

## RECOMMENDATION ITU-R RA.769-2

**Protection criteria used for radio astronomical measurements**

(Question ITU-R 145/7)

(1992-1995-2003)

The ITU Radiocommunication Assembly,

*considering*

- a) that many of the most fundamental astronomical advances made in the past five decades, (e.g. the discovery of radio galaxies, quasars, and pulsars, the direct measurement of neutral hydrogen, the direct measurement of distances of certain external galaxies, and establishment of a positional reference frame accurate to  $\sim 20$  arc  $\mu$ s) have been made through radio astronomy, and that radio astronomical observations are expected to continue making fundamental contributions to our understanding of the Universe, and that they provide the only way to investigate some cosmic phenomena;
- b) that the development of radio astronomy has also led to major technological advances, particularly in receiving and imaging techniques, and to improved knowledge of fundamental radio-noise limitations of great importance to radiocommunication, and promises further important results;
- c) that radio astronomers have made useful astronomical observations from the Earth's surface in all available atmospheric windows ranging from 2 MHz to 1 000 GHz and above;
- d) that the technique of space radio astronomy, which involves the use of radio telescopes on space platforms, provides access to the entire radio spectrum above about 10 kHz, including parts of the spectrum not accessible from the Earth due to absorption in atmosphere;
- e) that protection from interference is essential to the advancement of radio astronomy and associated measurements;
- f) that radio astronomical observations are mostly performed with high-gain antennas or arrays, to provide the highest possible angular resolution, and consequently main beam interference does not need to be considered in most situations, except when there is the possibility of receiver damage;
- g) that most interference that leads to the degradation of astronomical data is received through the far side lobes of the telescope;
- h) that the sensitivity of radio astronomical receiving equipment, which is still steadily improving, particularly at millimetre wavelengths, and that it greatly exceeds the sensitivity of communications and radar equipment;
- j) that typical radio astronomical observations require integration times of the order of a few minutes to hours, but that sensitive observations, particularly of spectral lines, may require longer periods of recording, sometimes up to several days;

- k) that some transmissions from spacecraft can introduce problems of interference to radio astronomy and that these cannot be avoided by choice of site for an observatory or by local protection;
- l) that interference to radio astronomy can be caused by terrestrial transmissions reflected by the Moon, by aircraft, and possibly by artificial satellites;
- m) that some types of high spatial-resolution interferometric observations require simultaneous reception, at the same radio frequency, by widely separated receiving systems that may be located in different countries, on different continents, or on space platforms;
- n) that propagation conditions at frequencies below about 40 MHz are such that a transmitter operating anywhere on the Earth might cause interference detrimental to radio astronomy;
- o) that some degree of protection can be achieved by appropriate frequency assignments on a national rather than an international basis;
- p) that WRCs have made improved allocations for radio astronomy, particularly above 71 GHz, but that protection in many bands, particularly those shared with other radio services, may still need careful planning;
- q) that technical criteria concerning interference detrimental to the radio astronomy service (RAS) have been developed, which are set out in Tables 1, 2, and 3,

*recommends*

- 1** that radio astronomers should be encouraged to choose sites as free as possible from interference;
- 2** that administrations should afford all practicable protection to the frequencies and sites used by radio astronomers in their own and neighbouring countries and when planning global systems, taking due account of the levels of interference given in Annex 1;
- 3** that administrations, in seeking to afford protection to particular radio astronomical observations, should take all practical steps to reduce all unwanted emissions falling within the band of the frequencies to be protected for radio astronomy to the absolute minimum. Particularly those emissions from aircraft, high altitude platform stations, spacecraft and balloons;
- 4** that when proposing frequency allocations, administrations take into account that it is very difficult for the RAS to share frequencies with any other service in which direct line-of-sight paths from the transmitters to the observatories are involved. Above about 40 MHz sharing may be practicable with services in which the transmitters are not in direct line-of-sight of the observatories, but coordination may be necessary, particularly if the transmitters are of high power.

