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Resilience of radio astronomy receivers

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REPORT ITU-R RA.2572-0

Resilience of radio astronomy receivers

(Question ITU-R 237/7)

(2026)

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1 Introduction

Receiving signals above the linear regime of a radio astronomy telescope frontend can result in a variety of effects, such as saturation of the low noise amplifiers (LNAs) or other devices (such as analogue-digital converters (ADCs), optical fibre links), generation of intermodulation products, or even worse, reaching the amplifiers' break point. While the use of filters may look as a potential solution to these issues, it comes associated with many challenges, which are reviewed in in this Report.

Modern radio astronomy is heavily dependent on both microwave front-end receiver and digital signal processing technology. To reach the required levels of sensitivity, a combination of huge collecting areas (radio telescopes), extremely low-noise amplifiers, cryogenically cooled passive microwave components, and digital acquisition systems is required. Besides state-of-the-art equipment, long integration times (often hours) and wide frequency bands are used by radio astronomers to reduce the thermal noise and to detect the faintest celestial signals. As the scientific instrumentation requires major investments, usually from governments, it requires appropriate protection from active radio transmitters. Astronomers do their part towards this protection by building new telescopes in very remote sites, often taking advantage of natural terrain shielding (see Recommendation ITU-R RA.611). Several administrations have also established radio-quiet zones (RQZ) or coordination zones around the RAS stations in their countries (see Report ITU-R RA.2259).

In order to justify the high cost of operation resulting from the heavy investments, astronomy stations need to stay internationally competitive and they need to maximize the scientific output of their instruments. Therefore, observing time is granted by independent refereeing committees, which will assign time slots only to those scientists, who submitted the highest-ranking observing proposals. Furthermore, most radio observatories are heavily overbooked, i.e. the amount of requested time is much higher than the available time, making the loss of observing time a critical factor for scientific development through radio astronomy observations.

One way to improve the overall observing efficiency and sensitivity is the installation of broad-band receivers, which can measure astronomical signals in several allocated radio astronomy service (RAS) bands at the same time. The merit of observing large bandwidths is not restricted to gaining extra sensitivity. Many important astrophysical sources can only be properly investigated if a significant fraction of their spectra is acquired. The relative strength of the electromagnetic signal as a function of wavelength or frequency allows us to determine the radiation mechanisms within the celestial sources. Likewise, spectral line ratios can be used to measure physical properties of the interstellar gas, such as temperature or pressure. Other motivations to perform multi-broadband observations are to measure the dispersive effect of the interstellar medium or calibrating high frequency observations by using low frequency targets. By measuring the delay of a pulsed (brief) signal at different frequencies, astronomers can estimate the density and distribution of the interstellar medium. Time-domain astronomy, which looks out for individual rare events such as fast-radio bursts (FRB), cannot even observe the different bands at different times because such events are singular.

An example of a modern receiver is the Ultra-Broadband Receiver at the 100 m telescope at Effelsberg (Germany) offering an observing band between 1 and 5 GHz, simultaneously, with ADC installed at the front-end. A second example of applied wide-band technology is the VGOS system, which uses four or more frequency bands in the range from 2.5 GHz to 14 GHz at the same time for highest precision and to calibrate out atmospheric delays.

Unfortunately, the extreme sensitivity of RAS receivers is also a burden. Even if more effort is made to increase the dynamic range, it is technically impossible to build a receiver capable of observing the faintest signals from the universe (reaching the sub-μJy to mJy regime, with 1 Jy = 10-26 W/(m^2 · Hz) = −260 dB(W/(m^2 · Hz)) and at the same time be robust against strong anthropogenic signal transmissions, which can easily cause levels 100 dB above the noise floor at the RAS receiver input, if active services and the RAS are not well-coordinated. Usually, the RAS and active services

do not share allocations in the same bands, especially in the case of airborne and spaceborne transmitters. In addition to the few shared bands, out-of-band and spurious emissions from active services in adjacent and nearby bands may generate harmful interference in protected radio astronomy bands.

