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| U.S. Radiocommunication SectorFact Sheet |
| **Working Party:** ITU-R WP 7D | **Document No:** USWP7D\_24-08\_NC |
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| **Document Title:** Updates to Working Document towards a Preliminary Draft Revision of Report ITU-R RA.2188-1 |
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| **Purpose/Objective:** This contribution provides input toward an update to ITU-R RA.2188, based on U.S. RAS experiences |
| **Abstract:** At the last WP7D meeting, an update to ITU-R RA.2188-1 was proposed (Annex 10 of 7D/41). Here we contribute for consideration input for the proposed update, based on experiences from current operation of RAS receivers, as well as design and development of next generation RAS instrumentation. |

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| **Radiocommunication Study Groups** |  |
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| Source: Document Annex 10 to 7D/41-ESubject: Revision of Report [ITU-R RA.2188](https://www.itu.int/pub/R-REP-RA.2188) |  |
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| English only |
| United States of America |
| UPDATES TO WORKING DOCUMENT TOWARDS A PRELIMINARY DRAFT REVISION OF REPORT ITU-R RA.2188-1 |
| Power flux-density and e.i.r.p. levels potentially damagingto radio astronomy receivers |

Summary

Report ITU-R RA.2188 contains levels of power that are potentially damaging for radio astronomy receivers. Based on an informal survey among several European RAS stations, which have state-of-the-art receiver design teams, the numbers provided in Report ITU-R RA.2188 do not match well the real equipment used in European observatories. The Report quotes a typical range of maximum RF powers, which a FET-based low noise amplifier (LNA) could tolerate at maximum below about 90 GHz, of 1 to 15 mW, corresponding to 0 to 12 dBm. However, most existing LNAs at real RAS stations (suited for use under cryogenic temperatures) – self-designed or bought of the shelf – would break at 0 dBm, some even at –10 dBm. Values of 10 dBm may still be realistic at lower frequencies (i.e. below 1 GHz and perhaps below a few GHz for some models), but further investigation is required.

While custom-built LNAs at observatories are rarely put under destruction tests (too costly), there are several vendors offering state-of-the-art cyrogenic LNAs. As technology has advanced significantly in recent years, these can often compete with self-made models and many observatories are buying LNAs off-the-shelf, at least for receivers at frequencies below few 10 GHz. Some examples are provided in the References below, and the manufactures often provide maximum tolerable RF powers in their datasheets. It is very likely, that self-made RAS LNAs would have similar breakpoints, as this is mostly defined by semiconductor materials and FET dimensions (e.g., gate length).

As the Report uses the upper range value of 12 dBm for its tables (which are referenced by other ITU-R deliverables), the numbers used in coordination may be up to 20 dB too high for real telescope receivers, which puts the sensitive and expensive equipment at risk.

Therefore, it is proposed to update Report ITU-R RA.2188 in order to fix this strong discrepancy. Furthermore, some additional text could be added to reflect more recent developments in LNA design, especially with regards to the used semiconductor materials.

Additional edits over Annex 10 of Document 7D/41-E and comments from the United States are provided with track changes and marked with turquoise highlighting.

References

<https://lownoisefactory.com/product-category/cryogenic-amplifier/>

<https://www.amplitechinc.com/categories/cryogenic-amplifiers>

<https://www.cosmicmicrowavetechnology.com/cryogenic-low-noise-amplifiers>

**Attachment**: 1

ATTACHMENT

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](https://www.itu.int/pub/R-QUE-SG07.145))

(2010-2022-2023)

{Editor’s Note: There are several proposed changes in this document that are included without supporting material. These changes are based on the characteristics of prototypes, commercial devices, or off-the-shelf devices. Before updating the ITU-R documentation to match these types of equipment, it is necessary for this information to be carefully considered in terms of compatibility with other radio communication services.}

# 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 limited to complete burnout of the receiver input stages and also includes permanent degradation of receiver performance due to repeated exposure to lower power signals. 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 100 GHz, and these are discussed separately below. The LNAs, which are based on Field-Effect Transistors (FET), such as Heterostructure Field-Effect Transistor (HFET) or high-electron mobility transistors (HEMT) are usually employed at frequencies up to 100 GHz, although first prototypes have been presented, which work up to about 200 GHz. Over the years, many different materials have been used for these, such as gallium-arsenide (GaAs), gallium-nitride (GaN), or indium-phosphid (InP), which allowed to significantly improve noise performance, operating frequency, and bandwidth. For low-frequency receivers (up to several GHz), also silicon-germanium (SiGe) heterojunction bipolar transistors (HBT) based amplifiers can be used. FET-based receivers are somewhat more susceptible to damage than the superconducting Superconductor-Insulator-Superconductor (SIS) mixers which are mainly employed above about 100 GHz.