## Annex 1

### Sensitivity of radio astronomy systems

#### 1 General considerations and assumptions used in the calculation of interference levels

##### 1.1 Detrimental-level interference criterion

The sensitivity of an observation in radio astronomy can be defined in terms of the smallest power level change  $\Delta P$  in the power level  $P$  at the radiometer input that can be detected and measured. The sensitivity equation is:

$$\frac{\Delta P}{P} = \frac{1}{\sqrt{\Delta f_0 t}} \quad (1)$$

where:

$P$  and  $\Delta P$ : power spectral density of the noise

$\Delta f_0$ : bandwidth

$t$ : integration time.  $P$  and  $\Delta P$  in equation (1) can be expressed in temperature units through the Boltzmann's constant,  $k$ :

$$\Delta P = k \Delta T; \quad \text{also} \quad P = k T \quad (2)$$

Thus we may express the sensitivity equation as:

$$\Delta T = \frac{T}{\sqrt{\Delta f_0 t}} \quad (3)$$

where:

$$T = T_A + T_R$$

This result applies for one polarization of the radio telescope.  $T$  is the sum of  $T_A$  (the antenna noise temperature contribution from the cosmic background, the Earth's atmosphere and radiation from the Earth) and  $T_R$ , the receiver noise temperature. Equations (1) or (3) can be used to estimate the sensitivities and interference levels for radio astronomical observations. The results are listed in Tables 1 and 2. An observing (or integration) time,  $t$ , of 2000 s is assumed, and interference threshold levels,  $\Delta P_H$ , given in Tables 1 and 2 are expressed as the interference power within the bandwidth  $\Delta f$  that introduces an error of 10% in the measurement of  $\Delta P$  (or  $\Delta T$ ), i.e.:

$$\Delta P_H = 0.1 \Delta P \Delta f \quad (4)$$

In summary, the appropriate columns in Tables 1 and 2 may be calculated using the following methods:

- $\Delta T$ , using equation (3),
- $\Delta P$ , using equation (2),
- $\Delta P_H$ , using equation (4).

The interference can also be expressed in terms of the pfd incident at the antenna, either in the total bandwidth or as a spectral pfd,  $S_H$ , per 1 Hz of bandwidth. The values given are for an antenna having a gain, in the direction of arrival of the interference, equal to that of an isotropic antenna (which has an effective area of  $c^2/4\pi f^2$ , where  $c$  is the speed of the light and  $f$  the frequency). The gain of an isotropic radiator, 0 dBi, is used as a general representative value for the side-lobe level, as discussed under § 1.3.

Values of  $S_H \Delta f$  (dB(W/m<sup>2</sup>)), are derived from  $\Delta P_H$  by adding:

$$20 \log f - 158.5 \quad \text{dB} \quad (5)$$

where  $f$  (Hz).  $S_H$  is then derived by subtracting  $10 \log \Delta f$  (Hz) to allow for the bandwidth.

## 1.2 Integration time

The calculated sensitivities and interference levels presented in Tables 1 and 2 are based on assumed integration times of 2000 s. Integration times actually used in astronomical observations cover a wide range of values. Continuum observations made with single-antenna telescopes (as distinct from interferometric arrays) are well represented by the integration time of 2000 s, typical of good quality observations. On the other hand 2000 s is less representative of spectral line observations. Improvements in receiver stability and the increased use of correlation spectrometers have allowed more frequent use of longer integration times required to observe weak spectral lines, and spectral line observations lasting several hours are quite common. A more representative integration time for these observations would be 10 h. For a 10 h integration, the threshold interference level is 6 dB more stringent than the values given in Table 2. There are also certain observations of time varying phenomena, e.g. observations of pulsars, stellar or solar bursts, and interplanetary scintillations for which much shorter time periods may be adequate.

## 1.3 Antenna response pattern

Interference to radio astronomy is almost always received through the antenna side lobes, so the main beam response to interference need not be considered.

The side-lobe model for large paraboloid antennas in the frequency range 2 to 30 GHz, given in Recommendation ITU-R SA.509 is a good approximation of the response of many radio astronomy antennas and is adopted throughout this Recommendation as the radio astronomy reference antenna. In this model, the side-lobe level decreases with angular distance (degrees) from the main beam axis and is equal to  $32 - 25 \log \phi$  (dBi) for  $1^\circ < \phi < 48^\circ$ . The effect of an interfering signal clearly depends upon the angle of incidence relative to the main beam axis of the antenna, since the side-lobe gain, as represented by the model, varies from 32 to -10 dBi as a function of this angle. However, it is useful to calculate the threshold levels of interference strength for a particular value of side-lobe gain, that we choose as 0 dBi, and use in Tables 1 to 3. From the model, this side-lobe level occurs at an angle of  $19.05^\circ$  from the main beam axis. Then a signal at the detrimental threshold level defined for 0 dBi side-lobe gain will exceed the criterion for the detrimental level at the receiver input if it is incident at the antenna at an angle of less than  $19.05^\circ$ . The solid angle

within a cone of angular radius  $19.05^\circ$  is 0.344 sr, which is equal to 5.5% of the  $2\pi$  sr of the sky above the horizon that a radio telescope is able to observe at any given time. Thus if the probability of the angle of incidence of interference is uniformly distributed over the sky, about 5.5% of interfering signals would be incident within  $19.05^\circ$  of the main beam axis of an antenna pointed towards the sky. Note also that the 5.5% figure is in line with the recommended levels of data loss to radio astronomy observations in percentage of time, specified in Recommendation ITU-R RA.1513.

