

## RECOMMENDATION ITU-R SM.1542-0\*

**The protection of passive\*\* services from unwanted emissions**

(2001)

**Scope**

This Recommendation serves as a basis for vulnerability of passive services and the mitigation techniques to minimize the interference generated by unwanted emissions to passive services.

**Keywords**

Unwanted emissions, mitigation, passive service, frequency bands, potential interference

The ITU Radiocommunication Assembly,

*considering*

- a) that it is desirable that unwanted emissions of new stations in any radio service should not render existing stations, operating in accordance with the Radio Regulations (RR) in those or other services, unable to operate effectively;
- b) that, in some cases, passive services and services employing high-power transmitters have been allocated to adjacent or nearby frequency bands;
- c) that in many cases passive services and space services (space-to-Earth) have been allocated to adjacent or nearby frequency bands;
- d) that in some cases space-based passive services and services using uplink earth stations or high density terrestrial stations have been allocated to adjacent or nearby frequency bands;
- e) that, in making these allocations, transmitter and receiver compatibility may not have been considered;
- f) that the RAS, the EESS (passive) and SRS (passive) are based on the reception of emissions at much lower power levels than are generally used in other radio services;
- g) that, due to these low received power levels, these passive services are generally more susceptible to interference from unwanted emissions than other services;
- h) that several footnotes to the Radio Regulations (RR) (such as Nos. 5.149, 5.340, 5.372) draw attention to the protection of these passive services, particularly from spaceborne, airborne, or high altitude platform stations (HAPSs), (for the radio astronomy stations) and from earth stations, HAPS, and high density fixed system (HDFS) stations (for the space-based passive services);
- j) that there are various operational practices and mitigation techniques that can be used by the passive and active services to minimize the impact of interference on the passive services;
- k) that there may be practical and economic limitations on the applicability of these mitigation measures;
- l) that general limits for spurious emissions may not protect to the desired extent the passive services from interference;

---

\* Radiocommunication Study Group 1 made editorial amendments to this Recommendation in the years 2018 and 2019 in accordance with Resolution ITU-R 1.

\*\* The radio astronomy service (RAS), the Earth exploration-satellite service (EESS) (passive) and the space research service (SRS) (passive) are considered in this Recommendation.

m) that Recommendation 66 (Rev.WRC-2000) requests in *recommends that ITU-R 5* “study those frequency bands and instances where, for technical or operational reasons, more stringent spurious emission limits than the general limits in Appendix 3 may be required to protect safety services and passive services such as radio astronomy, and the impact on all concerned services of implementing or not implementing such limits”;

n) that Recommendation 66 (Rev.WRC-2000) requests in *recommends that ITU-R 6* “study those frequency bands and instances where, for technical or operational reasons, out-of-band limits may be required to protect safety services and passive services such as radio astronomy, and the impact on all concerned services of implementing or not implementing such limits”;

o) that the RR state (No. 29.5) that the locations of the radio astronomy stations to be protected and their frequencies of observation shall be notified to the Radiocommunication Bureau in accordance with RR No. 11.12,

*noting*

a) that explanations of why passive services are more vulnerable to interference from unwanted emissions than other services are presented in Annex 1;

b) that Recommendation ITU-R SM.1540 provides guidance with regard to unwanted emissions in the out-of-band domain falling into adjacent allocated bands;

c) that an expeditious conclusion of band-by-band studies and the identification of other interference situations where more stringent limits on unwanted emission levels than those given in RR Appendix 3 and Recommendation ITU-R SM.1541 are needed for the protection of passive studies;

d) that appropriate levels for those situations need to be established and the impact be considered on all concerned services of implementing or not implementing such limits,

*recommends*

**1** that when allocating frequency bands to the satellite services, their proximity to frequency bands allocated to the RAS, the EESS (passive), and the SRS (passive) should be taken into account;

**2** that when designating frequency bands for specific terrestrial applications such as HAPS or HDFS, their proximity to frequency bands allocated to the RAS or the EESS (passive), and the SRS (passive) be taken into account;

**3** that where possible allocations adjacent to existing passive services bands should be such as to minimize the potential for interference;

