

International Telecommunication Union

**ITU-R**  
Radiocommunication Sector of ITU

**Report ITU-R RA.2188-1**  
(10/2022)

**Power flux-density and e.i.r.p. levels  
potentially damaging to radio  
astronomy receivers**

**RA Series**  
**Radio astronomy**



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*Note: This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.*

*Electronic Publication  
Geneva, 2022*

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## REPORT ITU-R RA.2188-1

**Power flux-density and e.i.r.p. levels potentially damaging to radio astronomy receivers**

(Question ITU-R 145/7)

(2010-2022)

**1 General explanation of concerns**

Telescopes of the radio astronomy service (RAS) are designed to achieve strong isolation from ambient radiation and have been placed in remote locations whenever possible, to enable detection of cosmic phenomena wherever they may occur on the sky (although typically above about 5-degree elevation). However, both cosmic and man-made signals which cross the main beam are received with very high gain, owing to the large apertures needed to detect weak cosmic signals. For man-made signals the combination of high receiving gain and high incident signal strength could suffice to permanently degrade the performance of a RAS receiver, or perhaps even destroy it. This Report describes the means by which the corresponding incident power flux-density (pfd) may be ascertained.

The nature of the possible damage of concern to the RAS is not necessarily complete burnout of the receiver input stages. Because the RAS has large investments in antenna collecting area it is necessary to use this most efficiently, so a long-term degradation of even 10% in the noise figure of a receiver input would be sufficient to warrant replacement. Servicing of input stages is time-consuming and expensive since cycling of cryogenic systems is involved and recent RAS instruments employ arrays of antennas and/or receiving elements numbering anywhere from tens to hundreds.

Receivers used by the RAS are designed to provide the lowest possible receiver noise temperatures to allow study of the widest possible range of astronomical signal levels. Receiver input stages are coupled directly to the antenna outputs without input filters or other components, since even very small losses can introduce significant levels of thermal noise. The amplifiers and mixers used in the input stages for high frequency observations necessarily require components with very small physical dimensions which limit their power-handling capacity.

Because the amplifier or mixer in RAS receivers is usually fed directly from the output of the antenna feed, damage can occur even if the transmitter frequency does not fall within the receiver passband. On the low-frequency side the damage is generally confined by waveguide cut off at the throat of the horn to frequencies no less than 0.6 times the centre frequency of the feed horn. On the high side the power delivered to the receiver by a horn feed will decrease by approximately 6 dB per octave as the beamwidth of the feed decreases, and by a further factor depending on the response of the coupling circuitry from the feed to the amplifier or mixer input. This second factor will depend upon the particular design of the coupling.

Two main types of low-noise input stages are presently used by the RAS, corresponding approximately to observations at frequencies below or above 90 GHz, and these are discussed separately below. The Heterostructure Field-Effect Transistor (HFET) low-noise transistor amplifiers which are used up to 90 GHz (and which are the only kind used below 70 GHz) are somewhat more susceptible to damage than the superconducting Superconductor-Insulator-Superconductor (SIS) mixers which are mainly employed above 90 GHz.

## 2 Conversion from empirically-determined, device-specific damaging power input levels to corresponding incident pfd and e.i.r.p.

Let  $P_d$  (W) be the empirically-determined power level that will cause damage at the receiver input and assume that this results from a pfd  $F_d$  (W/m<sup>2</sup>) incident on an RAS antenna. If the direction of the transmitter falls on the axis of the RAS main beam and the effective collecting area of the antenna is  $A_e$  (m<sup>2</sup>), then  $P_d = A_e F_d$  and:

$$F_d = P_d / A_e \quad (1)$$

Tables 1 and 2 give values of the empirically-determined  $P_d$  and derived  $F_d$  for various frequencies with RAS antennas of circular aperture and an assumed aperture efficiency of 0.7. The sizes of RAS antennas shown are those widely used for arrays (12 and 25 m) or for large single dishes (100 m). Also given in the last column of either table is an example of the radiated e.i.r.p. which will produce the specified  $F_d$  at a distance  $D = 400$  km corresponding to a satellite in low Earth orbit and assuming free space propagation, calculated as:

$$e.i.r.p._d = 4\pi D^2 P_d \quad (2)$$

## 3 Values of the damaging input power levels $P_d$ and corresponding incident pfd $F_d$

### 3.1 Frequencies up to 90 GHz: HFET amplifiers

HFET amplifiers are used as low-noise input stages for frequencies up to approximately 90 GHz and the maximum safe input power levels for such devices lie in the range  $P_d = 5$ -15 mW. It is difficult to give more precise figures for the maximum levels because the damage depends not only upon the characteristics of the transistors but also on the impedances presented by the circuits in which they are used. Such impedances can vary by factors of two or more over the bandwidth of an individual amplifier. The damage which has been observed during testing is believed to be largely due to voltage breakdown between the gate and the source or drain and thus should not be a function of gate width, as it would be for damage by thermal effects. However, it is expected that amplifiers used at higher frequencies would be more easily damaged than those at lower frequencies.