The particular case of non-GSO satellites presents a dynamic situation, that is, the positions of the satellites relative to the beam of the radio astronomy antenna show large changes within the time scale of the 2000 s integration time. Analysis of interference in this case requires integrating the response over the varying side-lobe levels, for example, using the concept of epfd defined in No. 22.5C of the Radio Regulations (RR). In addition it is usually necessary to combine the responses to a number of satellites within a particular system. In such calculations it is suggested that the antenna response pattern for antennas of diameter greater than  $100 \lambda$  in Recommendation ITU-R S.1428 be used to represent the radio astronomy antenna, until a model based specifically on radio astronomy antennas is available; see § 2.2 for further discussion.

#### 1.4 Bandwidth

Equation (1) shows that observations of the highest sensitivity are obtained when radio astronomers make use of the widest possible bandwidth. Consequently, in Table 1 (continuum observations),  $\Delta f$  is assumed to be the width of the allocated radio astronomy bands for frequencies up to 71 GHz. Above 71 GHz a value of 8 GHz is used, which is a representative bandwidth generally used on radio astronomy receivers in this range. In Table 2 (spectral line observations) a channel bandwidth  $\Delta f$  equal to the Doppler shift corresponding to 3 km/s in velocity is used for entries below 71 GHz. This value represents a compromise between the desired high spectral resolution and the sensitivity. There are a very large number of astrophysically important lines above 71 GHz, as shown in Recommendation ITU-R RA.314 and only a few representative values for the detrimental levels are given in Table 2 for the range 71-275 GHz. The channel bandwidth used to compute the detrimental levels above 71 GHz is 1 000 kHz (1 MHz) in all cases. This value was chosen for practical reasons. While it is slightly wider than the spectral channel width customary in radio astronomy receivers at these frequencies, it is used as the standard reference bandwidth for space services above 15 GHz.

#### 1.5 Receiver noise temperature and antenna temperature

The receiver noise temperatures in Tables 1 and 2 are representative of the systems in use in radio astronomy. For frequencies above 1 GHz these are cryogenically cooled amplifiers or mixers. The quantum effect places a theoretical lower limit of  $hf/k$  on the noise temperature of such devices, where  $h$  and  $k$  are Planck's and Boltzmann's constants, respectively. This limit becomes important at frequencies above 100 GHz, where it equals 4.8 K. Practical mixers and amplifiers for bands at 100 GHz and higher provide noise temperatures greater than  $hf/k$  by a factor of about four. Thus, for frequencies above 100 GHz, noise temperatures equal to  $4hf/k$  are used in Tables 1 and 2.

The antenna temperatures in the Tables are also representative of practical systems in use in radio astronomy. They include the effects of the ionosphere or the neutral atmosphere, ground pickup in side lobes resulting from spillover or scattering, ohmic losses, and the cosmic microwave background. At frequencies above 100 GHz the atmospheric losses due to water vapour in the neutral atmosphere become very important. For these frequencies the values given are typical of the terrestrial sites used for major millimetric-wave radio astronomy facilities, such as Mauna Kea, Hawaii, or the Llano de Chajnantor at an elevation of 5 000 m in Chile, which is the site chosen for a major international radio astronomy array for frequencies in the range 30 GHz to 1 THz.

## 2 Special cases

The levels given in Tables 1 and 2 are applicable to terrestrial sources of interfering signals. The detrimental pfd and spectral pfd shown in Tables 1 and 2 assume that interference is received through a 0 dBi side lobe, and should be regarded as the general interference criteria for high sensitivity radio astronomy observations, when the interference does not enter the near side lobes.

### 2.1 Interference from GSO satellites

Interference from GSO satellites is a case of particular importance. Because the power levels in Tables 1 and 2 were calculated based on a 0 dBi antenna gain, interference detrimental to radio astronomy will be encountered when a reference antenna, such as described in Recommendation ITU-R SA.509, is pointed within  $19.05^\circ$  of a satellite radiating at levels in accordance with those listed in the Tables. A series of such transmitters located around the GSO would preclude radio astronomy observations with high sensitivity from a band of sky  $38.1^\circ$  wide and centred on the orbit. The loss of such a large area of sky would impose severe restrictions on radio astronomy observations.

