RECOMMENDATION 611-2

PROTECTION OF THE RADIOASTRONOMY SERVICE FROM SPURIOUS EMISSIONS

(Question 145/7)

(1986-1990-1992)

The CCIR,

considering

a) that radioastronomy continues to be in the forefront of the expansion of scientific knowledge;

b) that the radioastronomy service 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 radioastronomy from spurious emissions (cf. Annex 1 to this Recommendation);

d) that the use of certain modulation techniques with inadequate filtering of spurious products can affect radioastronomy bands far removed from the wanted emission band;

e) that Appendix 8 to the Radio Regulations (RR) establishes the maximum permitted levels of spurious emissions from transmitters operating at frequencies below 17.7 GHz;

f) that stations in the space services operating at frequencies above 960 MHz are excluded from the application of Appendix 8 to the RR;

g) that spurious emissions from radio systems using digital modulation techniques are currently excluded from the application of Appendix 8 to the RR;

h) that radioastronomy observations are conducted in frequency bands up to, and above, 275 GHz;

j) that the technical criteria concerning harmful interference, referred to in Recommendation No. 61 of the WARC-79, should, in respect of the radioastronomy service, be those set out in Tables 1, 2 and 3 of Annex 1 to Recommendation 769 for transmitters operating outside the main beam of the radioastronomy antenna;

k) that the technical criteria for the special case of harmful interference due to spurious emissions from transmitters in geostationary space stations should, in respect of the radioastronomy service, be those set out in Annex 1 to Recommendation 769 enabling radioastronomy observations to be made at 5° or more from the geostationary-satellite orbit;

l) that progress has been made in meeting the requirements of the radioastronomy service without detrimental effects on other services;

m) that there are continuing improvements in antenna design and in techniques for filtering spurious emissions,

recommends

1. that the radioastronomy service continues to place observatories in locations which have good natural protection from harmful interference;

2. that the radioastronomy service should make all practicable efforts to minimize the side-lobe gains of radioastronomy antennas;

3. that, in bringing stations into operation in frequency bands not covered by the provisions of Appendix 8 to the RR, administrations should take into account, to the maximum extent practicable, the special risk of interference to radioastronomy observations due to spurious emissions from high-powered terrestrial stations or from space stations;

4. that, for the special case of geostationary space stations, administrations should take into account, to the maximum extent practicable, the objective of the radioastronomy service to be free of harmful interference (see Recommendation 769) from spurious emissions when observing at 5° or more from the geostationary-satellite orbit.

ANNEX 1

Interference to the radioastronomy service from spurious emissions

1. Protection criteria for the radioastronomy service

The sensitivity limit of most radioastronomy observations is at a flux-density level far below that used for reception of radiocommunication signals. Annex 1 to Recommendation 769 discusses harmful interference and protection criteria for frequency sharing between radioastronomy and other services; in Tables 1, 2 and 3 the sensitivity limits are listed for different frequencies. However, as a consequence of the sensitivity of radioastronomy observations, interference can occur from transmitters which do not share the same band. This may be classified as adjacent band interference (cf. Recommendation 517) and interference from spurious emissions of transmitters in other bands.

It should also be noted that not all types of radioastronomical measurements are as sensitive to interference as the single-antenna measurements to which Tables 1 and 2 of Annex 1 to Recommendation 769 apply. Interferometers and synthesis arrays have higher thresholds for harmful interference. However, these instruments are useful mainly for studying sources with very small angular structure, while single-antenna telescopes fulfil an important role in astronomy in observing extended sources in space.

A second criterion affecting the protection of the radioastronomy service relates to the fraction of the total sky for which radioastronomy observations are to be protected. For interferers operating from the Earth's surface a value of 0 dB is adopted for the gain of the radioastronomy antenna in the direction of the horizon. This value is adopted so that potentially interfering signals will not cause harmful interference to observations made at elevation angles greater than 19° (see Recommendation 509). The same antenna gain of 0 dB is acceptable for cases of interference from transmitters on aircraft or spacecraft in low orbit. However, for interference from geostationary spacecraft a value of +15 dB for the gain of the radioastronomy antenna is required to permit observations at 5° from the geostationary-satellite orbit (see Annex 1 to Recommendation 769).

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 radioastronomy band. Similarly, interference from inadequately filtered digitally modulated (e.g. spread-spectrum) signals can affect radioastronomy bands far removed from the carrier frequency.

Harmonic interference can occur in any band, and is generated mainly in the output 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 primary allocations of the radioastronomy service; only the second and third harmonic frequencies have been considered.