Here is used  $P_d = 15$  mW (−18 dBW) as a maximum safe input level for the frequency range 1-20 GHz,  $P_d = 10$  mW (−20 dBW) for 20-50 GHz and  $P_d = 5$  mW (−23 dBW) for 50 to 90 GHz. Table 1 gives derived values of the corresponding incident power flux-density  $F_d$  for frequencies up to 90 GHz.

### 3.2 Frequencies above 90 GHz: SIS mixer input stages

In RAS receivers for frequencies greater than about 90 GHz, SIS mixers are almost universally used. Unlike HFET transistor amplifiers, SIS mixers are not available commercially and are produced in small quantities to the specifications of individual observatories. As a result, the characteristics of SIS mixers in use in radio astronomy, including the damage levels, vary more widely than those for HFETs. Damage levels for SIS mixers result mainly from thermal effects, and are inversely proportional to the total junction area within the mixer and the thermal resistance for the transmission of heat generated within the junction to the outside. Tests made on two niobium SIS junctions have been used to estimate the corresponding levels for other junctions from calculations of the thermal resistance.

Table 2 shows the damaging input power levels for a number of SIS mixers currently in use at several observatories. A single SIS mixer can consist of up to six junctions in series, and in sideband-

separating mixers the input signal is divided between two mixer elements. Therefore, Table 2 shows the area for each junction and the number of junctions within the mixer, which are the quantities from which the damage power is calculated. The diameter of the antennas used at the particular observatories is also shown, and from this the corresponding potentially-damaging incident pfd levels  $F_d$  at the antennas have been determined using equation (1). As in Table 1, these pfd levels and equation (2) are used to calculate the corresponding e.i.r.p. at a separation distance of 400 km assuming free-space propagation.

#### 4 Summary: Threshold levels of the incident power flux-density

The entries in Tables 1 and 2 show that incident pfd above  $-60$  dB(W/m<sup>2</sup>) are potentially damaging at frequencies up to 90 GHz, while incident power flux-densities above  $-45$  dB(W/m<sup>2</sup>) are potentially damaging at frequencies above 90 GHz. Threshold power levels are lower at the higher frequencies in part due to the use of smaller antennas and in part because the SiS receivers used at higher frequencies are expected to be more robust. Note that, to order of magnitude, the input power levels capable of damaging radio astronomy receivers correspond to a voltage drop of approximately 1 V across 50  $\Omega$ , i.e. 20 mW.

TABLE 1  
Representative antenna diameters and values of  $F_d$ ,  
the potentially damaging pfd for HFET input stages from 1-90 GHz

Frequency (GHz)	RA antenna diameter (m)	RA antenna effective area (m <sup>2</sup> )	$P_d$ (mW)	$F_d$ (dB(W/m <sup>2</sup> ))	e.i.r.p. <sub>d</sub> at 400 km (dBW)
1-20	25	344	15	-43	80
1-20	100	5 500	15	-55	68
20-50	25	344	10	-45	78
20-50	100	5 500	10	-57	66
50-90	25	344	5	-48	75
50-90	100	5 500	5	-60	63

TABLE 2  
Representative values of  $F_d$ , the potentially damaging pfd for SIS mixer receivers  
at 90-275 GHz, for representative radio astronomy sites

Observatory <sup>(1)</sup>	Junction area ( $\mu\text{m}^2$ )	Number of junctions	Antenna diameter (m)	Antenna effective area (m <sup>2</sup> )	$P_d$ (mW)	$F_d$ (dB(W/m <sup>2</sup> ))	e.i.r.p. <sub>d</sub> at 400 km (dBW)
ALMA	3.8	8	12	79.2	55	-32	91
CARMA 6 m	1.21	1	6	19.8	4	-37	86
CARMA 6 m	2.24	1	6	19.8	5	-36	87
CARMA 10 m	1.44	2	10	55.0	9	-38	85
CARMA 10 m	3.8	4	10	55.0	27	-33	90
IRAM Bure	4.0	2	15	124	14	-40	83

