADCASTING (Regions 1 and 3) MOBILE (Region 3) MOBILE except aeronautical mobile (Regions 1 and 2)	2nd 2nd, 3rd (Region 2) 3rd 3rd 3rd
4 990-5 000 MHz	1, 2, 3	MOBILE-SATELLITE (space-to-Earth) MOBILE Radiolocation (Region 1), RADIOLOCATION (Regions 2 and 3) Radiodetermination-satellite (space-to-Earth) (Region 3); RADIODETERMINATION-SATELLITE (space-to-Earth) Mobile except aeronautical mobile	2nd 2nd 2nd 2nd 3rd
10.6-10.7 GHz	1, 2, 3	RADIOLOCATION, EARTH EXPLORATION-SATELLITE (active), SPACE RESEARCH (active) Mobile (Region 1), MOBILE except aeronautical mobile (Regions 2 and 3) FIXED-SATELLITE (space-to-Earth) Radiolocation	2nd 3rd 3rd 3rd
15.35-15.4 GHz	1, 2, 3	FIXED-SATELLITE (space-to-Earth), MOBILE except aeronautical mobile AERONAUTICAL RADIONAVIGATION	2nd 3rd
22.21-22.5 GHz	1, 2, 3	FIXED-SATELLITE (space-to-Earth), MOBILE except aeronautical mobile FIXED-SATELLITE (space-to-Earth), MOBILE except aeronautical mobile, METEOROLOGICAL-SATELLITE (space-to-Earth)	2nd 3rd
23.6-24 GHz	1, 2, 3	BROADCASTING (Regions 1 and 3) BROADCASTING-SATELLITE (Regions 1 and 3) FIXED-SATELLITE (space-to-Earth) (Region 2) MOBILE except aeronautical mobile MOBILE	2nd 2nd 2nd 2nd 3rd

TABLE 1 (continued)

Band allocated to the RAS on primary basis	Regions of the World with a primary allocation	Interfering service	Harmonic of allocated frequency
31.3-31.8 GHz	1, 2, 3	AERONAUTICAL RADIONAVIGATION RADIOLOCATION MOBILE Amateur Amateur-satellite	2nd 2nd, 3rd 3rd 3rd 3rd
42.5-43.5 GHz	1, 2, 3	MOBILE, BROADCASTING-SATELLITE (Regions 1 and 3) RADIONAVIGATION Radionavigation-satellite Space research MOBILE except aeronautical mobile	2nd 3rd 3rd 3rd 3rd
76-77.5 GHz	1, 2, 3	FIXED-SATELLITE (space-to-Earth), MOBILE, Earth exploration-satellite (space-to-Earth) INTER-SATELLITE, MOBILE, EARTH EXPLORATION-SATELLITE (space-to Earth)	2nd 3rd
79-94 GHz	1, 2, 3	FIXED-SATELLITE (space-to-Earth), MOBILE, MOBILE-SATELLITE (space-to-Earth), Earth exploration-satellite (space-to-Earth), BROADCASTING, BROADCASTING-SATELLITE, RADIONAVIGATION, RADIONAVIGATION-SATELLITE EARTH EXPLORATION-SATELLITE (space-to Earth), INTER-SATELLITE, MOBILE, Standard frequency and time signal-satellite (space-to-Earth), Space research (space-to-Earth)	2nd 3rd
94.1-116 GHz	1, 2, 3	AMATEUR, AMATEUR-SATELLITE, MOBILE, INTER-SATELLITE Mobile except aeronautical mobile, RADIONAVIGATION, SPACE RESEARCH (deep space) (space-to-Earth), INTER-SATELLITE, RADIOLOCATION, METEOROLOGICAL AIDS, EARTH EXPLORATION-SATELLITE (active), SPACE RESEARCH (active), FIXED-SATELLITE (space-to-Earth), SPACE RESEARCH (space-to-Earth)	2nd 3rd
130-134 GHz	1, 2, 3	EARTH EXPLORATION-SATELLITE, INTER-SATELLITE, MOBILE, MOBILE-SATELLITE, RADIONAVIGATION, RADIONAVIGATION-SATELLITE, SPACE RESEARCH MOBILE, MOBILE-SATELLITE, RADIONAVIGATION, RADIONAVIGATION-SATELLITE	2nd 3rd
136-158.5 GHz	1, 2, 3	INTER-SATELLITE, MOBILE, MOBILE-SATELLITE, RADIONAVIGATION, RADIONAVIGATION-SATELLITE, FIXED-SATELLITE (space-to-Earth), MOBILE-SATELLITE (space-to-Earth), BROADCASTING, BROADCASTING-SATELLITE, Space research (space-to-Earth), RADIOLOCATION, AMATEUR, AMATEUR-SATELLITE MOBILE, MOBILE-SATELLITE, RADIONAVIGATION, RADIONAVIGATION-SATELLITE, AMATEUR, AMATEUR-SATELLITE	2nd 3rd

