RECOMMENDATION ITU-R RA.1237

PROTECTION OF THE RADIO ASTRONOMY SERVICE FROM UNWANTED EMISSIONS RESULTING FROM APPLICATIONS OF WIDEBAND DIGITAL MODULATION

(Question ITU-R 145/7)

(1997)

The ITU Radiocommunication Assembly,

considering

a) that the radio astronomy service and other passive services continue to make important and substantial contributions to science;

b) that progress in research in radio astronomy depends critically upon the ability to make observations at the extreme limits of sensitivity;

c) that all services benefit from measures which reduce or remove unwanted emissions in the spectrum;

d) that transmitters, particularly those in space stations, are increasingly employing direct sequence spread spectrum (DSSS) and other wideband digital modulation techniques which can produce unwanted emission sidebands extending to frequencies far removed from the carrier frequency as discussed in Annex 1;

e) that technical means to filter unwanted emission sidebands have been developed and successfully used;

f) that spectrally efficient digital modulation techniques are known, which produce intrinsically low levels of unwanted emissions, and such techniques have been demonstrated;

g) that the definitions in the Radio Regulations (RR) do not provide a clear or adequate distinction between out of-band and spurious components of unwanted emissions;

h) that, from the point of view of the victim service in an allocated band outside the band allocated to the service producing the unwanted emissions, there is no practical distinction between spurious and out-of-band interference,

recommends

1 that, for systems employing wideband digital modulation techniques, all practicable steps be taken to reduce the level of sidebands which fall outside the band allocated to the service;

2 that, in establishing limits to unwanted emissions in bands for which the radio astronomy service has a primary allocation, note should be taken of the threshold levels of interference specified in Recommendation ITU-R RA.769.

ANNEX 1

Interference to radio astronomy from unwanted (spurious and out-of-band) emissions

1 Introduction

Experience over more than two decades has shown that most of the seriously damaging interference to radio astronomy has originated from transmitters on satellites. Most such interference has resulted from unwanted emissions, i.e. intermodulation effects and extended sidebands of digital transmissions, sometimes extending many megahertz outside the assigned band of the satellite transmitter. An observatory site that is well shielded from terrestrial transmitters offers no protection from satellite emissions, and satellites are not accessible for retrofitting of filters or other mitigating techniques. Thus unwanted emissions from satellites are the most serious threat to the radio astronomy service, especially in view of the present rapid expansion of satellite usage.

2 Spurious and out-of-band emissions from digital modulation

The use of digital modulation including direct sequence spread spectrum (DSSS) modulation can result in extended sidebands. The description of these sidebands in terms of spurious emission or out-of-band emission, as defined in the RR, Article 1, 138-140, is not entirely clear. Out-of-band emission results from the modulation process, as do the spread spectrum sidebands, but it is defined as *immediately* outside the necessary bandwidth. This is commonly interpreted to mean that the frequency range of out-of-band emissions is a few times wider than the necessary bandwidth. Spurious emission is outside the necessary bandwidth and may be reduced without affecting the corresponding transmission of information, both of which characteristics are true of spread spectrum sidebands. Sidebands of this type can cause serious interference in an adjacent band or one more widely separated in frequency, as will be shown in § 5.1.

3 Interference levels for radio astronomy

Studies of the levels at which interfering signals become harmful to radio astronomy are given in Recommendation ITU-R RA.769. These are in the form of power-flux density (PFD) and spectral power-flux-density (SPFD) at the radio astronomy antenna, and are calculated for a representative series of radio astronomy bands across the spectrum. Interference levels specified in this form are widely applicable to the large number of active services that may cause interference to radio astronomy. The results from Recommendation ITU-R RA.769 are summarized in Table 1.

Appendix 8 of the RR specifies limits on spurious emissions in terms of the power into the transmission line of an antenna. To interpret such limits in terms of interference to radio astronomy, details of the transmitting antenna characteristics for each potential source of interference would need to be known, as well as the path losses between such transmitting antennas and any radio astronomy antenna. Furthermore, limits of this form are inappropriate in the case of active antenna arrays where there is no one single transmitter output port. Such considerations lead to the suggestion that emission limits can best be specified in terms of the effective isotropically radiated power (e.i.r.p.) in the direction of a radio observatory.