With the improvement of commercial off-the-shelf devices, there are also more and more RAS receivers which employ LNAs bought from industry (which however are still often cyro-cooled to further improve the noise figures). This is much more cost-effective, but astronomers have fewer options to tailor the LNA parameters to their special needs (high sensitivity, bandwidth, and dynamic range, while maintaining a certain robustness against strong signals). Modern RAS receivers can easily have noise temperatures below 5 K (when cryo-cooled), some even provide 1‑2 K, which however is strongly dependent on the center frequency, i.e. towards higher frequencies the noise temperature is increasing.

In some cases, important radio astronomy observations occur in frequency bands that are not allocated for its use on either a primary or secondary basis. These observations must not claim protection from harmful interference or impose any limitations on other active services operating with their corresponding Radio Regulation allocations.

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

Let *Pd* (W) be the empirically-determined power level that will cause damage at the receiver input and assume that this results from a pfd *Fd* (W/m2) 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 *Ae* (m2), then *Pd* = *Ae* *Fd* and:

 (1)

Tables 1 and 2 give values of the empirically-determined *Pd* and derived *Fd* 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 *Fd*at a distance *D* = 400 km corresponding to a satellite in low Earth orbit and assuming free space propagation, calculated as:

 (2)

# 3 Values of the damaging input power levels *Pd* and corresponding incident pfd *Fd*

## 3.1 Frequencies up to about 100 GHz: FET- based amplifiers

FET-based amplifiers (including HEMT, HFET)are used as low-noise input stages for frequencies up to approximately 100 GHz and the maximum safe input power levels for such devices typically lie in the range *Pd* = [ or 00.1–10] mW, [.depending on the design and material of the LNA. Thus, when no further information is available, the lower end of 0.1 mW = –10 dBm = –40 dBW should be assumed] 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 and the repetition of the exposure. 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. *{US note: This is a significant change to the levels while no meaningful reasoning is included.}*

Typical LNAs (for cryo-cooling applications) available on the market offer noise temperatures down to 1–2 K below about 10 GHz and down to 5 K between above 10 GHz, which increases to 10–20 K at higher frequencies up to about 100 GHz.Table 1 gives derived values of the corresponding incident power flux-density *Fd* for frequencies up to 100 GHz. Further study to better quantify the maximum safe power levels due to one-time and repeated exposures would greatly improve the information provided in Table 1.

## 3.2 Frequencies above about 100 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 *Fd* 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. Further study to better quantify the maximum safe power levels due to one-time and repeated exposures would greatly improve the information provided in Table 2.

# 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/m2) are potentially damaging at frequencies up to GHz, while incident power flux-densities above −45 dB(W/m2) are potentially damaging at frequencies above 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 Ω, i.e. 20 mW.

{Editor’s note: significant modifications to the e.i.r.p levels as proposed in the following table needs to be supported by reliable information or studies. Furthermore, it should be carefully assessed whether the proposed values are representative}

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TABLE 1

Representative antenna diameters and values of *Fd*,
the potentially damaging pfd for HFET input stages from 1-100 GHz

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Frequency(GHz) | RA antennadiameter(m) | RA antennaeffective area(m2) | *Pd* (mW) | *Fd* (dB(W/m2)) | e.i.r.p.*d* at 400 km(dBW) |
| 0.1-100 | 10 | 55 | 0.1 | –57 | 66 or  |
| 0.1-100 | 25 | 344 | 0.1 | –65 | 56 or  |
| 0.1-100 | 70 | 2690 | 0.1 | –74 | 49 or  |
| 0.1-100 | 100 | 5 500 | 0.1 | –77 |  46 or  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |

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TABLE 2

Representative values of *Fd*, the potentially damaging pfd for SIS mixer receivers
at 100-275 GHz, for representative radio astronomy sites

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Observatory(1) | Junction area (µm)2 | Number of junctions | Antenna diameter (m) | Antenna effective area(m2) | *Pd*(mW) | *Fd*(dB(W/m2) | e.i.r.p.*d* 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 |
| 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 |
| (1) 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 *Fd* 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](https://www.itu.int/rec/R-REC-RA.1750/en), 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/m2), 40 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[[1]](#footnote-2). 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](https://www.itu.int/rec/R-REC-RS.2066/en).

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 | 0.25 |
| 100 | 12 | 1.0 |
|  | 25 | 0.5 |
| 200 | 6 | 1.0 |
|  | 12 | 0.5 |

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1. <https://www.sfcgonline.org/Resources/Radio%20Astronomy/default.aspx> [↑](#footnote-ref-2)