TABLE 1 (end)

Band allocated to the RAS on primary basis	Regions of the World with a primary allocation	Interfering service	Harmonic of allocated frequency
164-167 GHz	1, 2, 3	INTER-SATELLITE MOBILE, Space research (space-to-Earth)	3rd 2nd
182-185 GHz	1, 2, 3	MOBILE RADIOLOCATION INTER-SATELLITE	2nd, 3rd 2nd, 3rd 3rd
200-231.5 GHz	1, 2, 3	MOBILE INTER-SATELLITE, MOBILE, MOBILE-SATELLITE, RADIONAVIGATION, RADIONAVIGATION-SATELLITE, Space research (space-to-Earth), AMATEUR, AMATEUR-SATELLITE, RADIOLOCATION	2nd 3rd
241-248 GHz	1, 2, 3	INTER-SATELLITE, MOBILE, Amateur, FIXED-SATELLITE (space-to-Earth), MOBILE-SATELLITE (space-to-Earth), RADIONAVIGATION, RADIONAVIGATION-SATELLITE RADIOLOCATION, Amateur, Amateur-satellite, Space research (space-to-Earth), MOBILE	2nd 3rd
250-275 GHz	1, 2, 3	FIXED-SATELLITE (space-to-Earth), EARTH EXPLORATION-SATELLITE (active), AMATEUR, AMATEUR-SATELLITE INTER-SATELLITE MOBILE MOBILE-SATELLITE (space-to-Earth) RADIONAVIGATION RADIONAVIGATION-SATELLITE RADIOLOCATION MOBILE, Space research (space-to-Earth)	2nd 2nd 2nd 2nd 2nd 2nd 2nd 3rd

3 Unwanted emissions from broadband modulation

In certain types of transmissions, often associated with data in digital form, spectral sidebands are generated over a much broader frequency band than is used in the reception of such signals. In particular, the biphase phase-shift keying (2-PSK) modulation technique produces a power spectrum of the form $(\sin x/x)^2$ with recurring subsidiary maxima outside the wanted bandwidth which decrease only slowly with frequency. If unfiltered, the sidebands which occur at about ten bandwidths (3 dB) from the carrier frequency are reduced in power spectral density only about 36 dB below the power level at the band centre. If, in addition, the keying frequency of this 2-PSK transmission is 10-20 MHz, then these ten bandwidths encompass several hundred megahertz from the assigned frequency. For example, assume a simple 2-PSK transmitter with a keying frequency of 10 MHz centred on 1 615 MHz with 40 W of power and an isotropic transmitting antenna mounted on an aircraft at a line-of-sight distance of 400 km, which is the distance of the horizon at an aircraft flying at an altitude of about 10 000 m. Unwanted emissions from this transmitter would result in a pfd level even in the band 1 400-1 427 MHz at the receiver site which is 40 dB above the detrimental interference threshold given in Table 1 to Recommendation ITU-R RA.769. Emission

in the band 1 660-1 670 MHz, also allocated to radio astronomy, would of course, be at a significantly higher level. Transmitters of this type located on spacecraft could be even more troublesome sources of interference to radio astronomy. It is important that care be taken in the design of these types of transmitters to ensure adequate suppression of the unwanted emissions.