As an example of the use of e.i.r.p., consider the case of a transmitter on a geostationary satellite. Because any such satellite is visible above the horizon from a large area of the Earth, it is likely to present sidelobes in the direction of one or more radio observatories. However, the downlink footprint may cover a relatively small area of the Earth which may not include a radio observatory. Thus a satellite system designer may choose to reduce the sidelobe responses as one step in avoiding interference to radio astronomy. This would be possible if the limits are specified in terms of the e.i.r.p. in the direction of an observatory. However, if the limits are specified in terms of power into the antenna transmission line, as is currently the case in Appendix 8, then it would be necessary to assume, as a worst case, that the full gain of the transmitting antenna might be directed towards an observatory. Such limits could be much more difficult to meet. It thus appears that values of e.i.r.p. in the direction of a radio astronomy antenna provide a more appropriate form in which to specify the limits on unwanted emissions for the protection of radio astronomy. This conclusion applies equally well to any other type of transmission including those from ground based transmitters. The e.i.r.p. values can be derived from the values of PFD or SPFD in Recommendation ITU-R RA.769 so long as the propagation loss is known.

It should also be noted that in interference calculations the levels of unwanted emissions must be known in absolute terms, rather than as decibels relative to the main transmission. In many cases the unwanted emission is well removed in frequency from the main transmission, and the victim service and the main transmission occupy different allocated bands. It is therefore logical to specify the limits in absolute units of power, pfd or spfd, rather than as a fraction of the main emission.

4 Interference from satellites

For satellites, it can generally be assumed that there is a line-of-sight transmission path so only the distance of the satellite is required to determine the path loss. Table 1 gives values of the PFD and SPFD at Earth-based radio telescopes that correspond to the threshold limits quoted in Recommendation ITU-R RA.769 for the various radio astronomy bands. In cases where Recommendation ITU-R RA.769 gives values for observations of both continuum and spectral line radiation, the value in Table 1 is either the lower value of the limit or the one most appropriate to the usage of the band. These values are based on reception in the 0 dBi sidelobes of the radio astronomy antenna. Note that for the particular case of geostationary satellites, the interference limits for radio astronomy are 15 dB lower than the values in Table 1, to allow observations to within 5° of the satellites in the geostationary orbit, as explained in Annex 1 of Recommendation ITU-R RA.769.

For a transmitter on a satellite, we take the nearest distance of approach to an observatory to be equal to the height of the satellite, h (m), above the Earth's surface. The e.i.r.p. limit (dBW) is equal to the PFD in column 2 of Table 1 plus the following spreading-loss factor:

$$20 \log h + 11.0 \qquad \text{dB} \qquad (1)$$

Similarly, the e.i.r.p. limit (dB(W/Hz)) is equal to the sum of the SPFD in column 3 of Table 1 and expression (1). For a satellite in an orbit that is approximately circular, expression (1) can also be specified in terms of the orbital period, t (s), and is equal to:

$$20 \log (2.161 \times 10^4 \, t^{2/3} - 6.378 \times 10^6) + 11.0 \qquad \text{dB} \qquad (2)$$

Values of the spreading-loss factor in expressions (1) and (2) are given in Table 2 for various values of h and t.

5 Unwanted emissions from satellites of particular concern to radio astronomy

5.1 Direct sequence spread spectrum

In the absence of pulse shaping, this type of modulation results in a power spectrum that has the form of a sinc-squared function of frequency with very extensive sidebands. If f is frequency measured from the carrier frequency and T is the basic period of the spreading function, the form of the spectrum is:

$$(\sin (\pi f T) / (\pi f T))^2 \qquad (3)$$

The peak power levels in the sidebands fall away as f^{-2}, i.e. only 6 dB per octave in f. In the worst case the spectrum that is radiated follows expression (3) over a wide frequency range, and can cause serious interference to radio astronomy at frequencies well removed from the carrier. However, in systems that employ such techniques it is generally true that only the central maximum of the transmitted spectrum is accepted by the IF filters of the receiver, so the additional sidebands are unwanted emissions.