However, even if the active transmitter frequencies are well separated in frequency from the RAS observing band and out-of-band and spurious emissions are well coordinated, serious issues can still emerge. Receiving signals above the linear regime of a radio astronomy telescope front-end can result in a variety of effects, such as saturation of the LNAs or other active devices (such as second stage amplifiers, ADCs, optical fibre links), generation of intermodulation products, or even worse, reaching the amplifiers' break point, leading to (see Report ITU-R RA.2188). It is also worth noting that today a fair fraction of LNAs used in radio astronomy receivers, especially below about 100 GHz, are often off-the-shelf components. These devices usually come with a relatively large input bandwidth already.

If this worst-case situation occurs, the replacement of the damaged device is required to repair the receiver. This incurs a cost, which is reflected in the purchase of new components, their installation and the added cost of having the receiver out of operation for the duration of this process. But even in less drastic scenarios, mitigation techniques may need to be implemented to suppress the strongest signals, which is still costly, and as the spectrum environment is very dynamic and is subject to changes, this solution implies a continuous effort for the observatories.

While the use of filters may appear as a potential solution to improve compatibility between strong transmitters and a RAS station, it is not always technically feasible and it can have significant impact on sensitivity. First, analogue filters have finite suppression factors, so their effectiveness depends on the technology used and the frequency separation between active services and RAS bands. Second, frontend (notch-) filters installed in front of the first LNA add significant noise to the system, as their signal gets amplified by tens of dB in the signal chain. If at least the analogue part of the receiver is kept in the linear domain then, in principle, digital filters can be used further downstream to still use the unaffected frequencies.

This Report addresses *decides* 1 and 2 of Question ITU-R 237/7 (and to some extent also Question ITU-R 145-3/7) and studies the resilience and robustness of modern RAS receivers. This includes information about RAS receiver sensitivity in § 2, a summary about the non-linear effects that can occur when too much input power is introduced into a RAS receiver in § 3, possible mitigation measures and their impact on science capabilities in § 4, new developments in receiver design in § 5, and conclusions in § 6. Additional details and practical experience at specific RAS sites are collected in the Annex, as appropriate.

2 RAS receiver sensitivity

For telecommunication applications using a receiving system linked to an emitter, the artificial signal of interest is usually above the receiver system noise and so the signal-to-noise ratio (SNR) is greater than 0 dB. This is not the case for high sensitivity detection applications such as radio astronomy for which the natural signal of interest (for example a radio source as a star or a galaxy) can be 30 to 60 dB below the instantaneous thermal noise. One way to detect such a tiny stationary signal within uncorrelated noise is to decrease the noise fluctuation level using long integration times.

2.1 Sensitivity and radiometer equation

The goal of a radiometer is to convert the energy of the incident radio wave into an electrical signal, feasible to be analysed and processed in a computational system. In general, a radiometer is a high-sensitivity microwave receiver that detects and measures noise-like signals. The setup of a classical radiometer is composed of an antenna and its front-end amplifier (a mixer or a bolometer in

millimetric frequency), a radiofrequency conditioning system (filtering, frequency conversion) and a data acquisition system. A radio telescope can be viewed as a very high-performance radiometer. In astronomy, the sources of radiated emissions can be celestial bodies, such as planets, stars (including the Sun) or meteors, but also the interstellar or intergalactic medium. One can distinguish the celestial sources by spectral properties, e.g. continuum vs spectral-line emission, but also by temporal properties (constant vs intermittent or even pulse-like). Often the received signal has similar properties to the noise generated by the receiver itself or to terrestrial natural background signals coupled to the receiver, such as ground or atmospheric radiation. In rare cases receivers also detect diffuse anthropogenic signals that can be hard to distinguish from celestial signals of interest.

Assuming an antenna pointing to a celestial source, the received power at the output port of the radiometer is P (W) expressed as:

$$P = kBG(T_A + T_R) = kBGT_{sys}$$

where k is the Boltzmann constant (1.38×10^{-23} J/K), B is the receiver bandwidth in Hertz, G is the receiver gain. T_R is the receiver noise temperature, which represents the equivalent internal noise generated by the receiver itself brought to the input. Moreover, the antenna temperature (T_A) is the convolution between the sky brightness temperature and the antenna pattern (spatial distribution of the antenna response). In simple terms, the brightness temperature, T_B, of any source is the physical temperature of a black body which would produce the same power flux density at the RAS receiver as the source. The sky brightness includes all emitting factors seen by the radio telescope, such as the background signals from the universe (cosmic background noise or galactic centre or other strong celestial emitters), natural ground contribution, atmospheric emission etc. The sum of the two noise contributions, T_A and T_R, is usually denoted as the system temperature, T_{sys}.