2-PSK with a keying frequency of several megahertz is used in some types of spread-spectrum modulation. A characteristic of common spread-spectrum techniques is a wideband signal with low power density which resembles random noise. This characteristic usually reduces the possibility of these spread-spectrum systems causing interference to conventional, narrow-band communication systems, but not to the RAS. In radio astronomy, the cosmic signals have the form of random noise, and wide bandwidths are often used. At the low signal levels with which radio astronomers are concerned, there is usually no practical way to distinguish between spread-spectrum signals and cosmic signals. The detrimental thresholds of pfd for man-made signals falling within a radio astronomy band, which are given in Annex 1 to Recommendation ITU-R RA.769 apply to unwanted, as well as intentional emissions and to all types of modulation, including that discussed above. Present-day technology should allow the design of new generations of such transmitters to ensure proper suppression of the unwanted out-of-band emissions. Such transmitters could well perform without radiating far sidebands, provided the carrier phase is not switched abruptly by 180° , in the 2-PSK modulation scheme, but rather more smoothly so as to produce a power spectrum of the form $(\sin x/x)^n$ with $n > 2$. Detailed studies should be undertaken to determine how different modulation schemes affect the efficiency of such active systems and suppress the far sidebands that are adverse to the RAS.

4 Interference from satellite transmissions

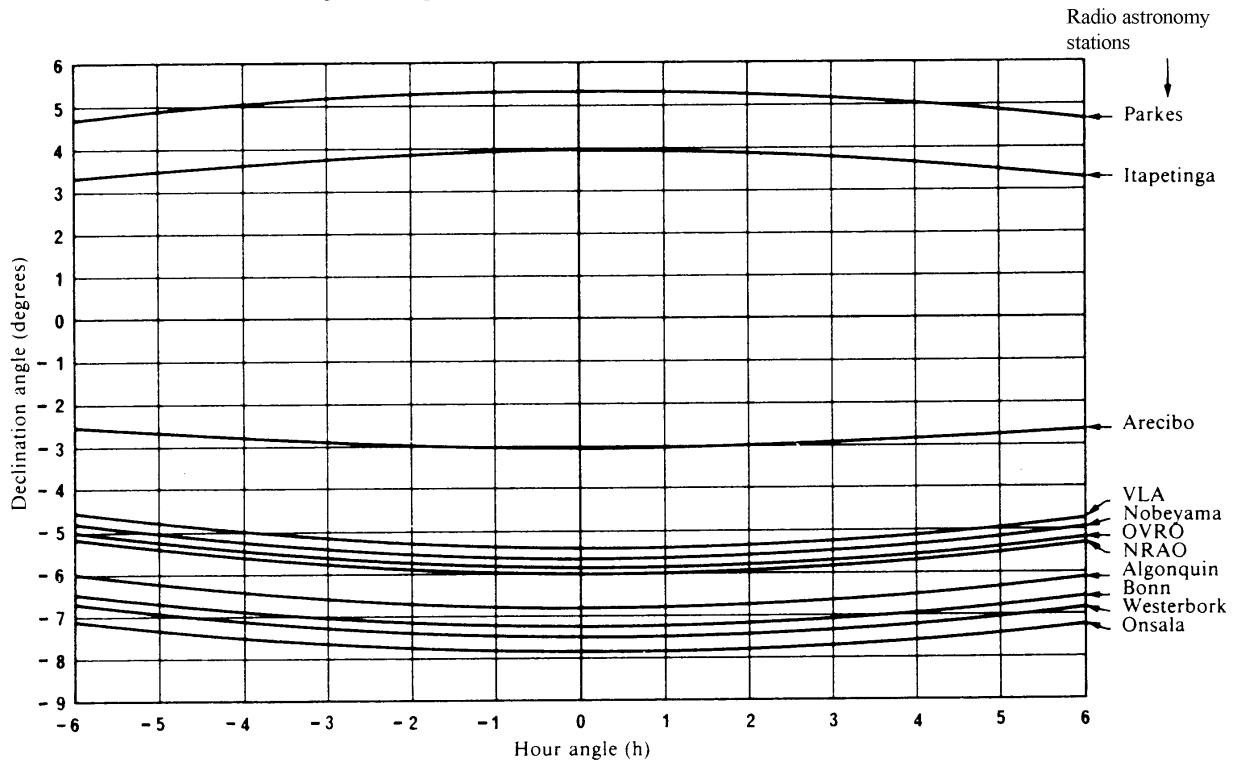
Satellite transmissions have the potential to cause severe interference to the RAS. Whereas terrestrial interference sources are usually in the far side-lobe region of the radio telescope antenna, and possibly further attenuated by the topography of the surroundings of the radio observatory, interference by satellite transmitters is likely to be received via the main beam and inner side lobes, with considerably higher gain. The nature of the interference depends on the type of transmitter and service provided by the system, whether the satellites are in GSO or non-GSO orbit, and the number of satellites in the system under consideration that are above the horizon at the radio observatory.