In general, it would not be practical to suppress the unwanted emissions from satellites to below the detrimental level when the main beam of a radio telescope is pointed directly towards the satellite. A workable solution is suggested by observing the projection of the GSO in celestial coordinates as viewed from the latitudes of a number of major radio astronomy observations (see Recommendation ITU-R RA.517). If it were possible to point a radio telescope to within  $5^\circ$  of the GSO without encountering detrimental interference, then for that telescope a band of sky  $10^\circ$  wide would be unavailable for high-sensitivity observations. For a given observatory this would be a serious loss. However, for a combination of radio telescopes located at northern and southern latitudes, operating at the same frequencies, the entire sky would be accessible. A value of  $5^\circ$  should therefore be regarded as the requirement for minimum angular spacing between the main beam of a radio astronomy antenna and the GSO.

In the model antenna response of Recommendation ITU-R SA.509, the side-lobe level at an angle of  $5^\circ$  from the main beam is 15 dBi. Thus, to avoid interference detrimental to a radio telescope meeting the antenna side-lobe performance of Recommendation ITU-R SA.509, pointed to within  $5^\circ$  of the transmitter, it is desirable that the satellite emissions be reduced 15 dB below the pfd given in Tables 1 and 2. When satellites are spaced at intervals of only a few degrees along the GSO, the emission levels associated with the individual transmitters must be even lower to meet the requirement that the sum of the powers of all the interfering signals received should be 15 dB below  $\Delta P_H$  in Tables 1 and 2.

It is recognized that the emission limitations discussed above cannot, in practice, be achieved so as to enable sharing of the same frequency band between radio astronomy and down-link transmissions from satellites to take place. The limitations are, however, applicable to unwanted emission from the satellite transmitters, which fall within the radio astronomy bands listed in Tables 1 and 2. These emission limitations have implications for the space services responsible for the interference, which require careful evaluation. Furthermore, the design of new radio astronomy antennas should strive to minimize the level of side-lobe gain near the main beam as an important means of reducing interference from transmitters in the GSO.

## 2.2 Interference from non-GSO satellites

In the case of non-GSO satellites, and in particular for low-Earth orbit satellites, the systems usually involve constellations of many individual satellites. Thus determination of interference levels requires analysis of the combined effect of many signals, most of which are received through far side lobes of the radio astronomy antenna. A more detailed side-lobe model than that of Recommendation ITU-R SA.509 is therefore desirable, and it is proposed that the model in Recommendation ITU-R S.1428 be used until such time as a more representative model for radio astronomy antennas is obtained. In using this proposed model the case for antennas with diameter greater than  $100 \lambda$  is generally appropriate for radio astronomy applications. It should be noted that Note 1 of Recommendation ITU-R S.1428, which allows cross-polarized components to be ignored, cannot be applied since radio astronomy antennas generally receive signals in two orthogonal polarizations simultaneously. The motion of non-GSO satellites across the sky during a 2000 s integration period requires that the interference level be averaged over this period, that is, the response to each satellite must be integrated as the satellite moves through the side-lobe pattern. One system of analysis that includes these requirements is the *epfd* method described in RR No. 22.5C. Values of *epfd* represent the pfd of a signal entering the antenna through the centre of the main beam that would produce an equivalent level of interference power. Since the threshold levels of detrimental interference in Tables 1 and 2 correspond to pfd received with an antenna gain of 0 dBi, it is necessary to compare them with values of  $(epfd + G_{mb})$ , where  $G_{mb}$  is the main beam gain, to determine whether the interference exceeds the detrimental level. Making use of the *epfd* method, Recommendation ITU-R S.1586 has recently been developed for interference calculations between radio astronomy telescopes and FSS non-GSO satellite systems. A similar Recommendation, Recommendation ITU-R M.1583 was developed for interference calculations between radio astronomy telescopes and MSS and radionavigation-satellite service non-GSO satellite systems. The applicability of the protection criteria given in Tables 1 and 2 is described in Recommendation ITU-R RA.1513.