The sensitivity of a radio receiver refers to its ability to detect weak signals and is usually defined as the minimum detectable temperature difference (ΔT) in the antenna temperature that can be measured by the receiver in a given bandwidth B and integration time τ. The sensitivity is given by the radiometer equation:

$$\Delta T = \frac{T_{sys}}{\sqrt{B\tau}}$$

where B is the bandwidth of the observation and τ is the integration time. The square root in the denominator of this equation is important. If the noise level of a measurement shall be reduced by a factor of two, the integration time needs to be quadrupled. Thus, even small degradations in the sensitivity have drastic consequences on the necessary integration times to reach a certain noise level, increasing the operation cost of a telescope accordingly.

It is common for radio astronomers to observe signals that have mean power levels several times less than background noise. Therefore, long integration exposure and wide integration band (for continuum observations) are commonly applied to increase the sensitivity.

In a radio astronomy receiver, uncorrelated noise, which is mainly caused by thermal noise, is the dominant type of noise added to the signal of the observed source. This noise is generated by the random motion of electrons in a conductor and is present in all electronic devices, contributing to receiver noise temperature. Additionally, thermal noise can also come from natural sources such as the atmosphere, ground emissions picked-up by the telescope antenna, and background signals from the universe, which may not be of primary interest to the observer. Because the random nature of the noise, integration reduces the level of fluctuations by averaging the signal over a longer period of time. The integration time used in radio astronomy can vary from seconds to several hours or even more. Longer integration times enable the detection of weaker and more distant sources. However, for some scientific applications, such as to detect fast transient phenomena, the integration time must be kept short to reach the desired time resolution. In this case only an increased bandwidth can be used to reduce the noise as described in the radiometer equation.

The calculation method and typical technical parameters that define the sensitivity of radio astronomy observations over a large range of frequencies can be found in Recommendation ITU-R RA.769. To quote some example values, power flux-density levels that must not be exceeded to protect RAS observations range from about −260 dB(W/(m^2 · Hz)) at lower frequencies (e.g. at 150 MHz) to approximately −220 dB(W/(m^2 · Hz)) above 200 GHz.

2.2 Noise figure

The noise figure is a standard way to express the noise temperature of a receiver. It is a metric for the amount of additional noise added by an electronic device to the input signal It is typically expressed in decibels (dB), and is calculated as the difference between the input SNR and the output SNR of the receiver.

$$F = SNR_{in} - SNR_{out}$$

In a multi-stage system with multiple filtering stages, the overall noise figure can be calculated using Friis' formula:

$$NF_{Total} = NF_1 + \frac{NF_2 - 1}{G_1} + \frac{NF_3 - 1}{G_1 G_2} + \cdots$$

where NF_1 is the noise figure of the first stage, NF_2 is the noise figure of the second stage, etc. G_1, G_2, etc. are the gains of the first, second, and subsequent stages.