**4** that the use of zones around stations used for radio astronomy observations where active services are excluded or restricted should be considered as a means of minimizing interference due to unwanted emissions from terrestrial transmitters;

**5** that mitigation techniques such as those described in Annex 2 and Annex 3 should be considered as appropriate means and employed as much as practicable by active services and passive services, to minimize the interference generated by unwanted emissions to passive services, bearing in mind the constraints placed on system design and operational effectiveness;

6 that the passive service frequency bands identified in Annex 4 are bands for which more stringent spurious emission limits than the general limits in RR Appendix 3 may be used to protect passive services;

7 that the active service frequency bands identified in Annex 4 are bands for which out-of-band limits may be used to protect adjacent or nearby passive service bands;

8 that the following measures should be taken to minimize the potential of interference to passive services:

- consultation and exchange of technical and operational information between the relevant parties,
- cooperation on the selection and implementation of the most suitable measures between operators of passive systems and active systems, and
- appropriate spectrum management techniques.

## ANNEX 1

### **Vulnerability of passive services**

Passive services are dedicated entirely to the study of naturally-occurring radio emissions. The extreme weakness of these emissions compared with man-made transmissions make facilities being used to observe them extremely susceptible to interference. In the case of radio astronomy, receiver sensitivities are as high as practicable. Making radio astronomical measurements may require large receiver bandwidths and integration and correlation of signals over hours or days. The extreme sensitivity of radio astronomy receivers together with long observing times give rise to interference thresholds lower than in any other service, leading to special protection needs and a consequent need for special consideration.

Similarly, spaceborne passive sensors detect very small changes in the ambient noise temperature of the observed phenomena. All matter emits and scatters electromagnetic energy. Spaceborne passive sensors measure the electromagnetic energy emitted and scattered by the Earth and constituents in its atmosphere. This means special consideration for protection of these passive services is required, because interference thresholds necessarily occur at significantly low power levels.

Airborne and spaceborne transmitters can be particularly serious sources of interference to the RAS. Space service downlinks close to frequency bands used by passive services, including the RAS, have the potential to cause interference to many radio astronomy stations. Reflections off the Earth from the space service downlinks also can cause interference to spaceborne passive sensors. Unwanted emissions from space service uplinks, HAPS uplinks and HDFS transmissions close to frequency bands allocated to EESS (passive) have the potential to cause interference to spaceborne passive sensors.

## 1 Satellite passive remote sensing

Interference thresholds for passive satellite remote sensing for various frequency bands are given in Recommendation ITU-R SA.1029. Performance criteria for satellite remote sensing are given in Recommendation ITU-R SA.1028. Permissible data loss for most passive sensing applications is less than 1%. That is, the interference levels given in Recommendation ITU-R SA.1029 should not be exceeded for more than 1% of the measurement cells (i.e. pixels) within the sensor's service area. However, for three-dimensional measurements of atmospheric temperature or gas concentration in the absorption bands, the interference levels should not be exceeded for more than 0.01% of the measurement cells in the sensor's service area. The frequency bands that require this greater degree of protection are: 50.2-50.4 GHz (see RR No. 5.340.1), 52.6-59.3 GHz, 114.25-122.5 GHz and 174.8-191.8 GHz.

## 2 Radio astronomy

Radio astronomy is the science of studying the properties of cosmic radio emissions. These emissions generally are noise-like, and indistinguishable in character from thermal noise radiated by the Earth or its atmosphere, or from noise generated in the receiver. Radio astronomical observations fall into two broad classes:

- continuum observations, where the average spectral power flux-density (spfd) and degree of polarization across the allocated band are measured. The type of observation being made might involve breaking the band into channels that are processed together or independently (as for example in imaging, interferometry or interference mitigation), but the final result is usually an average of observational quantities across the allocated band. These observations may be used in combination with measurements made in other radio astronomy bands in order to study broadband spectral structure or changes in the structure of the source of the emissions as a function of observing frequency;
- spectral line observations of narrow-band emissions from transitions in cosmic molecules, radicals or atoms. These are narrow-band emissions where the intensity, width, fine structure, Doppler shift, and polarization are of astrophysical interest. Observations involve dividing the band into many frequency channels in order to derive the properties of the line emission with frequency against the broadband background emission.

