International Telecommunication Union

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Recommendation ITU-R RA.1237-2
(01/2010)

Protection of the radio astronomy service from unwanted emissions resulting from applications of wideband digital modulation

RA Series
Radio astronomy

International Telecommunication Union

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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 RA.1237-2*

Protection of the radio astronomy service from unwanted emissions resulting from applications of wideband digital modulation

(Question ITU-R 145/7)

(1997-2003-2010)

Scope

This Recommendation is concerned with the protection of the radio astronomy service from unwanted emissions resulting from applications of wideband digital modulation. Technical information is provided in Annex 1, especially on interference levels to radio astronomy from satellite systems. The Recommendation recommends that for systems employing wideband digital modulation techniques all practicable steps be taken to reduce unwanted emissions.

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 Resolution **739 (Rev.WRC-15)** defines a consultation procedure, to be followed when the unwanted emissions of some space service downlinks that operate in specific bands exceed the detrimental interference level in certain radio astronomy bands;

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

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

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

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 domain and out-of-band domain interference,

noting

a) that examples of satellite systems utilizing DSSS modulation that may cause interference to radio astronomy station are given in Report ITU-R SM.2091,

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* Radiocommunication Study Group 7 made editorial amendments to this Recommendation in the year 2017 in accordance with Resolution ITU-R 1.

recommends

1 that, for systems employing wideband digital modulation techniques, all practicable steps should be taken to reduce the level of sidebands which fall outside the band allocated to the service, taking into account the guidance provided in Annex 1.

Annex 1

Interference to radio astronomy from unwanted (spurious and out-of-band) emissions resulting from applications of wideband digital modulation

1 Introduction

Experience has shown that much of the seriously damaging interference to radio astronomy originates from transmitters on satellites. Most such interference has resulted from unwanted emissions, i.e. intermodulation and other non-linear effects and extended sidebands of digital transmissions, sometimes extending many times the allocated bandwidth 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 expansion of satellite usage for many purposes.

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

The use of digital modulation including DSSS modulation can result in extended sidebands. The description of these sidebands in terms of spurious emission or out-of-band emission, is defined in Nos. 1.144 to 1.146 of the Radio Regulations (RR). 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 yet further 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. Mainly for the purpose of clarification of the definitions, the domains concept for unwanted emissions has been developed (see RR Nos. 1.146A and 1.146B).

3 Interference levels for radio astronomy

Threshold levels at which interfering signals become detrimental to radio astronomy are given in Recommendation ITU-R RA.769. These are in the form of received power at the antenna port, spectral density of received power, 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.

RR Appendix 3 specifies limits on spurious emissions in terms of the power into the transmission line of an antenna. However, these limits were not defined with the protection of passive services in mind, and may therefore be insufficient for the protection of the RAS in certain cases. In addition, 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 side lobes 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 side lobe 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 RR Appendix 3, 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

Interference in the RAS station comes from either GSO or non-GSO satellite service downlinks. In the first case the interference will not vary in either location. In the second case, the interference power will vary both in time and location in the sky. As a result, both are treated separately.

In bands where continuum observations predominate, the bandwidth used to compute the detrimental interference threshold level is the width of the band allocated to the RAS (from Table 1 of Recommendation ITU-R RA.769). In bands where spectral line observations predominate the channel bandwidth used to compute the interference threshold levels is the assumed spectral line channel bandwidth of the RAS receiver (from Table 2 of Recommendation ITU-R RA.769).

4.1 Unwanted emissions from GSO satellite systems (downlink)

The pfd of unwanted emissions can be assessed as follows:

$$pfd_{unwantedemission} = \int_{f_1}^{f_2} \frac{p(f)\,.\,g(f)}{SL\,.\,ATM(f)}\,\mathrm{d}f \qquad (1)$$

where:

$pfd_{unwanted\ emissions}$: pfd at the RAS station (W/m^2)

f_1, f_2: lower and upper edge respectively of the RAS reference bandwidth (Hz)

$p(f)$: unwanted emission power density at the transmission antenna flange (W/Hz)

$g(f)$: gain of the transmission antenna in the direction of the radio astronomy site

SL: spreading loss (dB)

$ATM(f)$: atmospheric absorption in the band $f_1 – f_2$ as a function of frequency.

It should be noted that the power density of the transmitted signal, the gain of the antenna sub-system, and the atmospheric absorption vary with frequency and as such are represented as functions of frequency. The pfd of unwanted emissions at the location of the RAS station is the integral of these functions as shown above over the passband frequency of the receiver. In cases where the unwanted emission power density, the antenna gain, and the atmospheric absorption are constant throughout the bandwidth of the passive service receiver, the function can be simplified as follows:

$$pfd_{unwantedemission} = \frac{p \cdot g}{SL \, . \, ATM}\left(f_2 - f_1\right) \tag{2}$$

In cases where the active band is adjacent to the passive band, it may be possible to assume that the transmission antenna gain remains approximately constant in both the transmission band and the passive band. However this may often not be the case, particularly when the passive band is below the cut-off frequency of the waveguide feed network in the antenna sub-system.

This pfd level then needs to be compared to the threshold levels contained in Recommendation ITU-R RA.769.

4.2 Unwanted emissions from non-GSO satellite systems (downlink)

To evaluate interference from non-GSO fixed-satellite service (FSS) systems to stations in the RAS, in addition to the calculation above giving the pfd of one particular satellite, the methodology of Recommendation ITU-R S.1586 should be used. Likewise, to evaluate interference from non-GSO mobile-satellite service (MSS) and radionavigation-satellite service (RNSS) systems to stations in the RAS, the methodology of Recommendation ITU-R M.1583 should be used.

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:

$$(\sin(\pi f T) / (\pi f T))^2 \tag{3}$$

The peak power levels in the sidebands fall away as f^{-2}, i.e. only 6 dB/ octave in f. In the worst case the spectrum that is radiated follows equation (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. This may not be the case for RNSS signals which may require taking into account also the side lobes in the correlation process to obtain sufficient precision in the location determined by the system (see Report ITU-R SM.2091).

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.

In order to meet the threshold levels detrimental to the radio astronomy service, systems using DSSS need to lower the levels of sidebands using a combination of filtering and spectrum shaping. These techniques have already been used in all RNSS systems in operation, although further improvements might be needed in the future in some of these systems.

Problems of satellite interference from extended sidebands of spread spectrum or other unwanted emissions could also 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. The radio astronomy bands involved are some of those used for observation of the highly red shifted 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.

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 equation (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 allocation of the band 1 452-1 492 MHz to digital audio broadcasting (DAB), used 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 equation (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 often less troublesome to radio astronomy than emissions from satellites or aircraft, because radio astronomy observatories are frequently located at remote sites chosen to take advantage of terrain shielding. However, as an example, uplink transmissions from terrestrial stations in the 1 610-1 626.5 MHz band could conflict with radio astronomy usage of the band 1 610.6-1 613.8 MHz. Since the radio astronomy service has a primary allocation in the 1 610.6-1 613.8 MHz band, which is also protected by RR Nos. 5.364 and 5.372 from unwanted emissions of the MSS operating in the band 1 610-1 626.5 MHz, coordination may be necessary. Uplinks of some systems may 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.