

International Telecommunication Union



**Report ITU-R RA.2259**  
(09/2012)

# **Characteristics of radio quiet zones**

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



International  
Telecommunication  
Union

## Foreword

The role of the Radiocommunication Sector is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including satellite services, and carry out studies without limit of frequency range on the basis of which Recommendations are adopted.

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## REPORT ITU-R RA.2259

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(2012)

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## 1 Introduction

### 1.1 Definition and general requirements of a radio quiet zone

Radio astronomy observations from the surface of the Earth are intrinsically sensitive to radio interference from man-made sources, whether intentional or unintentional. Radio telescopes are many orders of magnitude more sensitive than radiocommunication receivers used for telecommunications. To optimize the environment in which radio astronomy observations are carried out, particularly at advanced and costly modern facilities, radio quiet zones (RQZs) have been implemented by some Administrations. In the context of this Report, an RQZ is meant to be any recognized geographic area within which the usual spectrum management procedures are modified for the specific purpose of reducing or avoiding interference to radio telescopes, thereby maintaining the required standards for quality and availability of observational data.

There are a number of different procedures that can be used, and these may apply to some specific frequency bands, to some specific periods of time and/or to various classes of interference sources. The controls may be technical, geographic and/or regulatory. Different RQZ definitions and



management methods will therefore apply to different radio telescopes, depending on their specific requirements. In some cases, restrictions may be applied only in certain frequency bands or below a certain frequency, if no observations are carried out above that frequency at the site. As an example, transmissions below 15 GHz are restricted within a certain radius around the Arecibo Observatory, located in Puerto Rico. Since no observations are carried out, nor are any expected to be carried out above that frequency in the future, no restrictions are needed on higher frequency transmissions. The reverse is not necessarily true, however. For example, some restrictions may be imposed on transmissions below 30 GHz in the neighbourhood of the large international ALMA observatory even though it is not expected to ever observe below that frequency, due to its susceptibility to interference at these lower frequencies in the signal path.

Until recently, RQZs implemented for the protection of radio astronomy imposed power flux or power flux-density limitations only at certain well defined coordinates, as a rule, the focal point of the telescope. Most radio telescopes that are currently built are not single dish telescopes however, but are distributed systems, and the restrictions proposed to protect them reflect this situation. Because such systems are inherently less susceptible to interference than single dishes, but cover larger geographical areas, the RQZs proposed to protect them may be more extended but may impose somewhat less stringent power limitations on neighbouring transmitters. Finally, most restrictions implemented in RQZs around the world are limited to fixed, terrestrial transmitters, not air or satellite borne transmissions. The reason for this is that interference that originates in mobile, particularly aeronautical, sources is usually of short duration; the interference is easily identified, while the source of interference itself is usually gone by the time it can be identified. No RQZ restricts satellite transmissions. Satellite operations are covered by international regulations, while RQZ regulations have, to date, been established by the interested national administration. This Report identifies the broad range of controls used and provides examples of a variety of RQZs around the world.

It is important to emphasize that a RQZ does not imply a complete absence of radio transmissions. The existence of, and coexistence with, a range of man-made devices will always be necessary. A RQZ may include options for notification of other users and for negotiation in mitigating interference. On the other hand, a RQZ does not consist entirely of mitigating techniques implemented by the radio astronomy facility; some level of control on externally-generated interference is intrinsic to a RQZ.

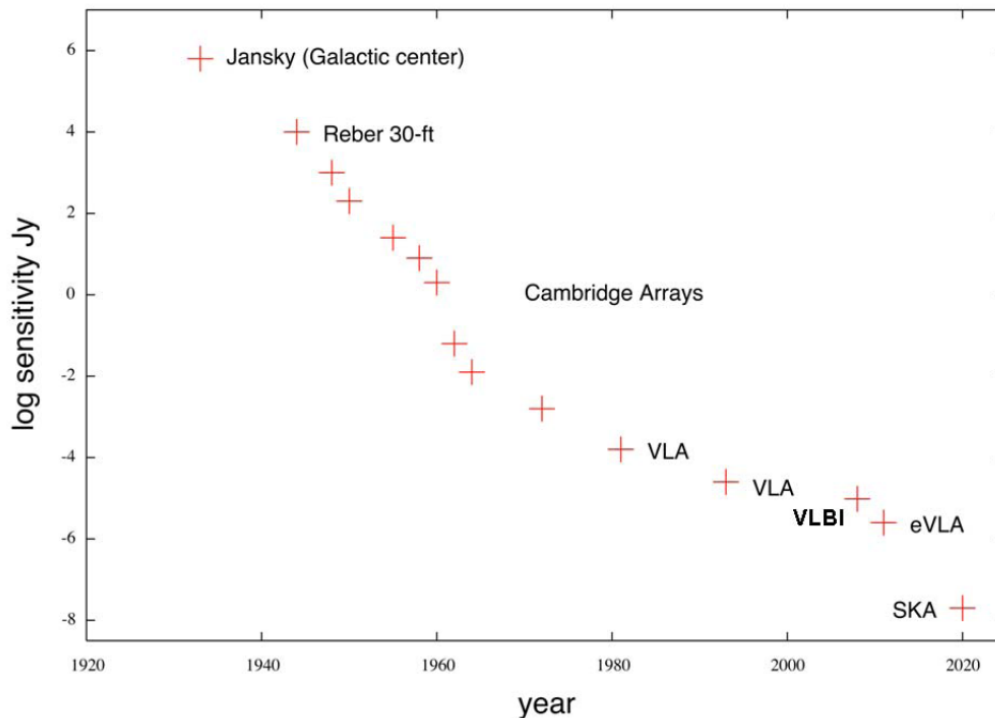
A RQZ is therefore a buffer zone that allows for the implementation of mechanisms to protect radio astronomy observations at a facility within the zone from detrimental radio frequency interference, through effective mitigation strategies and regulation of radio frequency transmitters.

## **1.2 Overview of the characteristics of radio astronomy instruments in relation to protection from radio-frequency interference**

A significant characteristic of radio telescopes, in relation to interference protection, is the level of sensitivity required to make astronomical observations. As a matter of comparison, a modern radio telescope is 15 orders of magnitude more sensitive than a GSM mobile phone.

The evolution of the sensitivity of radio telescopes is illustrated in Fig. 1, that shows the minimum detectable signal in terms of flux density (measured by radio astronomers in Janskys where  $1 \text{ Jansky} = 10^{-26} \text{ (W/(m}^2 \cdot \text{Hz))}$ ) vs. the year of the observation [1]. The Square Kilometre Array (SKA) is planned as the next generation radio telescope; all other points indicate actual measurements. Between 1933 and 1983 the sensitivity of radio telescopes improved some 10 orders of magnitude, a performance improvement similar to that described by Moore's law. The rapid improvement over time is due to system improvements, including decreases in system temperature and increases in collecting area, bandwidth and integration time.