Astronomical sources range in angular size from degrees to milliarcseconds or less. Some emissions, such as the cosmic background, cover the entire sky. A single large antenna might have the angular resolution needed to map the area or source of interest with sufficient detail. Where this is not the case, arrays of antennas distributed over distances of up to thousands of kilometres may be used as interferometers (arrays with even larger spacings are possible when one or more of the antennas are located in space). Producing maps might require up to two weeks of continuous observation to produce a single image. Current radio telescopes can measure spfd's below  $-290 \text{ dB(W/(m}^2 \cdot \text{Hz))}$ ; however, current research needs are driving the development of radio telescope systems capable of measuring spfd's in the region of  $-320 \text{ dB(W/(m}^2 \cdot \text{Hz))}$ .

Interference thresholds for the protection of radio astronomical observations are given in Recommendation ITU-R RA.769. Protection of radio astronomy from transmitters in adjacent bands is described in Recommendation ITU-R RA.517. Protection of radio astronomy from spurious emissions is described in Recommendation ITU-R RA.611.

The permissible rate of data loss to radio astronomy is described in Recommendation ITU-R RA.1513.

## ANNEX 2

### **Mitigation techniques that may be used at the transmitter**

Several examples of possible mitigation techniques have been described in ITU-R Recommendations such as Recommendation ITU-R SM.328, which may have direct relevance to the categories listed below. Consideration of all sources and modes of interference into the passive service should be taken into account when selecting mitigation methods to ensure that their application provides substantial benefit to the passive service. The implementation of mitigation techniques may impact the operational effectiveness of the systems involved, and also the nature and extent of user services that can be supported in the band under consideration. There may be a substantial technical and operational burden consequent to the implementation of such solutions. These factors will impact the practicabilities of mitigation techniques. Such measures may be considered at an early stage in the design of systems in order to reduce interference from unwanted emissions.

- Practical hardware and system measures, such as:
  - transmitter architecture;
  - guardbands;
  - radio frequency (RF) filters to reduce unwanted emissions;
  - design of the output power amplifier to avoid spectral regrowth of RF signals into adjacent bands, or intermodulation;
  - components that operate with linear characteristics, to the extent possible;
  - design of the modulation process to minimize unwanted emissions;
  - antenna patterns.
- Traffic loading management.
- Dynamic power control.
- Time sharing.
- In the case of multi-satellite systems, satellite constellation management.

Satellite communications provide vital telecommunication links around the world. The nature of satellite communications allows the implementation of networks especially in areas having minimal infrastructure, making them a communication medium well suited to reach many countries. The wide area that they serve also makes them well suited for broadcast applications.

New satellite networks must ensure that projects are implemented in a cost-effective, timely and competitive fashion. As a result, restraint and balance may be used in the application of the mitigation methods below.

## **1 Fixed-satellite service (FSS) systems**

### **1.1 RF filters to reduce unwanted emissions**

An additional aspect to consider is the suppression of spurious emissions from transmissions which cause harmonics which fall on the frequency bands allocated to radio astronomy. FSS system design should take these considerations into account. Test equipment and facilities to enable this adequately may not exist today at some FSS frequencies.

It should be noted that the use of filters to adequately protect passive services can have a significant impact on satellite services. The use of tighter filter specifications affects the group delay over satellite links, particularly for high data rates, which results in either a loss of capacity or the need for equalization equipment. In some cases the filtering requirements may lead to additional spacecraft hardware, resulting in an increase in spacecraft weight, power consumption, and project costs.

In particular, for satellites using active array antennas, filtering would need to be done on an element-by-element basis. This may have a huge impact on satellite weight and cost. Moreover, the physical space constraint between the elements of an active array may not allow the addition of filters. Therefore, the addition of filters to active array antennas may not be feasible.