TABLE 1

Services which could cause harmonic interference to the radioastronomy service*

Band allocated to radioastronomy on world-wide primary basis	Interfering service	Harmonic of allocated frequency
13.36-13.41 MHz	Aeronautical mobile	2
25.55-25.67 MHz	Maritime mobile	2, 3
322-328.6 MHz	Mobile (Regions 2 and 3) Broadcasting Aeronautical radionavigation	2 3 3
1 400-1 427 MHz	Broadcasting Mobile Meteorological-satellite (space-to-Earth)	2, 3 2 (Regions 2, 3), 3 (Regions 2 ([1]), 3) 3 ([1])
1 610.6-1 613.8 MHz	Broadcasting Mobile	2,3 2 (Regions 2, 3), 3 (Regions 2 ([1]), 3)
1 660-1 670 MHz	Broadcasting Mobile (Regions 2 and 3) Radionavigation (Region 3)	2, 3 2, 3 (Region 3) 3
2 690-2 700 MHz	Aeronautical radionavigation Radiolocation Broadcasting (Regions 1 and 3) Mobile (Region 3)	2 2 ([1]), 3 ([1]) 3 3
4 990-5 000 MHz	Mobile satellite (space-to-Earth) Mobile Radiolocation ISM Radiodetermination-satellite (space-to-Earth)	2 2 2 (Region 1 ([1])) 2 2 (Regions 2, 3 ([1]))
10.6-10.7 GHz	Radiolocation Mobile (Region 1) Fixed-satellite (space-to-Earth)	2, 3 3 ([1]) 3
15.35-15.4 GHz	Fixed-satellite (space-to-Earth) Aeronautical radionavigation	2 3
22.21-22.5 GHz	Fixed-satellite (space-to-Earth)	2, 3
23.6-24 GHz	Broadcasting (Regions 1 and 3) Broadcasting-satellite (Regions 1 and 3) Fixed-satellite (Region 2) Mobile	2 2 2 3

* Fixed and mobile except aeronautical mobile services are not included.

([1]) Secondary allocation.

TABLE 1 *(continued)*

Band allocated to radioastronomy on world-wide primary basis	Interfering service	Harmonic of allocated frequency
31.3-31.8 GHz	Aeronautical radionavigation Radiolocation Mobile Amateur Amateur-satellite	2 2, 3 3 3 (1) 3 (1)
42.5-43.5 GHz	Mobile Radionavigation Radionavigation-satellite Space research	2 3 3 (1) 3 (1)
86-92 GHz	Mobile Mobile-satellite Radionavigation Radionavigation-satellite Standard signals-Satellite (space-to-Earth)	2, 3 2 2 2 3 (1)
105-116 GHz	Inter-satellite Mobile Space research Meteorological aids Radiolocation Fixed-satellite (space-to-Earth)	2 2, 3 3 (1) 3 3 3
164-168 GHz	Fixed-satellite (space-to-Earth) Mobile Mobile-satellite (space-to-Earth) Inter-satellite	2 2, 3 2 3
182-185 GHz	Mobile Radiolocation Inter-satellite ISM	2, 3 2, 3 3 3
217-231 GHz	Mobile Amateur Amateur-satellite Radiolocation	3 3 3 3
265-275 GHz	Inter-satellite Mobile Mobile-satellite Radionavigation Radionavigation-satellite Radiolocation	2 2 2 2 2 2

(1) Secondary allocation.

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 power flux-density level even in the band 1 400-1 427 MHz at the receiver site which is 40 dB above the harmful interference threshold given in Table 1 to Recommendation 769. Emission in the band 1 660-1 670 MHz, also allocated to radioastronomy, 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 radioastronomy. 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 radioastronomy service. In radioastronomy, the cosmic signals have the form of random noise, and wide bandwidths are often used. At the low signal levels with which radioastronomers are concerned, there is usually no practical way to distinguish between spread-spectrum signals and cosmic signals. The harmful thresholds of power flux-density for man-made signals falling within a radioastronomy band, which are given in Annex 1 to Recommendation 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 radioastronomy service.

4. Interference from satellite transmissions

Satellite transmissions, in particular those associated with television and sound broadcasting, may cause severe interference to radioastronomy. By the nature of a satellite broadcasting system, large areas of the Earth will be illuminated and line-of-sight conditions will exist. Terrestrial interfering sources are normally in the far side-lobe region of a radio telescope, whereas a satellite transmission is likely to be received also in the main beam and near side lobes, with considerably higher gain. For example, as far as 5° from the main beam, the gain may be 25 dB higher than in the far side-lobe region (see Recommendation 509).

Geostationary satellites which are above the horizon at any observatory could be particularly troublesome. The radius of the geostationary-satellite orbit is approximately 6.6 times the radius of the Earth. The position of the orbit in celestial coordinates as seen from the latitudes of a number of major radioastronomy observatories is shown in Fig. 1. A severe problem of interference to radioastronomy observations could result as large numbers of geostationary satellites are put into service. A solution to this problem clearly involves a compromise between the area of sky lost to radioastronomy observations and the difficulty of suppressing unwanted emissions from the satellites. In considering the area of sky lost to radioastronomy, it should be noted that Fig. 1 indicates that if observations can be made to within a distance of about 5° from the geostationary-satellite orbit, each position in the sky can be observed from at least one existing observatory provided that it is suitably equipped.

The discussion of radiation from geostationary satellites presented above is based upon the assumption that the orbits of such satellites are located in the equatorial plane of the Earth. The effect of the orbital inclinations will depend upon the distribution of inclination angles of those geostationary satellites whose transmissions are potential sources of interference to radioastronomy. This effect requires further study.

In addition to geostationary satellites, one can expect a rise in the number of non-geostationary satellites used by some active services. The nature of such orbits will render the problem even more complex since the radio telescopes will have to look through an ever-changing grid of satellite networks. Active services foresee using such satellites more and more in the future (for instance radionavigation and low Earth orbit satellites of the mobile-satellite service). While numerous studies are carried out in order to decrease the side-lobe levels of present and future radio telescopes, such effort may be frustrated by the proliferation of non-geostationary satellites. Not only will the area of sky accessible to radioastronomers be considerably reduced but the scheduling of radio observations may become impracticable. This problem merits further study.

FIGURE 1

Projection of geostationary-satellite orbit on to the celestial sphere