FIGURE 1

**Improvement in the sensitivity of radio telescopes with time**

### 1.3 Overview of the characteristics of the electromagnetic environment

#### 1.3.1 Sources of RFI – Intentional radiators and unintentional radiators

Radio-frequency interference (RFI) to radio astronomy arises from a number of sources. These can be generally categorized into intentional radiators (other radiocommunication transmitters) and unintentional radiators (electrical equipment which produces radio noise as a by-product of operation).

In the mid-20<sup>th</sup> century, there were relatively few types of radiocommunication transmitters in operation. They included broadcasting (both sound and television), fixed point-to-point links, radar for navigation and meteorological applications, aeronautical and maritime communications and amateur radio. In 1963, satellite transmissions began, initially from the geostationary orbit. The following decades saw a gradual increase in the use of the commercial radio spectrum. However, a significant change occurred in the 1980s and onward, with the introduction of consumer radiocommunications; initially a vehicle-based mobile telephone, and later handheld cellular phones. The final years of the 20<sup>th</sup> century also brought the introduction of wireless computer networking and a proliferation of related devices. This trend is expected to continue into the future with a strong demand for mobility, higher data rates, and a wider range of applications.

There are three consequences of the growth of the wireless industry in the last 50 years. First, in the early days, most transmitters, with the exception of amateur radio, were operated and controlled by government bodies or by large corporations. In recent times, it is the general public who carry and operate a majority of transmitters, albeit low powered. This complicates the analysis and control of radio transmitters near a RQZ. Secondly, the early devices were few and, in many cases, fixed. The recent trend is towards a high density of mobile devices and towards rapidly deployed fixed systems. Third, the congestion of the radio spectrum and the increase in demand has led towards technology development at ever increasing frequencies. Mobile devices are currently limited, by propagation constraints, to an upper limit of about 6 GHz, but fixed services are expanding to the 80-100 GHz bands or beyond. There is interest in frequencies of 500 GHz and above for

short-range communications. Therefore radio quietness cannot be achieved simply by choosing frequencies that are not used by active radiocommunication systems.

The increase in radiocommunication devices has been paralleled, in the second half of the 20<sup>th</sup> century, by a growth in other electrical equipment which can unintentionally produce RFI. The number of automobiles, household appliances, microwave ovens, manufacturing and other industrial applications, computing equipment and entertainment systems (television and associated technology) has sharply increased in recent decades. While in some cases, improvements in the technology mean that each device produces less RFI, this is balanced (or perhaps overcome) by the growth in number of devices. In particular, computing equipment which produces RFI at clock speeds has experienced significant growth.

### **1.3.2 Regulatory controls of RFI: role of regulation**

Regulatory controls of local radio interference are managed on a national basis by government regulators. A core component of national regulation is a radio-frequency spectrum plan which identifies the allocation of frequency bands to services, including some bands allocated to radio astronomy. These national spectrum plans are based on the ITU Radio Regulations to the extent necessary to avoid harmful interference between different countries.

National regulation also includes a process to authorize specific transmitters (and in some cases, receivers) under a licensing programme, and technical limitations (power, bandwidth, modulation, etc.) on transmitters. However, many consumer-grade transmitters, generally low-powered devices, operate on a class-licence or licence-free basis, making it difficult to predict or manage the operation of these transmitters.

Finally, while licensing regimes are intended to minimize the probability of harmful interference between spectrum users, it is recognized that such interference may arise. Therefore, national regulation typically includes a process to identify and resolve interference complaints from licensed users.

For RQZs, national regulators may choose to implement a variety of controls as described later in this Report, and to assist in resolving problems of harmful interference that arise if the regulations are not followed.

In the case of interference between different national administrations, the ITU has processes to assist in resolving problems. This is unlikely to be relevant to RQZs.

## **1.4 Goals of creating a RQZ**

The basic goal of creating a RQZ is to minimize the potential for interference to radio astronomy or other passive sensing services. The first RQZ for the protection of radio astronomy observations was established in the United States of America. In the early 1950s the U.S. National Science Foundation (NSF) was considering the possibility of establishing a centre for radio astronomy, and contracted a consortium of universities to locate a suitable site. A total of 25 sites were surveyed; the final selection being based on considerations that included the availability of public land, particularly a large flat area suitable for the siting of radio interferometers, the radio quietness of the site, and the possibility to observe some prime astronomical targets, such as the galactic centre. The US National Radio Quiet Zone (NRQZ) was established in 1958 [2], upon approval by the agencies managing the radio spectrum, and has been continuously in existence since then. Descriptions of this and other RQZs are given in the Annexes of this Report.

## **2 Characteristics of radio astronomy instruments relevant to RQZ**

### **2.1 Geographic considerations**

A radio astronomy station is always located at a site that is consistent with its intended scientific purpose. Beyond that, however, there are certain geographic considerations that can possibly ease the creation and maintenance of a quiet zone.

There are different types of quiet zone models. In one model, no transmitters at all are allowed within the quiet zone. In another model, transmitters are allowed in the quiet zone as long as the received signal level at the radio astronomy station does not exceed a pre-determined interference threshold. Other quiet zones may be a combination of the two models, with, for example, an “inner ring” where no transmitters are allowed, and an “outer ring” in which transmitters that meet the specified interference criteria are allowed. In cases where interference criteria are specified, it is important to establish and clearly articulate one or more reference points (latitude, longitude, and height above mean sea level) at which the interference level will be computed or measured.

Besides locating radio astronomy stations as far from heavily populated areas as possible, placing them in areas that provide some level of natural terrain shielding, such as in valleys, can be helpful. This reduces RFI from transmitters beyond the terrain blockage, and allows fewer technical constraints on transmitters in those areas, which can make quiet zone compliance more amenable to potential licensees in the quiet zone.

Because most RFI to radio telescope systems is created by sources at the radio astronomy installation itself, terrain or other natural shielding within the installation should be a consideration during site design. Some observatories located in quiet zones have found benefits to surrounding their radio telescopes by forests of coniferous trees such as pines, which, due to the moisture content of their needles, can provide some additional protection from RFI coming from the horizon, particularly at frequencies above a few GHz.

Observatories located on mountain peaks with very large lines of sight (LoS) are particularly challenging for quiet zone coordination. There may be some situations, such as a radio telescope on a high mountain top with a large metropolitan area within line of sight, where establishing a quiet zone would be exceedingly challenging.