However, efforts have been made by an operator of geostationary-satellite orbit (GSO) FSS networks at 11-14 GHz, to work with satellite manufacturers to use improved filtering in combination with other mitigation techniques to meet the requirements of Tables 1 and 2 of Recommendation ITU-R RA.769, when specifying unwanted emission requirements. In this connection, the specification of a recently launched satellite transmitting in the frequency band 10.7-12.75 GHz, meets the pfd levels of Table 1 of Recommendation ITU-R RA.769 in all passive bands between 1.4 GHz and 31.8 GHz.

### **1.2 Site shielding**

For FSS earth stations located near land-based passive sensors, it may be possible to use the local geography in order to achieve the desired level of protection. In cases where local terrain does not provide sufficient shielding, additional shielding may be erected.

### **1.3 Shaped antenna patterns**

If the locations of particularly sensitive sites are known in advance, it may be possible to design the FSS antenna pattern such as to minimize the impact on the sites.

## 2 Radar systems

Various interference mitigation methods have been proposed to enhance the compatibility between radar systems and radio-relay systems. These mitigation methods may be generally applied to radar systems to reduce unwanted emissions, and hence may mitigate interference to passive services. These methods have been discussed further in Recommendation ITU-R F.1097.

### 2.1 Operational measures

#### 2.1.1 Sector blanking

Sector blanking constitutes momentarily switching off the emission when its main beam is pointing in the direction of a victim receiver. This method may be simple to implement with minimal or no expense, either by hardware measures in older radars, or by control software commands in modern installations. This kind of mitigation option has been implemented in some countries resulting in a successful co-existence of installations of the radiodetermination service and the fixed service (FS).

#### 2.1.2 Selection or adjustment of transmitter frequency

In some types of fixed radar systems it may be possible to select or adjust the fundamental frequency of the radar transmitter within the frequency range allowed for the radar system, such that harmonic spurious emissions will not be received by the victim receiver. In particular, it may be possible to place the radar harmonic in the guardband, between the upper and lower radio-relay half band of the frequency plan, or outside the radio-relay band altogether. This kind of mitigation option has already been implemented in some countries resulting in a successful co-existence of installations of the radiodetermination service and the FS.

### 2.2 Replacement of transmitter device

Variations in ground-based radar spurious emission levels have been observed in radars using either conventional or coaxial magnetron power tubes. These variations may be attributed to ageing phenomena, resulting in:

- changes in the pulse shaping networks of the modulator;
- changes in anode voltage and current of the power tube; or
- arcing in the tube.

The ground-based radar operators, on a routine basis, may need to perform periodic checks of the radar transmitter to determine whether these transmitters have, because of ageing, developed additional spurious components. In some reported cases, interference problems have been corrected by replacing the radar transmitter output device.

### 2.3 RF filter installation in the radar transmitter

RF waveguide filters have been used in several types of radar to reduce interference to radio-relay systems to acceptable, low levels. Thus RF low pass, absorptive filters have been used in fixed 1.3 GHz ground-based radars to mitigate interference by the 3rd harmonic into the 4 GHz band allocated to the FS. Similarly, 5 GHz ground-based radars had band pass/low pass filters installed to suppress spurious components interfering in the lower and upper 6 GHz FS bands. Filter technology

has been developed by the radar industry in order to suppress radar spurious emissions by approximately 40 to 50 dB, while having an insertion loss of a few tenths of a dB at the fundamental operating radar frequency. The radar performance (detection range) is reduced by only a small amount by such filters. When interference into digital radio-relay systems is caused by spurious emissions from radars, the installation of an RF filter in the radar transmitter may provide a suitable solution.

### **3 Broadcasting-satellite service (BSS) systems**

Some of the considerations in Section 1 above (FSS systems) also apply to the BSS, namely RF filtering and antenna beam-shaping.

For example, an advanced filter technique for a BSS system, planned to operate in the band 21.4-22 GHz, achieves a rejection of at least 19 dB at frequency offsets of 210 MHz or more from the band edge, thereby enabling the spurious spfd level predicted at the ground to be reduced to  $-199 \text{ dB(W/(m}^2 \cdot \text{Hz))}$  for narrow-band emissions across the frequency band 22.21-22.5 GHz, and  $-145 \text{ dB(W/(m}^2 \cdot \text{Hz))}$  for aggregate wideband emission across the same frequency band.