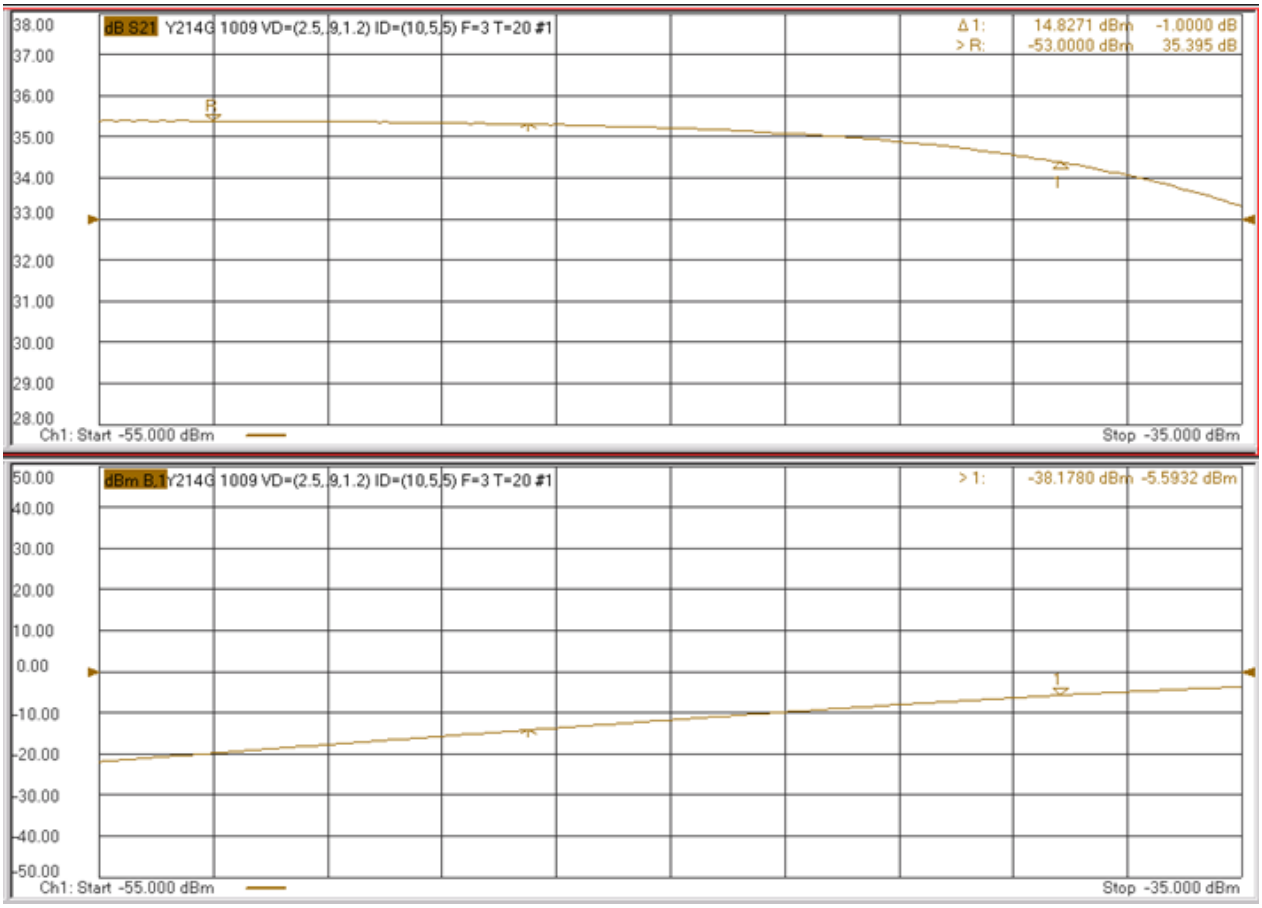
Therefore, the noise figure of a multi-stage system cannot be lower than the noise figure of the first stage and also that subsequent stage's noise figures are decreased by cumulative gains of previous stages. Therefore, it is essential to minimize the noise figure of the first stage and use subsequent stages only when necessary, in order to achieve the desired gain.

For high sensitivity receiving systems, as those used in radio astronomy, the receiving chain is usually composed by the so-called feed-system consisting of passive components to couple the incoming radio wave reflected by the mirrors of the radio telescopes into a guided transmission line. Such components typically consist of the following elements: feed-horn, polarizer, ortho-mode transducer and noise marker coupler. Since all these components come before the first amplifier, their contribution to the overall receiver noise is significant. Therefore, they are cooled to cryogenic temperatures to minimize their ohmic attenuation together with the first LNA. Positioning a microwave filter to increase immunity to interference would add further losses in this sensitive section of the chain and therefore it should be considered as a last resource mitigation measure. Filters are typically placed after the first stage of amplification, lowering their noise contribution and also because the last stages of the receiver are more prone to get saturated due to the additional gain provided by the previous stages.

As a rule of thumb, modern LNAs achieve noise temperatures of 0.25-0.5 K times the centre frequency f_0 [GHz], e.g. a 4-8 GHz LNA would have between 2 to 4 K when cooled to cryogenic temperatures of 15 K, and thus provide a very sensitive receiver. This implies that its dynamical margin cannot cope with very strong active-service transmissions (e.g. radars or telecommunication towers) in the immediate vicinity. The typical compression level at the input of an LNA is around −50 to −40 dBm noting that this value depends on the material of the transistors of the LNA, the polarization of the different stages, the frequency, etc. Figure 1 shows the gain and output power vs input power for a typical LNA used in radio astronomy.