Some of the most significant interference to radio astronomy is due to airplanes and satellites. While satellites will never come under quiet zone regulations, the possibility of creating a no-fly zone above an observatory should be examined. However, even if successful, such no-fly zones will not eliminate airborne sources of interference, because the radio horizon of an aircraft at cruising altitude may be close to 400 km, and the diameter of a no-fly zone to rid all sources of airborne interference to an observatory would therefore need to be as large as 800 km.

### **2.2 Frequency range**

Until comparatively recently, the frequencies used for radio astronomy have mostly been those listed in Recommendation ITU-R RA.769. Many of these bands, with frequencies ranging from 13 MHz to 270 GHz, have been allocated for passive use only, but some are shared with active transmitters on a co-ordination basis using agreed protection levels (see § 2.4). In addition to the above, there are many frequency bands which are of particular interest to, and have been identified for, use for radio astronomy for which protection is encouraged but not guaranteed by the Radio Regulations. Some of these frequency bands are identified in Footnotes to the Radio Regulations (e.g. RR No. 5.149 refers to a band containing a spectral line arising from the methanol molecule) and are listed in the International Table of Frequency Allocations.



At WRC-2000, bands for observations of spectral lines by passive services (including radio astronomy) at frequencies in the range 275 GHz to 1 000 GHz were identified by inclusion of RR No. 5.565, and it was noted that there could be additional bands of interest in this frequency range.

With improvements in receiver technology and the introduction of mitigation techniques to remove unwanted signals from radio astronomy observations, radio astronomy is now being conducted at frequencies across the whole of the radio spectrum. However, this does not mean that there is no longer a need for specific bands allocated to radio astronomy. Such allocations are still extremely important, as they provide bands which should be completely free of interference, which are essential for calibration and observations of the weakest radio sources.

### 2.3 Modes of operation

The largest class of cosmic radio sources is associated with continuum radiation; this is emission that extends relatively smoothly over most of the spectrum. Radio astronomy observations in continuum mode strive to achieve very high sensitivities and require the most strict protection thresholds, as described in the next section. In a RQZ, observations can occur over bands not allocated to RAS thus greatly increasing the available bandwidth and hence the sensitivity of the observations. In new radio astronomy receiver systems, bandwidths of up to 2 GHz at centimeter wavelengths and 8 GHz or more at millimetre wavelengths are common. Continuum observations over the whole part of the spectrum can provide unique information on radio sources and are only feasible under the protection of an RQZ.

Radio astronomers cannot always choose their frequencies arbitrarily. Many of the cosmic signals that they study take the form of spectral lines covering a limited frequency range. These lines are generated at characteristic frequencies associated with transitions between quantized energy states of atoms or molecules. Thus, allocations for observation of these lines must be made at specific frequencies. Important new lines continue to be detected, and many thousands of lines are routinely observed. For spectral lines in distant galaxies, an observed frequency that normally falls within a radio astronomy band may be Doppler shifted outside the band because of the large motions of the galaxies relative to the Earth. Therefore, practically all parts of the radio spectrum are of potential scientific interest. Hence, the access over large parts of the spectrum afforded by a RQZ allows observations of many lines not previously accessible.

Observations of spectral lines are often in narrow bands and hence the protection criteria for spectral line observations are less strict than for continuum observations by typically 10-20 dB. However, observation times of many hours are often required to obtain the sensitivities necessary to form conclusions of astrophysical interest. Absence of harmful interference is necessary over bandwidths sufficiently broad to include Doppler-shifted lines, together with comparison bands bordering the line emission.

To increase both the sensitivity and resolution of radio astronomy observations, arrays of radio telescopes have increasingly been deployed in radio astronomy. With such instruments two effects reduce the response to interference. These are related to the frequency of the intensity oscillations that are observed when the outputs of two antennas are combined, and to the fact that the components of the interfering signal received by different and widely-spaced antennas will suffer different relative time delays before they are recombined. With these effects the protection thresholds for interferometers over 10s of kilometres are about 20 dB greater than single telescope continuum systems.

In the case of VLBI the antennas are very widely separated, making the chance of occurrence of correlated interference very small. The interference threshold is then determined by the level at which the interference begins to degrade the measured correlation of the signals from two antennas. Thus the detrimental thresholds for VLBI are approximately 40 dB greater than for continuum total

power systems at the same frequency. Hence RQZs around VLBI antennas can have more relaxed protection criteria.

## 2.4 Sensitivity

The sensitivity of an observation in radio astronomy can be defined in terms of the smallest change in the power level at the radiometer input that can be detected and measured. The detrimental interference threshold level is directly related to the sensitivity; it is defined as that interference power which causes a 10% increase in the noise temperature of the receiver. Under the conditions described in Recommendation ITU-R RA.769, such interference is supposed to have an insignificant impact on astronomical observations (see Recommendation ITU-R RA.769, for a mathematical formulation of the sensitivity equation). Tables 1 and 2 of Recommendation ITU-R RA.769 list detrimental threshold levels, in terms of power flux and power flux densities, for continuum and spectral line observations in primary radio astronomy bands under representative conditions. These levels are generally accepted as the levels that are protective of radio astronomy observations. This, however, need not be the case when dealing with an RQZ specifically established for the benefit of radio astronomy.

We recall here the conditions under which the values in Tables 1 and 2 in Annex 1 of Recommendation ITU-R RA.769 were derived:

- The source(s) of interference appear in the 0 dBi sidelobe(s) of the telescope.
- The integration time of the astronomical observation is 2 000 seconds in all cases.
- The bandwidth of a continuum observation is:
  - The width of the allocated primary radio astronomy band for observations below 70 GHz.
  - 8 GHz for observations above 70 GHz.
- The bandwidth of spectral line observations is as given in Table 2.

Sidelobe levels of radio telescopes are poorly known, and the 0 dBi sidelobe level assumption is probably as good an approximation as possible. It is worth noting that under this assumption the detrimental interference level is independent of the collecting area of the telescope.

The other two assumptions may, however, be relaxed in an RQZ. Integration times as long as several days may be used to detect faint sources in modern observations, resulting in 30 dB better sensitivity than the thresholds in Recommendation ITU-R RA.769. The bandwidth of modern radio astronomy receivers are much wider than the allocated bandwidth that in some cases is only a fraction of a percent of the centre frequency, resulting in up to 20 dB more sensitivity than defined in Recommendation ITU-R RA.769.

## 2.5 Effect of RFI on RAS observations

The effect of RFI on radio observations varies greatly, from simple increases in noise levels that can be mitigated to levels that can destroy the receivers in a radio telescope.

The combination of high receiving gain of the astronomy antenna and high incident signal strength from a communications service could suffice to permanently degrade the performance of a RAS receiver, or perhaps even destroy it. Technical details are given in Report ITU-R RA.2188 on “Power flux-density and e.i.r.p. levels potentially damaging to radio astronomy receivers”.