### **4 Mobile-satellite service (MSS) systems**

Some of the considerations in Section 1 also apply to MSS downlinks. An analysis has been made of the impact of a proposed MSS downlink in the frequency band 405-406 MHz, for future non-GSO systems, on the primary services allocated in the upper adjacent band (406-406.1 MHz: COSPAS-SARSAT system, and 406.1-410 MHz: RAS). The main conclusion of this preliminary study is that a minimum of 106 kHz has to be planned as a guardband between the upper frequency to be used as a carrier by the future potential low Earth orbit (LEO)-MSS satellites in the 405-406 MHz and the lower frequency of the COSPAS-SARSAT bandwidth, that is to say 406 MHz, in order not to cause harmful interference to the COSPAS-SARSAT system and to the RAS.

### **5 HAPS systems**

The bands 47.2-47.5 GHz and 47.9-48.2 GHz (see RR No. 5.552A) have been designated to be used by HAPS systems and are close to the RAS spectral line band at 48.9-49.0 GHz (see RR No. 5.149) and the 50.2-50.4 GHz EESS (passive) and SRS (passive) frequency band (see RR No. 5.340).

At the World Radiocommunication Conference (Istanbul, 2000) (WRC-2000), RR No. 5.543A was adopted which designated the band 31.0-31.3 GHz also for use by HAPS in some countries mainly in Region 3. The adjacent band 31.3-31.5 GHz is a purely passive band.

Important factors for controlling interference from HAPS airborne stations include the geographical separation, the power and the spectral roll-off of the HAPS transmitter and the gain of the HAPS antenna directed towards RAS sites and other parameters.



Important factors for controlling interference from HAPS ground stations include the geographical separation, the power and the spectral roll-off of the HAPS ground station transmitter, and the gain of the HAPS ground station antenna directed towards RAS sites or EESS (passive) passive sensors.

A fixed service using HAPS is a special case of FS and could be considered in the band-by-band studies in Annex 4. Preliminary studies in the 31.0-31.3 GHz band, indicate that low e.i.r.p. density together with guardbands and stringent spectral roll-offs may be necessary to reduce interference into passive sensors to an acceptable level.

## **6 FS HDFS applications**

HDFS are meant to provide simple and inexpensive FS systems for large-scale deployment. They are essentially characterized by:

- short-distance transmission;
- a higher and evolving transmitter density than the normal FS systems;
- no commitment to use antenna classes with high directivity and limited back lobe emission;
- the possibility of higher elevation angle transmission with respect to the normal FS systems;
- the possibility of point-to-multipoint configuration; and
- the possibility of the distribution of low-price and low-performance equipment suitable for ubiquitous deployment.

The above characteristics make these systems potentially more likely to cause interference to EESS (passive) and RAS systems than the conventional FS systems.

RR No. 5.547 designates the following bands for use by HDFS: 31.8-33.4 GHz, 37-40 GHz, 40.5-43.5 GHz, 51.4-52.6 GHz, 55.78-59 GHz and 64-66 GHz. Some of these bands overlap or are close to bands used by passive services. All the bands where overlaps exist have been analysed before the designation was made and sharing criteria were defined.

For the bands adjacent or close to passive service bands, studies on the effect of unwanted emissions are needed. In particular, the effects of HDFS in the band 31.3-31.8 GHz on RAS and EESS (passive) operating in the adjacent purely passive band 31.3-31.5 GHz need to be evaluated. The effects of HDFS in the band 51.4-52.6 GHz on EESS (passive) operating in the band 50.2-50.4 GHz have been studied with positive conclusions about the compatibility.

## ANNEX 3

**Mitigation techniques that may be used by passive services**

Appropriate mitigation techniques may significantly improve the ability of passive services to operate in an environment in which the presence of active services has an increased significance. However, the implementation of such techniques may also impact the operational effectiveness of the systems involved, and the nature and extent of the activities that can be supported in the band under consideration.

The operating requirements assigned to radio astronomy observatories set limits to the extent to which the overall effectiveness of the facilities may be so reduced.