Very serious interference resulting from spread spectrum sidebands has occurred from the GLONASS radionavigation satellites which operate in the band 1 597-1 617 MHz, and radiate a spectrum closely represented by expression (3). Severe interference is caused to radio astronomy in the band 1 610.6-1 613.8 MHz by satellites for which the wanted emission is well outside this band. Serious interference from GLONASS is also experienced as far away as the 1 660-1 670 MHz radio astronomy band. In the case of the GLONASS signals the spectrum also shows frequency spikes (i.e. narrow-band components) in the minima between the sinc pattern lobes. These result from non-ideal performance of the modulator and can be particularly troublesome to radio astronomy measurements of narrow spectral lines. The somewhat similar Global Positioning System (GPS) uses satellites with DSSS transmissions centred at 1 575.42 MHz. The second generation of GPS satellites cause very much less interference to radio astronomy, in spite of the use of spreading functions with chip frequencies approximately twice those of GLONASS. The reason is not only the greater frequency separation from the radio astronomy bands, but better filtering of the far sidebands and the absence of the narrow-band frequency spikes in the spectrum. Plans to eliminate GLONASS interference to radio astronomy by a combination of moving the required frequencies away from the radio astronomy band and including additional filtering in the satellites have resulted from discussions between the GLONASS Administration and the Inter-Union Commission for the Allocation of Frequencies for Radio astronomy and Space Science (IUCAF), and first steps to relieve the situation have now been taken. Nevertheless, the GLONASS problem stands as a clear warning of the danger of unfiltered DSSS from satellites to radio astronomy.

TABLE 1

Interference threshold levels for radio astronomy observations in bands for which there is a primary allocation

Radio astronomy band	PFD (dB(W/m^2))	SPFD (dB(W/(m^2·Hz))
13.36-13.41 MHz	–201	–248
25.55-25.67 MHz	–199	–249
73.0-74.6 MHz	–196	–258
150.05-153.0 MHz	–194	–259
322.0-328.6 MHz	–204	–258
406.1-410.0 MHz	–189	–255
608-614 MHz	–185	–253
1 400-1 427 MHz	–196	–255
1 610.6-1 613.8 MHz	–194	–238
1 660-1 670 MHz	–194	–251
2 690-2 700 MHz	–177	–247
4 990-5 000 MHz	–171	–241
10.6-10.7 GHz	–160	–240
15.35-15.4 GHz	–156	–233
22.21-22.5 GHz	–162	–233
23.6-24.0 GHz	–161	–233
31.3-31.8 GHz	–141	–228
42.5-43.5 GHz	–153	–227
86-92 GHz	–144	–222
105-116 GHz	–141	–222
164-168 GHz	–136	–216
182-185 GHz	–135	–216
217-231 GHz	–133	–215
265-275 GHz	–131	–213

TABLE 2

Space-to-Earth propagation loss

Height of satellite, *h* (km)	Orbital period[(1)], *t*		Spreading loss (dB)
	(s)	(h)	
250	5 371	1.49	119
500	5 678	1.58	125
750	5 990	1.66	128
1 000	6 308	1.75	131
2 000	7 633	2.12	137
5 000	12 081	3.36	145
10 000	20 865	5.80	151
20 000	42 646	11.8	157
35 800[(2)]	86 164	23.93	162

(1) For satellite in circular orbit.

(2) Geostationary satellite (period equals one sidereal day). Note that for this case the allowable PFD or SPFD should be reduced by 15 dB to allow observations by the radio astronomy service to within 5° of a satellite in the geostationary orbit (see Recommendation ITU-R RA.769, § 2.1 of Annex 1).