When RFI signals are of sufficient strength to drive the amplifiers in a radio telescope receiver system into saturation or even just into the non-linear regime, the radio observations cannot be accurately calibrated and hence no useful data could be obtained. For any radio observations the RFI signals must allow operation of the amplifiers in the linear region.

RFI that is present at low enough levels so that radio observations are possible still requires some form of mitigation. The simplest form of mitigation is excision in frequency and/or time if the RFI can be unambiguously detected, but this leads to loss of data and sensitivity. More sophisticated RFI mitigation methods are possible but most of them require considerable development and operational effort and can be very costly. Detailed discussion on RFI mitigation for radio astronomy is given in Report ITU-R RA.2126.

The greatest advantage of RQZs is the inherent low levels of RFI that not only protect radio astronomy receivers but also allow for simpler and easier forms of mitigation.

## **2.6 Geometric considerations**

Radio astronomy antennas are typically very high gain with narrow beamwidth, and the main beam is directed at least several degrees above the horizon. Interference directly into the main beam is therefore not likely from terrestrial sources, and infrequent from aircraft or satellite sources. However, given the sensitivity of the radio astronomy receiver, as discussed above, even the interference into the side lobes of the antenna can be harmful to radio astronomy observations. As the side lobe gain can vary significantly depending on the orientation of the antenna and the position of the interference source, for convenience a side lobe level of 0 dBi is assumed for interference analysis.

For large parabolic dishes and similar antennas, another practical consideration may be interference directly into the receiver at the focal point of the antenna.

## **3 The electromagnetic environment**

There are a number of possible interference sources to radio astronomy observations, and they may require different types of controls. These are summarized in the following sections. This Chapter also provides an overview of the main propagation mechanisms that should be considered in assessing the potential for interference.

### **3.1 Intentional radiators**

Intentional radiators are those systems and devices which produce radio-frequency emissions for the purpose of communication or sensing; that is, the transmission of radio energy is intrinsic to their operation. In general, this means that the frequency band, bandwidth, transmitted power level, modulation scheme and other radio parameters are known or can be estimated with some accuracy. Intentional radiators also operate, in general, in narrow frequency band compared to astronomy observations, compared to unintentional radiators which are wideband.

The ITU defines a large number of radio services including terrestrial systems (aeronautical mobile, aeronautical radionavigation, amateur, broadcasting, fixed, land mobile, maritime mobile, maritime radionavigation, meteorological aids, radiolocation, radionavigation, standard frequency and time) and satellite systems (Earth-exploration satellite, fixed satellite, inter-satellite, meteorological satellite, mobile satellite, space operations and space research).

#### **3.1.1 Licensed radio devices**

Licensed radio devices are those for which the national regulator has authorized operation. They may be licensed on an individual (apparatus) basis, in which case the regulator has knowledge of the location (or area of operation), frequency, power, bandwidth, modulation, antenna height and radiation pattern, and other parameters of the station. These licenses are maintained by the regulator and in most cases must be renewed on a regular basis. This allows some control for a radio quiet

zone by restricting or limiting certain types of transmitters, for example, by frequency band or by power level.

Many administrations also have a spectrum licensing option, where users have the right to a given frequency band in a given geographic area, possibly for a given period of time. This is often used for frequency bands with high demand; for example, the band around 2 GHz was sold as spectrum licences in many administrations for the introduction of 3rd generation mobile telephony. Under spectrum licences, users may deploy radio transmitters within the nominated frequency and geographic space as desired. This makes control for a radio quiet zone more difficult than for the individually licensed devices described above unless the spectrum licence conditions specifically include RQZ limits.

### **3.1.2 Class-licensed (unlicensed) radio devices**

Class-licensed devices are those which are operated without a specific licensing agreement between the user and the regulator (in some administrations this is referred to as “unlicensed”). These are restricted to identified frequency bands, often the same bands as ISM devices (see § 3.2.1), and devices are limited in power, bandwidth and other parameters by national regulation. Under a class licence, transmitters must not cause interference to other users, nor claim protection from interference.

Examples of class-licensed devices are cordless telephones, wireless computer networks (e.g. Wi-Fi), RFID (Radio-frequency identification), automatic door sensors, vehicle keyless entry, motion sensors and many others. In general they are consumer-grade devices or used by industry in large deployments. They are also typically low-powered and often mobile.

Ultra-wideband (UWB) devices (for communication or for sensing) are also typically class-licensed. As the name indicates, UWB systems operate over much wider bandwidths than other radio systems, although at correspondingly lower frequency spectral density. Regulators are exploring options for the licensing and interference management of UWB systems.

Control of class-licensed transmitters for a RQZ is more difficult than for licensed devices as the location of operation and other parameters are not known to the national regulator.

### **3.1.3 Spacecraft- and aircraft-based radio transmitters**

Transmissions from satellites, other spacecraft and aircraft are authorized in a large number of frequency bands of interest to radio astronomy. As satellites and space systems are coordinated internationally, it is often difficult for a national regulator to control transmissions for the purpose of a radio quiet zone. Geostationary satellites maintain a constant position with regard to the telescope, and interference mitigation may be possible by avoiding the geostationary arc in observations. Non-geostationary satellites may be more problematic as they appear on the horizon and cross through the observing area.

Aircraft-based radio transmitters (for communications and navigation) may also cause interference to radio astronomy receivers. It is sometimes practical for routine air overflight routes to be arranged to not overfly a RQZ. In Puerto Rico these have been arranged to be off-shore to the greatest practical extent.

Likewise, some transmitting systems used by aircraft, such as GLOBALSTAR mobile earth stations, have undertaken coordination agreements, whereby they switch their frequencies while within 500 miles of the telescope, when their use would interfere with an advertised telescope program. Such accommodations require an active on-going coordination activity with the operators of transmitters, and a timely communication of telescope schedules.



### **3.2 Unintentional radiators**

Unintentional radiators produce radio-frequency noise as a by-product of their main function. Typically this is at lower power spectral density than intentional radiators, but over wider frequency bands. The characteristics of the emitted radio-frequency energy are not well characterized in power level, frequency or statistical characteristics. Recommendation ITU-R P.372 provides information on the general characteristics of man-made noise in a variety of environments; this represents noise from a number of discrete sources within the environment rather than a particular piece of equipment. Man-made noise is characterized by a combination of background noise with Gaussian statistics and impulse noise of higher levels but lower probability.