Examples of mitigation methods for use by passive services are listed below. Some of these are already implemented. Others are under investigation.

**1 Spaceborne passive sensors****1.1 Receiver architecture**

Adjustment of receiver characteristics to mitigate unwanted emissions may be possible in some cases. However, for satellite passive remote sensing described in Recommendation ITU-R SA.1029, the sensor's receiver is the radiometer, which is used to measure a small change in noise temperature to describe some atmospheric or climatic condition. Therefore, any change in the receiver sensitivity adversely impacts the sensor resolution and the usefulness of the sensor data.

**1.2 Analogue filtering at either the RF or intermediate frequency (IF) stages**

This technique is mainly used to protect against emissions lying outside the passive service bands.

**1.3 Antenna patterns**

Satellite passive remote sensor antenna patterns are very directional by nature. In some cases, the use of a more directive antenna pattern for satellite passive sensors could possibly mitigate certain unwanted emissions if the concomitant reduction in sensor pixel size is acceptable for the application in question.

In the few cases where the sources of interference are limited in number and their location is known, it may be possible in the future to reduce the interference levels using phased array antennas with null steering. It is to be noted that this technology is currently not used by spaceborne passive sensors because of its complexity and is not suitable for many of the EESS (passive) applications.

**1.4 Interference excision techniques**

These techniques need further investigation, to better understand their possible applicability.

### **1.5 Digital adaptive interference cancelling**

This technique needs further investigation to better understand its possible applicability.

### **1.6 Adjustment of sensitivity levels**

This technique would be similar to the adjustment of receiver characteristics as in § 1.1 above.

### **1.7 Time sharing**

For many remote-sensing satellite applications, time sharing could be difficult because lost pixels may not be recoverable until a later orbit. However, this technique requires further investigation.

### **1.8 Shielding at the prime focus of parabolic receiving antennas**

This technique does not appear to be applicable to passive remote sensors on board satellites due to their measurement of very small changes in observed noise temperature and the use of highly directive antennas.

### **1.9 Use of orbital geometry**

The use of orbital geometry can minimize interference received: for example, by taking measurements only when the spaceborne passive sensor is moving away from the equator, some mitigation of the reflections from geostationary satellite downlinks would be realized.

## **2 Radio astronomy receivers**

### **2.1 Site shielding and site selection**

For radio telescopes, which are relatively compact in size, site shielding can be used to suppress interference from ground-based transmitters. For certain telescopes site shielding has been applied successfully. For multi-antenna array telescopes spread over a large area this technique is not feasible because of the large spatial dimensions, the requirement to observe at low elevation angles, and the cost involved.

The selection of new sites for passive sensors may take into account the global distribution of terrestrial spectrum occupancy and the distribution of the service footprints of satellite systems.

### **2.2 Quiet zones and coordination zones**

The establishment of a quiet zone by administrations around a radio astronomy station may prohibit all transmissions in this zone.

The establishment of a coordination zone by administrations around a radio astronomy station and outside a quiet zone may facilitate the protection of the radio astronomy station from existing and new transmitting services. Further discussion of coordination zones is provided in Recommendation ITU-R RA.1031.

### 2.3 Receiver architecture

For in-band interference in radio telescope systems, the parameters determining the receiver characteristics cannot easily be adapted for the purpose of minimizing the effect of interference. The reason is that radio astronomy receivers are optimized for very low  $S/N$ s, as the instantaneous astronomical signals usually are much weaker than the system noise levels. In most cases, in-band suppression techniques in receivers immediately leads to unacceptable system noise increases. However, techniques to suppress in-band interference are being studied, like for example feed forward systems and interference cancellation systems. The relevant design parameters are linearity and system noise.

Interference outside the radio astronomy bands can be suppressed, to a certain extent, in the radio astronomy receiver system by filtering and by optimizing the mixing scheme of the receiver system. Strong interferers close to the radio astronomy bands are difficult to suppress by filtering because this filtering usually has to be done in the first stages of the receiver system, where the system noise constraints on losses are strong.