Elimination of the unwanted sidebands of spread spectrum near the carrier by means of filters at the carrier frequency may not be practicable if the spread spectrum carrier is close to the radio astronomy band. An alternative approach to reducing the unwanted sidebands is to modify the modulation process so as to attenuate them. Accurate spectrum shaping can be achieved through modern digital processing techniques (for example Gaussian filtered minimum shift keying) acting at the baseband level on spread spectrum signals.

Problems of satellite interference from extended sidebands of spread spectrum or other unwanted emissions could arise as a result of allocations for space-to-Earth transmissions of the mobile-satellite service in the bands 137-138 MHz, 387-390 MHz and 400.15-401 MHz. The radio astronomy bands in this case are 150.05-153 MHz, 322-328.6 MHz, 406.1-410 MHz and possibly 608-614 MHz. It is expected that transmissions in many of these cases will involve DSSS. The radio astronomy bands involved are some of those used for observation of the highly redshifted emissions of the line of neutral hydrogen which allows investigation of the most distant parts of the universe. For such studies, the radio astronomy bands at frequencies below 1 400 MHz provide a unique capability, of the greatest scientific importance, that cannot be replaced by observations in other frequency bands. The new giant metre-wave radio telescope in India is an example of a major facility designed specifically to pursue research in this area of science, and it would be severely incapacitated by the loss of the bands mentioned above.

5.2 Phase modulation of digital signals

Transmission of digital data using binary phase-shift keying (BPSK) or quadrature phase-shift keying (QPSK) modulation results in spectra of the same sinc-squared form as DS spread spectrum. In this case, T in expression (3) represents one bit period if BPSK is used and twice the bit period if QPSK is used. For high data rates the sidebands can be as troublesome as those of spread spectrum. The same solutions, filtering or attenuating the sidebands in the modulation process, can be applied.

An example of another form of wideband digital modulation which could be a problem to radio astronomy results from the World Administrative Radio Conference for Dealing with Frequency Allocations in Certain Parts of the Spectrum (Malaga-Torremolinos, 1992) (WARC-92) allocation of the band 1 452-1 492 MHz to digital audio broadcasting (DAB). This is for use by both terrestrial and satellite transmissions. Sidebands of such transmissions falling within the 1 400-1 427 MHz radio astronomy band, if not sufficiently attenuated, could exceed the interference threshold for radio astronomy. An adopted form of modulation, coded orthogonal frequency division multiplex (COFDM), consists of 1 536 individual carriers, each QPSK modulated, and with a power spectrum of the form described by expression (3) with $T = 1.25$ ms. Each is a narrow-band digital modulation channel. The carriers are spaced 1 kHz apart. The resulting composite power spectrum is flat over a 1.54 MHz band and falls abruptly by approximately 45 dB at the band edge. The far out sideband level falls approximately as f^{-2}, where f is frequency measured from the composite band centre. Additional filtering may be necessary to avoid the aggregate unwanted sideband spfd exceeding the radio astronomy interference threshold. Such filtering may not be deleterious to the operation of the COFDM system which is specifically designed to be tolerant of additional filtering. Should some alternative form of modulation be used for DAB in this band, there might be an interference problem which should be addressed through coordination between terrestrial DAB and radio astronomy.

6 Spurious and out-of-band emissions from terrestrial transmitters

Spurious and out-of-band emissions from terrestrial transmitters are less troublesome to radio astronomy than emissions from satellites or aircraft, because radio astronomy observatories are generally located at remote sites chosen to take advantage of terrain shielding. However, as the mobile-satellite service develops it is expected that uplink transmissions from terrestrial stations in the 1 610-1 626.5 MHz band will be in conflict with radio astronomy usage of the band 1 610.6-1 613.8 MHz. Since both services have primary allocations in the 1 610.6-1 613.8 MHz band, coordination will be necessary. Uplinks of some systems will use DSSS transmissions, and without coordination interference can be caused by the sidebands of these, even when the wanted central lobe of the emitted spectrum falls outside the radio astronomy band.