FIGURE 1

Characterization of a broadband LNA (2-14 GHz) for a VGOS receiver. Top: gain vs input power. Bottom: output power versus input power, the marker indicates the P1dB level (−38 dBm at the input)



3 Non-linear effects

An important figure of merit in radio astronomical receivers is the linearity. If the active stages do not operate in linear regime some distortions will occur affecting the astronomical observation. Signals at new frequencies would appear at the output of the receiver and might be interpreted as actual radiation entering in the antenna. Nowadays, this is of primary concern in radio astronomy due to the presence of strong artificial emitters.

The amplifier's burning point and compression points are crucial levels of input power for the LNA. The burning point is the maximum output power level that an amplifier can sustain without damaging itself due to excessive heat generation. This is also called the amplifier's maximum power handling capability.

Report ITU-R RA.2188 provides guidelines for the maximum power flux-density and equivalent isotropically radiated power (e.i.r.p.) levels that could potentially cause damage to radio astronomy receivers in the frequency range of 1 to 275 GHz. Tables 1 and 2 in Report ITU-R RA.2188 list the maximum allowable power flux-density and e.i.r.p. levels in units of dB(W/m^2) and dB(W/Hz) for two different technologies in the active stages.

3.1 Compression point and intermodulation points

The saturation points are the points at which the amplifier enters the non-linear regime. Two types of saturation points should be considered at minimum: the compression point and the intermodulation point, considering amplitude and frequency, respectively, of the non-linear effects.

1 dBc compression point

At the compression point, the output power level stops to increase, even if the input signal level is increased further. An amplifier is said to be "saturated" at this point and can no longer provide any additional gain. Further increases in the input signal level will result in distortion of the output signal. This results in a distortion of the received signal and a loss of information because the receiver's output signal becomes clipped.

The 1 dBc compression point represents the power level at which the output power of the LNA is reduced by 1 dB with respect to a linear scale due to compression. One refers to the input and output power levels associated with the 1-dB compression points as IP1 and OP1, respectively. Higher 1 dB compression points indicate better linearity and less distortion of the signal.

Intermodulation points

When operating in the non-linear regime, the amplifier can also produce harmonics or intermodulation products that emerge above the noise floor. The latter effect is typically the most problematic, due to the proximity of the fundamental tones to be amplified. From the different tones, the third order intermodulation product is generally the most problematic, by falling inside the frequency band of reception. It should be noted that, considering the low level of noise in RAS receivers, intermodulation products can be detected well before the power level reaches the 1 dB compression point.

A common figure of merit for intermodulation products is the IP3, which describes third-order effects. Its value is derived as the intercept point of the fundamental (in log scale has 1 dB slope) and the third order product curve (3 dB slope). In essence, it shows the maximum amplitude of a signal that can be applied to the device before intermodulation distortion occurs.

4 Mitigation measures

4.1 Filtering and insertion loss

One possibility to improve the resilience of a receiver is to use filters. First active stages in radio astronomical receivers are designed primarily for optimum noise figure and secondarily for high gain, because the radio astronomical power level entering the receiver is very low. As a consequence, initial active stages lack for high robustness performance. On the other hand, subsequent amplifiers in the receiving chain usually have relatively high 1 dB compression points to handle the amplification of the previous stages. Depending on the specific architecture of the receiver, the weakest stage to get compressed earlier in the chain can be either at the initial or at end of the chain.

Filters are commonly used to increase a receiver's resilience to interference by attenuating the entire band that contains interference. However, this solution is not always applicable in radio astronomy. In particular, it is not feasible to place narrow passband filters just around RAS bands. This is especially true if the RAS band is on the first or second adjacent channel of a strong transmitter.

In electronic filter design, the insertion loss is a figure of merit that is frequently employed. This metric is defined as the ratio between the signal level without the filter (V_1) and the signal level with the filter installed (V_2), and it is calculated in decibels. The insertion loss can be calculated as follows:

$$Insertion\ Loss\ [\mathrm{dB}] = 10 \log_{10} \frac{|V_1|^2}{|V_2|^2}$$

Insertion loss can have a significant impact on the noise figure of a system, which can influence the overall sensitivity and performance of the system. When a component with insertion loss is added to the system, it can reduce the signal power, leading to a decrease in the SNR at the input of the component.