#### **3.2.1 Industrial, scientific, medical**

Industrial, scientific and medical (ISM) devices are those which use radio-frequency energy for a purpose other than communication. Microwave ovens (domestic and industrial), medical diathermy and RF welders are well-known examples. Specific frequency bands are allocated for ISM devices and the frequency and power characteristics are typically known. For the purposes of a RQZ, they are very similar to class-licensed devices and often share the same frequency bands.

#### **3.2.2 Vehicles**

The ignition systems of vehicles (cars, trucks, buses, trains, boats, etc.) produce radio-frequency noise. Typically this noise decreases with increasing frequency, so that bands below about 1 GHz are of most concern. In addition, other motors on a vehicle (fans, wipers, heaters, etc.) can produce RF noise. In recent years, many vehicles have included computerized engine management systems which are further potential sources of interference.

Vehicles may also include intentional radio transmitters that may not be obvious to the operator. Modern rail systems incorporate radar sensors for speed measurement as well as wireless communication between different components of the drive mechanism. Current model road vehicles are available with Bluetooth and other wireless communication systems. In addition, vehicles are increasingly being equipped with collision-avoidance radar systems.

#### **3.2.3 Power lines**

Radio interference from power lines is typically generated from sparking, otherwise known as tracking, and corona discharge. More recently, the use of power distribution systems as a medium for the delivery of telecommunication services has been considered.

Corona discharge is an inherent property dependent on the electric field strength of a conductor and air moisture content. The onset of corona discharge is therefore highly dependent on weather conditions, becoming more aggressive with higher moisture content, and will typically occur on line voltages of approximately 70 kV and above. Corona discharge is found in all three voltage phases, and is characterized as a partial discharge. That is, there is a partial breakdown of the air in the vicinity of the conductor.

Sparking is typically the only source of radio interference on low voltage lines, less than 70 kV, and is more prevalent in dry, windy conditions that may open up spark gaps. Sparking phenomena are rarer on high voltage lines due to the use of steel structures and high mechanical tension. Spark-over across gaps may take place several times in one power frequency cycle, and is usually only found on one voltage phase. Unlike corona discharge, which is seen as an inherent property of a line, a spark gap is regarded as a fault on a line that can be fixed, or avoided, through proper maintenance.

Power line telecommunications (PLT) systems make use of radio frequency signals of up to 200 MHz applied on mains power distribution lines. PLT signals on these lines have the potential to cause interference to radiocommunication services, including the radio astronomy service. The two

main families of PLT applications that currently exist are *Access PLT*, providing last mile connectivity, and *Indoor PLT*, providing connectivity within buildings. These new families of applications are sometimes referred to as PLC (Power Line Communications), BPL (Broadband over Power Lines) as well as PLT (Power Line Telecommunications). Due to the ionospheric effects on HF propagation and the cumulation of PLT radiation, the implementation of PLT modems, even when far from radio astronomy observatories, may cause detrimental interference to radio astronomy observations.

#### **3.2.4 Electrical and electronic equipment**

The quantity of equipment in industrial and consumer use having the potential to radiate radio interference is increasing rapidly. One consequence is that although on an individual basis devices may be producing levels of interference not exceeding established standards such as CISPR-11 and CISPR-22 [3], the total emission may be strong enough to create an interference problem for radio observatories. Such interference is likely to have a broad-band, noise-like spectrum upon which narrow-band time-varying signals are superimposed.

Typically, interference problems due to equipment in industrial usage are easier to address than those arising from domestic equipment, due to more controlled operating conditions, availability of local expertise and the tendency for industrial development to be more tightly regulated. Consumer equipment is acquired and deployed with less planning, and is less well maintained. In addition, a mass deployment of consumer electronics has a cumulative detrimental effect.

#### **3.2.5 Cumulative interference, the noise floor and its increase with time**

Individual interference issues arising from single or associated sources can at least in most cases be addressed through current spectrum management and administration processes. A major issue is the growing deployment of mainly unlicensed devices in industrial and domestic use, which emit signals either intentionally or unintentionally, or even both. These add up to a noise floor that rises as the number of devices increases. The difficulty in identifying and addressing contributions to the total noise increases as the noise floor rises.

For example, in the zone surrounding the Dominion Radio Astrophysical Observatory (Penticton, Canada), it has proved extremely difficult to control the deployment of electronic devices in houses in a nearby community, and politically counterproductive to try. Microwave ovens and wireless computer networks, which were rare a decade ago, are now standard requirements in houses, and governments are pressuring the populace to use “energy-saving light bulbs”. Therefore the only way found to at least partially mitigate interference is to keep centres of community expansion well away from radio observatories, preferably out of line-of-sight.

A programme for systematically measuring the noise floor and its changes with time are essential in identifying problems before they manifest themselves as significant losses of data and observing time. A component of this programme is to work closely with the national, regional and local spectrum managers, and with local community administrations.

### **3.3 Propagation of RFI signals**

In evaluating the potential for interference from the sources described above to a radio astronomy site, it is necessary to predict the propagation of the RFI signal.

It is essential to distinguish between propagation prediction for radio system design and that for interference analysis. System design must account for the maximum (or near maximum) loss on a path between transmitter and receiver to ensure that a sufficient power level is received. Interference analysis, on the other hand, must calculate the minimum (or near minimum) loss on a path between transmitter and victim receiver to evaluate the maximum power level likely to be

received. In using the Recommendations of ITU-R Study Group 3 or other propagation prediction methods, this distinction should be observed.

### 3.3.1 Free-space

Free-space propagation loss refers to the geometric loss of radio energy due to the distance between transmitter and receiver, without any obstacles or material loss on the path. For most scenarios, it is the lower bound on the propagation loss for a path<sup>1</sup>.

Recommendation ITU-R P.525 describes free-space propagation and provides a formula using convenient units:

$$L_{bf} = 32.4 + 20 \log f + 20 \log d \quad \text{dB} \quad (1)$$

where:

$L_{bf}$ : basic free space propagation loss (dB)

$f$ : frequency (MHz)

$d$ : distance (km).

### 3.3.2 Diffraction

Where the path between the transmitter and receiver is obstructed by terrain, buildings or other obstacles, additional loss due to diffraction will occur. Recommendation ITU-R P.526 provides prediction methods for diffraction over a smooth Earth, over individual obstacles, or over rough terrain (with the use of a digital terrain map).

In the case of diffraction over buildings, and to some extent in very mountainous terrain, the dominant path may not be directly over the top of the obstacle but around it. The use of two-dimensional profiles in such situations may not be appropriate.

It must also be noted that sub-path diffraction may affect paths even if the direct line between the transmitter and receiver is clear, if the clearance to the terrain (or other obstacles) is less than 60% of the first Fresnel zone. A prediction procedure is given in § 3.2 of Recommendation ITU-R P.526.