## 2.3 The response of interferometers and arrays to radio interference

Two effects reduce the response to interference. These are related to the frequency of the fringe oscillations that are observed when the outputs of two antennas are combined, and to the fact that the components of the interfering signal received by different and widely-spaced antennas will suffer different relative time delays before they are recombined. The treatment of these effects is more complicated than that for single antennas in § 1. Broadly speaking, if the strength of the received interfering signal remains constant, the effect is reduced by a factor roughly equal to the

mean time of one natural fringe oscillation divided by the data averaging time. This typically ranges from some seconds for a compact array with the longest projected spacing  $L' \sim 10^3 \lambda$ , where  $\lambda$  is the wavelength, to less than 1 ms for intercontinental arrays with  $L' \sim 10^7 \lambda$ . Thus, compared to a single radio telescope, the interferometer has a degree of immunity to interference which, under reasonable assumptions increases with the array size expressed in wavelengths.

The greatest immunity from interference occurs for interferometers and arrays in which the separation of the antennas is sufficiently great that the chance of occurrence of correlated interference is very small (e.g. for very long baseline interferometry (VLBI)). In this case, the above considerations do not apply. The tolerable interference level is determined by the requirement that the power level of the interfering signal should be no more than 1% of the receiver noise power to prevent serious errors in the measurement of the amplitude of the cosmic signals. The interference levels for typical VLBI observations are given in Table 3, based on the values of  $T_A$  and  $T_R$  given in Table 1.

It must be emphasized that the use of large interferometers and arrays is generally confined to studies of discrete, high-brightness sources, with angular dimensions no more than a few tenths of a second of arc for VLBI. For more general studies of radio sources, the results in Tables 1 and 2 apply and are thus appropriate for the general protection of radio astronomy.



TABLE 1

## Threshold levels of interference detrimental to radio astronomy continuum observations

Centre frequency <sup>(1)</sup> $f_c$ (MHz)	Assumed bandwidth $\Delta f$ (MHz)	Minimum antenna noise temperature $T_A$ (K)	Receiver noise temperature $T_R$ (K)	System sensitivity <sup>(2)</sup> (noise fluctuations)		Threshold interference levels <sup>(2) (3)</sup>		
				Temperature $\Delta T$ (mK)	Power spectral density $\Delta P$ (dB(W/Hz))	Input power $\Delta P_H$ (dBW)	pdf $S_H \Delta f$ (dB(W/m <sup>2</sup> ))	Spectral pdf $S_H$ (dB(W/(m <sup>2</sup> · Hz)))
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
13.385	0.05	50 000	60	5 000	-222	-185	-201	-248
25.610	0.12	15 000	60	972	-229	-188	-199	-249
73.8	1.6	750	60	14.3	-247	-195	-196	-258
151.525	2.95	150	60	2.73	-254	-199	-194	-259
325.3	6.6	40	60	0.87	-259	-201	-189	-258
408.05	3.9	25	60	0.96	-259	-203	-189	-255
611	6.0	20	60	0.73	-260	-202	-185	-253
1 413.5	27	12	10	0.095	-269	-205	-180	-255
1 665	10	12	10	0.16	-267	-207	-181	-251
2 695	10	12	10	0.16	-267	-207	-177	-247
4 995	10	12	10	0.16	-267	-207	-171	-241
10 650	100	12	10	0.049	-272	-202	-160	-240
15 375	50	15	15	0.095	-269	-202	-156	-233
22 355	290	35	30	0.085	-269	-195	-146	-231
23 800	400	15	30	0.050	-271	-195	-147	-233
31 550	500	18	65	0.083	-269	-192	-141	-228
43 000	1 000	25	65	0.064	-271	-191	-137	-227
89 000	8 000	12	30	0.011	-278	-189	-129	-228
150 000	8 000	14	30	0.011	-278	-189	-124	-223
224 000	8 000	20	43	0.016	-277	-188	-119	-218
270 000	8 000	25	50	0.019	-276	-187	-117	-216

<sup>(1)</sup> Calculation of interference levels is based on the centre frequency shown in this column although not all regions have the same allocations.

<sup>(2)</sup> An integration time of 2 000 s has been assumed; if integration times of 15 min, 1 h, 2 h, 5 h or 10 h are used, the relevant values in the Table should be adjusted by +1.7, -1.3, -2.8, -4.8 or -6.3 dB respectively.

<sup>(3)</sup> The interference levels given are those which apply for measurements of the total power received by a single antenna. Less stringent levels may be appropriate for other types of measurements, as discussed in § 2.2. For transmitters in the GSO, it is desirable that the levels be adjusted by -15 dB, as explained in § 2.1.