4.2 Ultra-low insertion loss filters

As a tentative solution, high-temperature superconductor (HTS) filters have been used at some radio telescopes. The idea is that such a filter can even be placed before the cryo-cooled LNA without affecting the sensitivity too much –HTS filters have very low insertion loss. The HTS technology is maturing, but is still costly and not flexible enough compared to the quick changes that we see in some parts of the radio spectrum. HTS filters are static components, whose response cannot be adjusted/tuned based to the given scenario. Furthermore, component tests cannot be performed at room temperature, which makes designing the filters more challenging than classical analogue filters. During the last few years, a number of HTS microwave filters have been designed and fabricated for three receivers installed on the 64 m Sardinia Radio Telescope (SRT). All these filters are based on an Yttrium Barium Copper Oxide (YBCO) film laid on a Magnesium Oxide (MgO) substrate with a thickness of 0.5 mm and a dielectric constant of 9.65. The front-end receivers for which they have been developed are: a P-band receiver (305-410 MHz), a "High" C-band receiver (5.7-7.7 GHz), and a "Low" C-band receiver (4.2-5.6 GHz). Although there have been strikingly successful and hopeful deployments of HTS microwave filters at a few observatories, they cannot be seen at the moment as the universal solution for the receiver problems associated with very powerful out-of-band signals. High gain wide-band LNAs often have frequency intervals where they are not unconditionally stable and together with low loss filters being LC circuits attenuating via impedance mismatch this can lead to spurious oscillations, often outside the pass band of the amplifier and difficult to detect, but severely degrading its performance. Many specific technical factors determine the feasibility of using appropriate input filters. Retrofitting such filters to existing radio astronomical receivers is often impossible and the question of their use for new receivers has to be evaluated on a case-to-case basis for each band and for each observatory.

4.3 Microwave filters

All optics systems (including the primary reflector and feed horn) necessarily act as filters to an extent, so we also consider the feasibility of filtering out harmful transmissions in the optical domain rather than the coaxial domain. The principle of optical filtering relies on waveguide components attenuating radiation below the cutoff frequency, which is inversely proportional to the dimensions of the waveguide. That is, a length of waveguide may be used as a high-pass filter, providing strong attenuation of any signals below the cutoff frequency. The caveat is that access to all frequencies below the cutoff frequency is lost, and not just the frequencies occupied by an exemplary troublesome transmission that needs to be filtered out. Waveguide cannot be employed in the application of bandstop filtering, because there is no upper cutoff frequency.

A key challenge in traditional single-pixel receiver design is the need to improve the impedance match between free space and the transition to the coaxial domain. This requires careful design of the optics system, and while the benefit of waveguide filtering is the minimization of loss for propagated modes, the degradation of the impedance match with free space will introduce other aspects of undesirable performance reduction, such as bandpass ripple.

In conclusion, the RAS receiver is best optimized when the minimum of required waveguide components is used, such as the feed horn and OMT, and extra waveguide components introduced in an attempt to counter powerful terrestrial transmissions should be avoided.

5 New developments in receiver design

Until a couple of decades back, most existing receivers at European radio telescopes were single- or dual-pixel receivers, owing to the physical tension imposed by the cooling process. These receivers typically consisted of a single chain for each of the two polarizations needed to sample the ensemble of randomly polarized photons that are focused onto the phase centre of the receiver's feed horn.

However, in order to increase the operational capacity of radio telescopes, radio receiver development has tended towards placing an array of receivers on the telescope's focal plane. There are two basic configurations of such an array, multi-beam receivers and phased array feeds, which use a planar aperture of dozens of antenna elements (similar to active antenna systems in telecommunications, but here there is a large reflector attached – the radio telescope).

A multi-beam receiver takes the form of an array of independent traditional single-pixel receivers. Each pixel of the array is positioned on the focal plane of the telescope in such a way as to point not just along the boresight axis, but also at positions away from the boresight axis. Despite the loss of forward gain associated with placing a feed horn's phase centre off-axis, the advantages in increasing the instantaneous field-of-view far outweigh the disadvantages in required engineering effort, mostly by enhancing the survey speed especially of large single dish radio telescopes. Examples of very successful multi-beam receivers include the Jodrell Bank Multi-beam that operates in the protected L-band, and the Effelsberg 7-Beam, which is used extensively as a survey instrument, for both spectral lines and pulsar research.