4.1 GSO satellites

Multiple GSO satellites are visible from almost all the radio telescopes currently in operation, and occupy a more-or-less constant range of azimuths and elevations. They have therefore the potential to cause troublesome sources of interference to radio astronomy observations. The radius of the GSO orbit is approximately 6.6 times the radius of the Earth. At that distance a single satellite can illuminate a third of the Earth's surface – and consequently many radio telescopes – with line-of-sight signals. Figure 1 shows the position of the GSO satellite belt in celestial coordinates as seen from the latitudes of some of major radio astronomy observatories. Plans for the development of some active services call for a large number of GSO satellites. Such a series of potential sources of interference that may be received through the near side lobes of the radio telescope antenna pattern could present a unique interference problem to radio astronomers.

FIGURE 1

Projection of geostationary-satellite orbit on to the celestial sphere



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Detrimental thresholds for interference to radio astronomy are given in Annex 1 to Recommendation ITU-R RA.769. Listed there is the level, in each radio astronomy band, of the power into the receiver which is just sufficient to cause detrimental interference. Also listed are the pfd's ($\text{dB}(\text{W}/\text{m}^2)$) causing detrimental interference which are calculated with the assumption that the gain of the radio telescope is 0 dBi in the direction of the interfering source. Such a gain is appropriate for consideration of terrestrial sources of interference confined to the neighbourhood of the horizon. For the case of GSO sources, the situation is different.

If we assume that the radio astronomy antenna has the side-lobe characteristics assumed in Recommendation ITU-R SA.509, the side-lobe gain would fall to 0 dBi at 19° from the axis of the main beam. For such an antenna the detrimental interference level will be exceeded if the main beam is pointed within 19° of a satellite that produces within the radio astronomy bandwidth a pfd at the radio observatory equal to the detrimental threshold in Annex 1 to Recommendation ITU-R RA.769. A series of satellites spaced at intervals of about 30° along the GSO orbit radiating interference at this level would result in a zone of width approximately 38° centred on the orbit in which radio astronomy observation free from detrimental interference would be precluded. The width of this precluded zone would increase with the number of interfering satellites in the orbit, and could, in principle, cover the whole sky. The effective number of interfering satellites will depend upon whether the interfering signals are beamed by the satellites transmitting antennas or are more widely radiated. Unwanted emissions that are not widely separated from the satellite's transmitter frequency is likely directed by the antennas in a way similar to that of the intended signals.

4.2 Non-GSO satellites

The potential for detrimental interference from non-GSO low-Earth orbit satellites is due to their operation in large numbers, which make it possible for many of them to be simultaneously above the horizon at a radio observatory, and in line-of-sight with the radio telescope antenna. This factor leads to a situation where the radio telescope antenna can receive unwanted emissions from those visible non-GSO low-Earth orbit satellites through many near and far side lobes of the antenna beam, and also through the main beam. The interference problem is exacerbated by the continually changing directions of arrival of the interfering signals, and the need for the radio telescope antenna to track the celestial source under observation. Multiple inputs of strong signals may drive the operating point of the receiver into a non-linear region, resulting in the generation of intermodulation products.

The impact of unwanted emissions produced at radio astronomy sites by a constellation of satellites in (low) non-GSO orbits may be determined using the *epfd* methodology described in Recommendation ITU-R S.1586 – Calculation of unwanted emission levels produced by a non-geostationary fixed-satellite service system at radio astronomy sites, or Recommendation ITU-R M.1583 – Interference calculations between non-geostationary mobile-satellite service or radionavigation-satellite service systems and radio astronomy telescope sites, and the antenna gains given in Recommendation ITU-R RA.1631.

These Recommendations may be used to determine the percentage of data lost encountered during observations made at a particular radio astronomy site due to interference from a given satellite system. The acceptable percentage of data lost is defined in Recommendation ITU-R RA.1513.