### 3.3.3 Gaseous absorption and rain attenuation

Atmospheric gases provide additional attenuation although the effect is very minimal except in the oxygen absorption band near 60 GHz and at frequencies above about 100 GHz. At frequencies above about 500 GHz, the attenuation due to gaseous absorption can provide significant additional protection from interference sources.

At frequencies above about 10 GHz, rain attenuation becomes significant, but only for relatively small percentages of time. Therefore, attenuation due to rain should not be included in predicting interference levels for RQZs.

### 3.3.4 Ducting and other enhancement mechanisms

Ducting can occur due to reflection or refraction of signals by layers in the atmosphere. It can be significant over long distances (250-300 km) and may reduce the loss due to diffraction. Ducting is modelled as a time-varying phenomenon based on the climatic statistics of the area. Recommendation ITU-R P.452 provides prediction methods for ducting and other interference propagation mechanisms.

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<sup>1</sup> In some specialized situations, it is possible to achieve a ducting mode which provides a loss less than free space, but this is unlikely to be relevant to radio astronomy protection.

In general, the inclusion of ducting in a RQZ prediction can lead to separation distances that are impractical, up to several hundred kilometres. It is possibly more appropriate to evaluate ducting statistics to determine the likelihood of interference from distant sources and use this information in the design of mitigation techniques.

Signal levels received within a RQZ may also be enhanced for short periods of time by scatter from rain. As this occurs infrequently and depends on the climate and the geometry of the interference source, receiver and rain cell, it should be considered in tracing interference problems rather than used to define the RQZ limits.

### **3.3.5 Reflection and scattering**

At low frequencies, particularly below 200 MHz, interference may be scattered into a radiotelescope from meteors or aircraft. As the sources of interference are often at a great distance from the radio astronomy site, it is difficult or impossible to control through RQZ mechanisms.

About  $10^9$  to  $10^{12}$  meteors enter the Earth's atmosphere each day and produce ionization at altitudes from about 80 to 100 km. The region of mutual visibility extends out to approximately 2 000 km. At this distance the path loss due to scattering is about 195 dB at 65 MHz, with an increase of 30 dB per decade of frequency. Meteor scatter propagation is frequently the mode of reception of distant FM radio broadcasting signals in remote areas and is characterized by its "bursty" nature [4].

Aircraft scatter is another way signals from distant transmitters can propagate over large distances beyond the horizon. At 12 km altitude an aircraft can be mutually visible to the transmitter and receiving site out to distances of about 800 km. For an aircraft scattering cross-section of  $10 \text{ m}^2$  the path loss at 150 MHz for a distance of 200 km from the transmitter and receiver from the aircraft is about 229 dB. This path loss is not sufficient to bring the signal of a 100 kW e.i.r.p. FM radio broadcasting station down to a level below the Recommendation ITU-R RA.769 levels for radio astronomy.

For example, even in remote locations (e.g. Boolardy in Western Australia and the Catlow valley in Oregon), 88-108 MHz FM radio broadcasting and 175-216 MHz signals from analog and digital television create "bursty" interference throughout the day and night via meteor scatter and sporadic E ionospheric propagation. The typical signal level is equivalent to about 10 kelvin as measured with an isotropic antenna [5]. Occasionally, these have been seen to increase by 20 to 30 dB and become more constant for periods of several hours owing to propagation via tropospheric refraction. This occurs when low lying water vapor provides sufficient refraction for the wavefront to follow the curvature of the Earth for hundreds of km.

## **4 Methods to achieve an RQZ**

A range of methods can be implemented to achieve a RQZ. These can conveniently be classified into receiver-side methods and transmit-side methods. Several of these methods may be used in combination, the choice of method being highly dependent on frequency, location, type of observation required, current land use and other factors.

### **4.1 Receive-side Methods**

The need to achieve a very low noise figure limits the ability of radio astronomy observatories to remove RFI through filtering on the RF receiver, particularly from strong sources of interference that render radio astronomy receivers inoperable due to non-linearities. To achieve the optimal radio frequency environment in which radio astronomy observations are made, radio astronomy observatories make use of geophysical factors and their impact on radio frequency signal propagation. A judicious choice of these factors provides a methodology for meeting the requirements of a RQZ.



#### 4.1.1 Geographic location

The nature of radio frequency propagation is such that interference power decreases with increasing distance from transmitters. The most basic approach, therefore, is to select a geographic location that is sufficiently far away from population centres and traffic. This is ideal for new, major facilities but may not be practical for all telescope facilities. For example, both the South African and Australian sites proposed for the next generation Square Kilometre Array (SKA) telescope have been chosen in remote, lightly populated areas.

Mountain top sites are often useful for their remoteness; they also provide a shorter path through the atmosphere which can be advantageous at the higher frequencies. For example, the IRAM telescope in Spain, with a frequency range of 70 to 275 GHz, is situated on the peak of a mountain, in the midst of a ski resort.

An extreme example of remote sites would be the far side of the moon, with the whole of the lunar mass as shielding from terrestrial interference sources. The Lagrangian points have also been suggested as possible future sites for radio astronomy.

#### 4.1.2 Site shielding

Where possible, natural shielding of the site by terrain should be used. In contrast to the mountaintop site described above, this approach gives preference to valley locations surrounded by hills or mountains. The absence of a direct LoS between interference sources and the RQZ does not guarantee absolute quiet, however, as signals will arrive via diffraction paths over the terrain or via reflections from large structures such as wind-turbines. Diffraction losses are frequency dependent, with increased attenuation at higher frequencies. At low frequencies in particular (below about 1 GHz), site shielding may offer marginal benefit. The effect of diffraction should be estimated for the frequency range of interest using detailed knowledge of the local terrain whenever possible.

For example, the Arecibo telescope in Puerto Rico is surrounded by rugged limestone hills which are the first means of site protection.

However, in situations where terrain by itself might provide adequate protection, this could be negated by the erection of just a single large reflecting structure, such as a wind-turbine, on top of nearby hills. Fixed link transmissions, which would otherwise be shielded from the telescope site by the terrain, could be reflected into a telescope at a detrimental level, even if the reflecting structure is not directly in the path of the fixed link.

### 4.2 Transmit-side Methods – Managing an RQZ

The major component in managing an RQZ is the control of radiators of potentially interfering signals within the zone, while ensuring the delivery of telecommunication and other services to small pockets of population within an RQZ. Since the investment in setting up and maintaining the RQZ, together with the investment in instruments within it are significant and extend over decades, both the planning of the zone and methods for dealing with potential and real sources of interfering signals have to take this into account. When defining the zone, it should not be only on the basis of the instrumentation intended for it at the time; there should also be a realistic assessment of what additional capabilities and instrumentation might be added during the life of the zone. This could affect the frequency bands used and the nature of the observations made, and consequently the definition and management of the RQZ.