TABLE 2 (*end*)

Observatory <sup>(1)</sup>	Junction area ( $\mu\text{m}^2$ )	Number of junctions	Antenna diameter (m)	Antenna effective area ( $\text{m}^2$ )	$P_d$ (mW)	$F_d$ (dB(W/m <sup>2</sup> ))	e.i.r.p. <sub>d</sub> at 400 km (dBW)
IRAM Veleta	2.25	6	30	495	32	−42	81
IRAM Veleta	1.44	4	30	495	17	−45	78
Kitt Peak	8.55	6	12	79.2	62	−31	92
Onsala	4.01	2	20.1	222	14	−42	81

<sup>(1)</sup> Observatory locations are: ALMA, Atacama desert, Chile; CARMA, Cedar Flat, California, United States of America; IRAM, Plateau de Bure, France and Pico Veleta, Spain; Kitt Peak, Arizona, United States of America; Onsala, Sweden. For more information on these and other radio telescope sites (<http://www.iucaf.org> or <http://tinyurl.com/yrvszk>).

## Annex 1

### Operational concerns relevant to avoidance of damage

RAS operators will always program or otherwise protect their instruments so as to avoid possibly-damaging situations, if they are aware that such situations could occur. The need to protect an instrument may influence its basic design as well as its future operations.

To prevent damage to an RAS receiver it is necessary to avoid any situation in which the RAS antenna points toward a transmitter that is producing a pfd at the RAS antenna equal to, or greater than, the corresponding value of  $F_d$  in Tables 1 and 2. In practice this requires either that the transmitting service avoids pointing the transmitting antenna in a direction such that an RAS observatory falls within its main beam, or that the RAS operator avoids pointing near the transmitter. In general the latter option is possible if the RAS operator is given forewarning of any such event, including the location and operational properties of the transmitter. Approximate beamwidths for antennas in Tables 1 and 2 are shown in Table 3. These range from just under one degree down to one quarter of an arcminute, so the probability of a main-beam encounter by chance is not large. However, in the case of a large antenna array such as ALMA which contains approximately 60 dual-polarization receivers, the damage resulting from a main beam encounter could be very costly.

The Cloudsat cloud profiling radar of the Earth exploration-satellite service (EESS), operating in a shared RAS-EESS band at 94-94.1 GHz in accordance with RR Nos. **5.562** and **5.562A** and described in Annex 2 of Recommendation ITU-R RA.1750, provides an example of potentially damaging transmissions whose effect upon RAS receivers has been successfully mitigated by ongoing provision of orbital elements and exchange of other information between the RAS and the EESS. The peak transmitter power is 1 kW, the peak transmitting antenna gain is 63 dBi, and the orbital height is 705 km, resulting in a peak pfd of −35 dB(W/m<sup>2</sup>), 10 dB above the threshold levels of the incident pfd given in Table 2. For Cloudsat the transmitting antenna points toward the nadir, so main-beam to main-beam coupling may occur only if the RAS antenna is pointing toward the zenith, which simplifies the avoidance problem. However, implementations of similarly high-powered 94 GHz radar are presently being flown on aircraft and driven on trucks in the vicinity of several mm-wave telescopes.

Other high power satellite radars, in operation or proposed, include synthetic aperture radars (SARs) in the EESS near 5 GHz and 9.6 GHz such as RISAT and TerraSar-X. For these, the orientation of the transmitting antenna beam can fall within a large range of angle with respect to the nadir, greatly complicating the problem of avoidance on the part of the RAS operator. Information on these and other EESS missions of concern is available from the Space Frequency Coordination Group<sup>1</sup>. EESS radars using the spectrum bands 9.2-9.4 and 9.9-10.4 GHz are subject to RR No. **5.474B** and should not directly illuminate radio astronomy sites without advance notice as discussed in Recommendation ITU-R RS.2066.

TABLE 3  
Approximate half power beamwidths for some frequencies  
and antenna diameters used in Tables 1 and 2

Frequency (GHz)	RAS antenna diameter (m)	Half-power beamwidth (arcmin)
1	25	50
	100	12
10	25	5
	100	1.2
50	12	2.1
	25	1.0
100	100	0.25
	12	1.0
200	25	0.5
	6	1.0
	12	0.5

<sup>1</sup> <https://www.sfcgonline.org/Resources/Radio%20Astronomy/default.aspx>