### 2.4 Antenna patterns

Most parabolic radio telescopes are designed to have an optimal match between side lobe level and dish illumination. For most parabolic telescope designs, a decrease of the side lobe level by mechanical modifications, like shielding the primary dish or by shielding the receiver box, immediately leads to a decrease in dish illumination properties and are therefore not attractive. Simply increasing the parabolic dish area would both decrease the side lobe levels and increase the sensitivity. But this cannot be done without a major mechanical redesign and very high cost. In general, most parabolic telescopes are already optimized for sensitivity-to-side lobe ratio. The only additional practical shielding which can be done is site shielding against ground-based transmitters for compact radio telescope systems.

For phased array type receivers one has to distinguish between the single antenna element level and the levels in which the elements form a phased array. Both levels need a different interference suppression approach. The single antenna element, together with its RF system, is comparable to the conventional receiver system and needs to be treated likewise. For the phased array level, the new parameter to be used for interference suppression is the beamshape. This beamshape can be deformed in such a way (by adapting the antenna element complex weights) that “nulls” in the beamshape can be directed at the interference source, thus suppressing it. In radar techniques this is widely used. For phased-array radio astronomy it has potential, but much research is still needed. Issues to be solved are for instance calibration of a rapidly varying beam and keeping a large scale phased array affordable and linear.

### 2.5 Analogue filtering at either RF or IF stages

This is useful only for interference which is not in the radio astronomy bands. The receiver frontends in use today at radio observatories normally contain cooled high electron mobility transistors (HEMT) amplifiers, which are inherently broadband. The passband of the first stage

amplifier drops slowly outside the edge of the designed bandwidth. If strong transmitters are close enough to the observing direction to cause non-linearity of the receiving system, filtering may be required before the first amplifier stage of the receiver frontend. However, this is not a preferred option because it would degrade the system sensitivity.

At some frequencies under consideration the filter technology is insufficiently well developed. A potentially successful option is to apply high temperature super-conducting (HTSC) filters in the first stages of the receiver. HTSC demonstrator filters have been applied successfully, but more research is needed to make practical HTSC filters for radio astronomy.

## 2.6 Interference-excision techniques

Various interference-excision techniques are currently studied by the radio astronomical community. Already it is clear that no single technique can provide a general solution for doing radio astronomical observations in all hostile interference environments. Putting together several kinds of interference mitigation techniques will be necessary in complex interference environments. In general, the following interference-excision techniques can be identified:

- excision at the baseband/digital level:
  - gating/blanking;
  - single channel filtering (conventional filter, wavelet transform);
  - for phased arrays: nulling, gating, projection techniques (spatial-spectral-temporal);
  - adaptive filtering/side lobe cancelling;
  - time sharing;
- excision at the post-processing level:
  - removing interference by blanking/gating;
  - cleaning interference from maps by using mathematical-type algorithms.

Research programmes on these issues have been initiated. It is expected that estimates of realistic interference mitigation levels will become available in the coming years.

## 2.7 Digital adaptive interference cancellation

Interference cancellation can be used to subtract the impact of interference. Either an omnidirectional or a directional antenna in the direction of a known interferer can be used to obtain an error signal. Correlating the error signal can be used to adjust an adaptive cancellation scheme that subtracts the interference from the signal.

## 2.8 Adjustment of sensitivity levels

The radio astronomical signals of interest usually are many orders of magnitude lower than the instantaneous receiver noise power levels. As receiver systems already are designed to have the lowest possible noise level, adjusting the sensitivity level in order to suppress interference is no option.

## 2.9 Cooperative solutions

As more services are squeezed into an already crowded spectrum, and problems arise when largely incompatible services find themselves allocated to adjacent bands, general regulations and mitigation techniques applied uniformly across the spectrum are likely to be inefficient. Services with mutual interference problems may need to cooperate in seeking, developing, and implementing appropriate mitigation measures. This collaboration should begin at the system design level. In cases where interference problems are demonstrably unavoidable, time-sharing, collaborative scheduling, or procedures to accommodate time-varying interference levels might be appropriate.