An additional need is for processes by which the RQZ can be managed over decadal timescales, dealing with applications for community and industrial development and other natural processes of land management. These involve most of the procedures listed below, but on an ongoing basis. Similarly, in the definition of the zone, the possibility of new instruments and observing capabilities should be taken into account.

#### **4.2.1 Legislative and regulatory control**

Legislation in a number of countries provides a regulatory framework to control sources of RFI within a RQZ. This includes the regulation of licensed and unlicensed (or class-licensed) radio transmitters, and other activities which may cause interference.

##### **4.2.1.1 Regulation of radio devices – Notification and restriction**

Many RQZs define restriction and notification areas around the site. The restricted area is a zone where radio devices are restricted. This may be limited to transmitters within a specific frequency band or bands. Management of the restricted area may be through the regulators licensing activity.

For example, the Administration of Mexico has created a RQZ which is described by footnote Mex 163 to the (Mexican) Table of Frequency Allocations. An English-language translation of footnote Mex 163 is as follows:

“The radio telescope called the large millimetre telescope (LMT) working initially in the range 85-115 GHz has been installed on Volcano Sierra Negra-Pico de Orizaba by the National Institute of Astrophysics, Optics and Electronics (INAOE). For its correct operation the LMT requires a quiet or silent zone extending 20 km in distance, and the operation of no other system of communication is permitted in this area.”

The notification area is a zone within which any proposed radio installations (in specified frequency bands) must be notified to the regulator or the telescope operator. This notification process then starts a negotiation period where the telescope operator assesses the effect of the proposed radio transmitter on radio astronomy observations and attempts to find a suitable solution for both parties. Typically these solutions may include beam shaping, spectral shaping and separation, and reduction in e.i.r.p. of the transmitted signal. The national regulator may be involved in the negotiation. Typically the notification area is much larger than the restricted area.

For example, the Government of Chile has designated two partly-overlapping zones for the purpose of protecting radio astronomy observations. The first is a protection zone with a radius of 30 km; third-party transmitters operating within certain frequency bands may not be stationed within this zone. This is augmented by a coordination zone with a radius of 120 km; operators wishing to station certain kinds of transmitters within this zone are subject to coordination with the operators of the ALMA telescope, within certain frequency bands.

In general these regulations can only be applied to licensed (apparatus or spectrum) radio devices, and are of limited value in controlling unlicensed radio devices or unintentional radiators.

It is essential to note that the use of notification and restriction zones involves an ongoing, collaborative, dynamic management of the RQZ over the lifetime of the radio astronomy observatory. It also implies that implementation of RQZs should provide for as many options as possible (for example, in terms of frequency bands) to allow for later expansion of radiotelescope capabilities.

##### **4.2.1.2 Physical control of access to site**

Regulatory control may also be extended, in limited geographical areas, to cover unlicensed radio devices or unintentional radiators. As these types of devices are generally low power, the geographic limit is often not much of a constraint. Within the immediate vicinity of the telescope site, physical access may be controlled to ensure that no transmitting devices are brought onto the premises.

For example, in Brazil a municipal law defines an “electrical silence zone” specifies a circle of 4 km diameter, centred at the Itapetinga observatory. No urban expansion is allowed in this area to avoid interference from power line transmission, microwave ovens, radio control devices, neon

signs, and other devices capable of producing radio interference. The few people already living in this area receive instruction in order to avoid generating harmful interference to the observatory. This area is also protected from urbanization and deforestation, since it is classified as a permanent protection area (PPA) according to federal law.

#### 4.2.1.3 Legislative control of activities near site

The national regulator or other appropriate government body may also implement legislation to control certain classes of activities in areas within the RQZ. For example, heavy industry or manufacturing may be prohibited in areas where the noise from machinery would create unacceptable levels of interference.

For example, the West Virginia Radio Astronomy Zoning Act [6] regulates the emissions of unshielded electrical equipment within 10 miles of radio astronomy receiving equipment anywhere within the State. For equipment located three (ten) miles from the radio astronomy receiver, the electric field must not exceed 2  $\mu\text{V/m}$  (9  $\mu\text{V/m}$ ) when measured at a distance of 10 (50) feet from the equipment. Intermediate limits for equipment located between three and ten miles are specified in the Act, along with monetary fines and mechanisms for relief from interfering equipment.

As a further example, the Murchison Radio Observatory (MRO) in Western Australia is protected under an agreement with the Government of Western Australia which requires that new mining activities within 70 km of the site core are coordinated with the telescope requirements to ensure that harmful interference is not generated.

Table 1 shows examples of a number of different national RQZs and the methods of control or regulation they use.

TABLE 1  
Control at various national RQZs

RQZ/country	Control of licensed radio transmitters	Control of class-licensed radio devices	Aircraft controls	Control of unintentional radiators
LMT/Mexico	20 km radius – no other radiocommunications			
NRQZ/USA	34 000 sq km area – fixed transmitters required to coordinate			Controls on electronic equipment within 10 miles
ALMA/Chile	No transmitters within 30 km; coordination within 120 km			
Arecibo/Puerto Rico	Restrictions within 4 km; coordination for Puerto Rico and neighbouring islands	Restrictions within 4 km	No fly zone over telescope	Restrictions within 4 km
Various/Australia	Notification zones for coordination to as much as 250 km		No fly zone over telescopes	
MRO/Australia	Frequency band plan – RAS is primary within 70 km; coordination zone to 260 km	Class licences – no interference allowed within 70 km	No fly zone over site	Protocol for electronic equipment used by RAS within 10 km

TABLE 1 (*end*)

RQZ/country	Control of licensed radio transmitters	Control of class-licensed radio devices	Aircraft controls	Control of unintentional radiators
IRAM/Spain	Restrictions on transmitters up to 5 km radius; coordination to 10 km radius			1 km minimum separation to industry, rail, HV power lines
Itapetinga/Brazil	4 km diameter zone with no new urban activity	4 km diameter zone with no new urban activity		4 km diameter zone with no new urban activity
AGAA/South Africa	No transmissions in area of 140 km <sup>2</sup> , essential services only in area of up to 123408 km <sup>2</sup>		Core area of 140 km <sup>2</sup> controlled to 18500 m altitude	
Pushchino/Russian Federation	2 km diameter zone with no new urban activity	Control within 5 km zone (Pushchino town)		Control the level of attended interferences
Dominion RAO/Canada	Licensing tightly controlled out to 200 km	Nothing within line-of-sight and restrictions within 4 km, whichever is the larger	There was a no-fly zone but that has now expired	No new urban activity within line of sight, and restricted out to 4 km, whichever is the larger
FAST/China	No transmitters within 5 km; coordination within 75 km radius			

#### 4.2.2 Alternative technologies and network design

The national regulator or the telescope operator may choose to provide alternative technologies to those which cause harmful levels of interference. For example, if television broadcasting is of concern, the provision of cable television over fibre-optic cable may be appropriate. One mobile radio network could be replaced by another at a more convenient frequency band.