Phased array feed (PAF) receivers (sometimes also called focal-plane arrays, or colloquially radio cameras) are a development of the multi-beam concept, and take the form of a planar array of detectors that populate the focal plane. The principle of the PAF is to maximally sample the complex voltage field on the focal plane, such that the axis of peak forward gain may be determined in post-processing by appropriately weighting the complex voltages received by every antenna element of the PAF, e.g. in FPGAs. This allows for an arbitrary number of overlapping beams independent of any optical limitations that a feed horn may impose reducing off-axis effects significantly.

Multi-beam receivers and phased array feed receivers are, by definition, optimized to maximize the number of beams in order to maximize science capability, and are typically limited by size and weight considerations. As such, their cryostats are densely populated with RF components, which further drives the development of each antenna's chain of RF components towards simplicity; a typical PAF will consist of an antenna, an LNA, a bandpass filter, and either a digitizer or further electronics to interface with an RF-over-Fiber system. As such, PAFs are particularly susceptible to being driven nonlinear.

In the context of the potential future requirement to retrofit one or more band-stop filters in order to reject specific powerful transmissions, such a retrofit may be impossible without a substantial redesign. While an alternative approach is to limit the fraction of sky in which such a receiver may be operated, this places heavy limits on the science capability of the instrument. The potential future omnipresence of such transmissions may simply make operation of the receiver unfeasible.

In summary, placing a requirement on the RAS to make their receivers robust to present, and future strong active transmitters will eventually direct the RAS away from developing towards maximizing the science capability of their instruments – their *raison d'etre* – instead towards optimization for maximum interoperability with commercial users of the spectrum, with necessarily heavily-limited science capability.

6 Summary

A special treatment is necessary for the receiving equipment used at radio astronomy stations. The extreme sensitivity of RAS receivers is a technical challenge. Even if significant effort is made to increase the dynamic range, it is impossible to build a receiver capable of observing the faintest signals from the universe that, at the same time, is robust against strong anthropogenic signal transmissions, which can easily cause levels 100 dB above the noise floor at the RAS receiver.

Receiving signals above the linear regime of a radio astronomy telescope frontend can result in a variety of effects, such as saturation of the LNAs or other devices (such as ADCs, optical fibre links),

generation of intermodulation products, or even worse, reaching the amplifiers' break point. While the use of filters may look as a potential solution to these issues, it comes associated with many challenges. Thus, certain activities to improve receiver resilience may not be applicable to the same level as they would be for active services, without severely impacting the scientific capabilities of modern RAS stations.

In conclusion, it is important to preserve unique operational conditions of scientific equipment, and especially RAS operations, to enable future scientific breakthroughs. RAS study objects are natural sources of cosmic origin, which are of analogue nature and are not only out of control, but also beyond human reach. Therefore, radio astronomy receiving systems require a certain level of general radio quietness in the environment of an observatory in order to protect them.

7 References and related ITU-R documents

Recommendation ITU-R RA.314 – Preferred frequency bands for radio astronomical measurements

Recommendation ITU-R RA.769 – Protection criteria used for radio astronomical measurements

Recommendation ITU-R RA.1031 – Protection of the radio astronomy service in frequency bands shared with other services

8 List of acronyms and abbreviations

ADC	Analogue-digital converter
e.i.r.p.	Equivalent isotropically radiated power
FRB	Fast-radio bursts
HTS	High-temperature superconductor
LNA	Low noise amplifiers
RAS	Radio astronomy service
RQZ	Radio-quiet zones
SNR	Signal-to-noise ratio
SRT	Sardinia Radio Telescope
VERA	VLBI Exploration of Radio Astrometry
VGOS	VLBI Global Observing System
VLBI	Very Long Baseline Interferometry
YBCO	Yttrium Barium Copper Oxide

Annex 1

Site-specific information and examples

100-m radio telescope Effelsberg (Germany)

At the 100 m radio telescope at Effelsberg (Germany), negative experience was made with a very broad L-band receiver (called UBB). Originally, it was designed to offer frequencies between 600 MHz and 3 GHz, but strong interferers below 1 GHz drove the system into non-linearity and measurements were impossible. Later the receiver was significantly modified and now covers a range between about 1.2 and 5 GHz. Several well-known IMT bands, e.g. at 1 800 and 2 100 MHz are filtered out with stop-band filters. Fortunately, the LNA of the UBB is robust enough to allow placing these filters after LNA, such that the overall system performance is not heavily affected.