TABLE 2\*

## Threshold levels of interference detrimental to radio astronomy spectral-line observations

Frequency $f$ (MHz)	Assumed spectral line channel bandwidth $\Delta f$ (kHz)	Minimum antenna noise temperature $T_A$ (K)	Receiver noise temperature $T_R$ (K)	System sensitivity <sup>(2)</sup> (noise fluctuations)		Threshold interference levels <sup>(1) (2)</sup>		
				Temperature $\Delta T$ (mK)	Power spectral density $\Delta P_S$ (dB(W/Hz))	Input power $\Delta P_H$ (dBW)	pdf $S_H \Delta f$ (dB(W/m <sup>2</sup> ))	Spectral pdf $S_H$ (dB(W/(m <sup>2</sup> · Hz)))
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
327	10	40	60	22.3	-245	-215	-204	-244
1 420	20	12	10	3.48	-253	-220	-196	-239
1 612	20	12	10	3.48	-253	-220	-194	-238
1 665	20	12	10	3.48	-253	-220	-194	-237
4 830	50	12	10	2.20	-255	-218	-183	-230
14 488	150	15	15	1.73	-256	-214	-169	-221
22 200	250	35	30	2.91	-254	-210	-162	-216
23 700	250	35	30	2.91	-254	-210	-161	-215
43 000	500	25	65	2.84	-254	-207	-153	-210
48 000	500	30	65	3.00	-254	-207	-152	-209
88 600	1 000	12	30	0.94	-259	-209	-148	-208
150 000	1 000	14	30	0.98	-259	-209	-144	-204
220 000	1 000	20	43	1.41	-257	-207	-139	-199
265 000	1 000	25	50	1.68	-256	-206	-137	-197

\* This Table is not intended to give a complete list of spectral-line bands, but only representative examples throughout the spectrum.

<sup>(1)</sup> An integration time of 2 000 s has been assumed; if integration times of 15 min, 1 h, 2 h, 5 h or 10 h are used, the relevant values in the Table should be adjusted by +1.7, -1.3, -2.8, -4.8 or -6.3 dB respectively.

<sup>(2)</sup> The interference levels given are those which apply for measurements of the total power received by a single antenna. Less stringent levels may be appropriate for other types of measurements, as discussed in § 2.2. For transmitters in the GSO, it is desirable that the levels need to be adjusted by -15 dB, as explained in § 2.1.

COLUMN DESCRIPTIONS FOR TABLES 1 AND 2

**Column**

- (1) Centre frequency of the allocated radio astronomy band (Table 1) or nominal spectral line frequency (Table 2).
- (2) Assumed or allocated bandwidth (Table 1) or assumed typical channel widths used for spectral line observations (Table 2).
- (3) Minimum antenna noise temperature includes contributions from the ionosphere, the Earth's atmosphere and radiation from the Earth.
- (4) Receiver noise temperature representative of a good radiometer system intended for use in high sensitivity radio astronomy observations.
- (5) Total system sensitivity (mK) as calculated from equation (1) using the combined antenna and receiver noise temperatures, the listed bandwidth and an integration time of 2 000 s.
- (6) Same as (5) above, but expressed in noise power spectral density using the equation  $\Delta P = k \Delta T$ , where  $k = 1.38 \times 10^{-23}$  (J/K) (Boltzmann's constant). The actual numbers in the Table are the logarithmic expression of  $\Delta P$ .
- (7) Power level at the input of the receiver considered harmful to high sensitivity observations,  $\Delta P_H$ . This is expressed as the interference level which introduces an error of not more than 10% in the measurement of  $\Delta P$ ;  $\Delta P_H = 0.1 \Delta P \Delta f$ . the numbers in the Table are the logarithmic expression of  $\Delta P_H$ .
- (8) pfd in a spectral line channel needed to produce a power level of  $\Delta P_H$  in the receiving system with an isotropic receiving antenna. The numbers in the Table are the logarithmic expression of  $S_H \Delta f$ .
- (9) Spectral pfd needed to produce a power level  $\Delta P_H$  in the receiving system with an isotropic receiving antenna. The numbers in the Table are the logarithmic expression of  $S_H$ . To obtain the corresponding power levels in a reference bandwidth of 4 kHz or 1 MHz add 36 dB or 60 dB, respectively.

TABLE 3

**Threshold interference levels for VLBI observations**

Centre frequency (MHz)	Threshold level (dB(W/m <sup>2</sup> · Hz))
325.3	-217
611	-212
1 413.5	-211
2 695	-205
4 995	-200
10 650	-193
15 375	-189
23 800	-183
43 000	-175
86 000	-172