Time-sharing based on daily time-blocks can in principle be used in some cases in some bands, assuming that the management problem of the time sharing issues can be solved. Because of the regularity or the irregularity of certain astronomical phenomena, the allocation of time slots for radio astronomy should be flexible. Sharing with services needing fixed and constant time-blocks is therefore not generally possible. Time-sharing based on time-division multiple-access operations on timescale of minutes and less is not easily implemented because of the long integration times of the current radio receiver systems and backends.

If the time scale of the variation of the astronomical source is smaller than the time scale of the sharing procedure, time-sharing is not practicable.

### 1. Guardbands

Guardbands may be used at the passive receiver to avoid detrimental interference due to strong signals transmitted in an adjacent band. The use of guardbands inside the passive allocation will generally reduce the observing bandwidth used and is done at the cost of reducing the  $S/N$  of the data.

## ANNEX 4

### **List of transmitter/passive band pairs that are most problematic and band-by-band studies**

The number of potential interference situations due to unwanted emissions from active services into passive service bands may be very high, particularly if non-adjacent band interference is also taken into account. A partial list of such bands and situations, identified by the passive services, where spurious emission limits more stringent than the general limits contained in RR Appendix 3 may be required, and where active transmitters may need to limit out-of-band emissions, is given in Table 1.

It is to be noted that Table 1 lists only interference situations that occur below 71 GHz. A number of passive service bands above 71 GHz have been added to the Table of Frequency Allocations by WRC-2000. Identification of possible interference situations at frequencies above 71 GHz is ongoing.

A more complete list of interference situations is being considered as part of the band-by-band study mandated by Recommendation 66 (Rev.WRC-2000).

TABLE 1

Passive service band	Possibly impacting active service allocation	Comments
1 400-1 427 MHz (RAS)	1 452-1 492 MHz (BSS)↓	No pfd limits on BSS sound allocation; RR No. 5.340
1 400-1 427 MHz (EESS, RAS)	1 350-1 400 MHz (Radiolocation)	RR No. 5.149
1 610.6-1 613.8 MHz (RAS)	1 559-1 610 MHz (RNSS)↓	Existing problem of interference to RAS; RR No. 5.149
1 610.6-1 613.8 MHz (RAS)	1 613.8-1 626.5 MHz (MSS)↓	Existing problem of interference to RAS; RR No. 5.149
2 690-2 700 MHz (RAS)	2 655-2 690 MHz (BSS, FSS)↓	No pfd limit on BSS (sound); RR No. 5.340
10.6-10.7 GHz (EESS, RAS)	10.7-11.7 GHz (FSS)↓	Potential problem with systems under development in the FSS; RR No. 5.340
21.2-21.4 GHz (EESS)	20.2-21.2 GHz (MSS, FSS)↓	RR No. 5.524
22.21-22.5 GHz (RAS)	21.4-22 GHz (BSS)↓	Only coordination thresholds on BSS (Res. 525 (WARC-92)); RR No. 5.149
23.6-24 GHz (EESS)	22.55-23.55 GHz (ISS)	ISS used by LEOs, main-beam-to-main beam coupling possible
31.3-31.5 GHz (EESS)	30-31 GHz (FSS, MSS)↑	Potential problem from main beam coupling
31.3-31.5 GHz (RAS, EESS)	31.0-31.3 GHz (FS)	Resolution 122 (Rev.WRC-2000)
31.5-31.8 GHz (RAS, EESS)	31.8-33.4 GHz (FS, RNS)	Resolution 75 (WRC-2000)
42.5-43.5 GHz (RAS)	40.5-42.5 GHz (BSS, FSS)↓	Resolution 128 (Rev.WRC-2000); Resolution 79 (WRC-2000)
50.2-50.4 GHz (EESS)	47.2-50.2 GHz (FSS)↑	Potential problem from main beam coupling
50.2-50.4 GHz (EESS)	50.4-51.4 GHz (FSS, MSS)↑	Potential problem from main beam coupling
52.6-52.8 GHz (EESS)	51.4-52.6 GHz (FS)	RR No. 5.547

ISS: inter-satellite service

RNS: radionavigation service

RNSS: radionavigation-satellite service