However, since late 2022 a nearby IMT base station was upgraded to provide LTE/4G supplemental downlinks at 1 452-1 472 MHz, which caused intermodulation products throughout the observing bands. Even worse, the Effelsberg "powerhorse" – the 21-cm 7-feed receiver –, was completely saturated for more than half of the accessible sky. This receiver is used for more than 25% of the time, as it provides superb survey capabilities. Equipping this system with new filters would not only have been extremely costly (as there are 14 independent channels), but it would also require enormous efforts to ensure that the calibration can be done consistently for old and newer data. Surveys can take several years, and it is usually a no-go to change the system properties in the middle of the observations. It is currently not even clear, whether stop-band filters after the LNAs in the 7-feed system would suffice to mitigate the issues. The alternative, putting stop-band filters before the LNAs, would have a huge impact on the sensitivity and require hundreds if not thousands of additional measurement hours to finish ongoing surveys.

Fortunately, coordinated and very constructive efforts (including several fields tests) with the involved IMT operator resulted in an acceptable solution for both parties. The IMT base station could provide the required service quality also with stronger electrical downtilts of the antenna and a 10 dB reduction of the transmitter power, which reduced the input power into the Effelsberg 7-feed sufficiently to stop the system from becoming non-linear for most of the accessible sky.

Jodress Bank Observatory (UK)

Jodrell Bank Observatory (JBO, UK) has been badly affected by powerful ground-based transmissions. The L-band receivers on the 76 m Lovell, and 25 m Mark II Telescopes each have an unfiltered observing bandwidth ~1 GHz, however long-standing transmissions necessitate increasingly strong bandpass filtering to their current designs with ~500 MHz bandwidth centred on ~1 500 MHz.

IMT allocations in the 1 452-1 472 MHz band for LTE downlinks became active in 2018. The transmissions are sufficient to force the receiver system into the nonlinear regime for all directions except those for which the primary reflector itself provides shielding from the transmitter. In other words, more than half of the sky was lost.

It was later discovered that backend components were the first to be driven nonlinear, and as such it was possible to fit bandstop filters behind the LNA rather than ahead of them. These filters act in addition to the existing band-defining filters and their use necessarily degrades system performance at the ~10% level, which reduces the observatory's effectiveness in its science mission.

The extent of the problem that the 1 452-1 472 MHz transmissions caused can be summarized as follows:

1 The bandstop filters had to be custom-designed and could not be obtained off-the-shelf.

2 Consequently, the unit price was high and the lead time was long (~months).

3 Further, the cryostats for each receiver needed to be modified to accommodate the bandstop filters, which required extensive engineering time.

4 The total expenditure required to adapt the L-band systems to co-operate with the new transmissions in hardware and effort is estimated at ~5% of the observatory's total operating budget, which is unsustainable for any potential future requirement to repeat this operation for other transmissions.

European VGOS stations

Some radio telescopes in Europe have suffered from the high-power signal received from radars very close to the radio telescopes. In Ny-Alesund (Norway) and in Onsala (Sweden) observatories, the signal received from ship-borne radars close to the radio telescopes were so powerful that it drove the LNAs into their breaking point and, hence, were destroyed. In the RAEGE Santa María station (Azores, Portugal) a nearby radar makes it impossible to use the broadband receiver (VGOS radio telescope, 2-14 GHz) without any preventive measure to avoid driving the LNAs into the breaking point. Measurements were only possible after the installation of a filter in the cryostat at the input of the LNAs. This solution implies a degradation of 17% of its sensitivity. VGOS radio telescopes are planned to observe four different sub-bands of 1 GHz width in the 2-14 GHz range. With the installation of the filter, the lowest sub-band has been sacrificed to be able to observe in the three other sub-bands.