### 5 Implications in establishing an RQZ

#### 5.1 Maintenance of RQZs

RQZs require considerable effort to maintain after their creation. Almost all of the burden falls upon the operator of the radio astronomy facility, and therefore must be properly accounted for when estimating the facility's operating budget and staffing level.

One activity that must be supported is routine monitoring of the radio environment. This activity is often conducted with standalone monitoring stations that are typically separate from the radio telescope itself. The monitoring station data will be much less sensitive to RFI than the actual telescope, but is useful for finding strong RFI that may suddenly appear due to, for example, an unauthorized transmitter within the quiet zone. The monitoring station antenna is sometimes located



near the highest point of the telescope structure (or structures), is sometimes on a tower located elsewhere on the radio astronomy site, and is sometimes vehicle-mounted, which can help better pinpoint the location of the RFI.

Another activity is identifying sources of RFI that appear in telescope data, but that might not be sufficiently strong to detect with the monitoring station(s). Analysis of these cases can be very difficult, because radio telescopes are not particularly good spectrum analysers when examining terrestrial interference. This is for several reasons, including: the use of wide channel bandwidths that make identification of exact frequency difficult; the use of Doppler tracking, which causes the topocentric reference frequency of the radio astronomy observation to change during accumulation of a single spectrum; long integration times that mask the time variability of the RFI; unpredictable antenna response in the direction of the RFI, which is often coming from the horizon, and which prohibits calibration of signal strength; and unknown direction from which the RFI is arriving.

Once RFI has been identified, quiet zone administrators themselves, or engineers operating under their direction, must mitigate the source of the RFI. Experience has shown that the bulk new RFI cases arise from equipment on the observatory grounds itself, such as computers, monitors, industrial equipment, equipment brought in by visitors, etc. Because of this, most observatories establish RFI buffer zones within the observatory grounds, with increasingly stringent restrictions on potentially RFI-generating equipment as distance to the radio astronomy equipment decreases. Quiet zone staff must establish these zones, educate staff and visitors, and be prepared to enforce the local rules. Considerations for RFI zones should ideally be in place before the observatory is even built, as physical barriers, RFI shielding of buildings and outdoor equipment, and other construction-related activities will likely be needed.

Quiet zone staff will also need to address cases of RFI that arise from sources beyond the observatory grounds. Unauthorized transmitters that otherwise require an operating license may be the easiest situation to deal with, since national regulators can be contacted if needed to enforce the quiet zone rules. The most difficult case that arises in quiet zone administration is RFI from unlicensed devices that are external to the observatory property. This may include RFI from Wi-Fi, cordless telephones, wireless speakers, and similar equipment that is often employed in homes and businesses, and which may not be covered under quiet zone rules. Dealing with these situations within existing quiet zones is becoming increasingly problematic. No clear solution is at hand.

A substantial burden in large quiet zones can be the processing of license applications for new transmitters within the quiet zone. Some quiet zones may be easy to administer, if transmitters are simply not allowed within the quiet zone. Other quiet zones may establish detrimental interference thresholds, in which case license proposals must be carefully analysed using the best-available engineering methodologies, to see if the transmitted signal will exceed established interference thresholds at the observatory. In at least one existing quiet zone, this single activity requires more than one full time employee.

Lastly, observatories should not underestimate the need for education and public outreach to explain the need for the quiet zone, and to make spectrum users aware of their obligations under quiet zone rules. Inviting the public and potential spectrum licensees to the observatory to show off the radio astronomy facilities and talk about astronomical discoveries that have been made is a proven method to obtain cooperation in keeping the quiet zone quiet.

## **5.2 Increase in capabilities**

Experience shows that RQZs have often been designed with particular telescopes in mind. The most usual subsequent evolution of the telescope has then been to increase its utility for higher frequencies through an upgrading of the instrument. This happened for instance with the Arecibo telescope, which was constructed initially for operation from 50-700 MHz, while it is currently

capable of observations up to 13 GHz. More recently a trend exists towards collocation of telescopes onto sites where their purposes can be adequately met, while they share in the economies of installed infrastructure and regulation, as well as to shared access to power, communications, and roads. This in turn may well be accompanied by an increase in the frequency range to be protected for the instruments on a site. It is accordingly advisable to design the parameters of a RQZ as broadly as circumstances will allow.

### 5.3 Life of a facility

Modern radio telescopes tend to be expensive in terms of the funding available for basic science, so their construction envisages a useful life of upward of 50 years. These might also be replaced or upgraded in turn to become yet larger instruments. Hence once a RQZ is agreed to, it is required to be in place for a considerable time. This suggests that its economic impact and its potential impact on future population distribution and development in the affected area be taken thoroughly into account when designing a RQZ.

### 5.4 Evolution in the EMC environment

The pace of technical development in society must be expected to continue to result in new innovations leading to changes in the EMC environment around a RQZ. Whereas the almost unpopulated karst terrain around the Arecibo telescope in 1960 offered considerable protection, by 1989 this was grossly inadequate. Indeed the original 1960 restriction to enable EMC was simply on the operation of any “machinery, mechanism, instrument or device, which may cause interference with electromagnetic reception by the facility”. After just 29 years this had to be clarified to explicitly cover “among others, (1) AM, FM, or TV transmitters or repeaters, or both, (2) commercial communications transmitters, repeaters, or both, (3) arc welding, (4) high voltage transmission or distribution power lines without adequate insulation, (5) radio control devices, (6) defective household appliances, (7) diathermic machines, (8) neon signs, (9) high power arc lights, (10) high power electric motors/generators with brushes, (11) high power microwave industrial equipment, and (12) industrial electric controls with electromagnetic radiation”. Time and experience will add more items to such lists.

## 6 References

- [1] “Spectrum Management for Science for the 21<sup>st</sup> Century”, National Research Council, Washington, DC, 2010.
- [2] <http://www.gb.nrao.edu/nrqz/>.
- [3] <http://webstore.ansi.org>.
- [4] D.L. Schilling. *Meteor burst communications – Theory and practice*. John Wiley & Sons, New York, 1993.
- [5] Reports at [http://www.haystack.mit.edu/ast/arrays/Edges/EDGES\\_memos/EdgesMemo.htm](http://www.haystack.mit.edu/ast/arrays/Edges/EDGES_memos/EdgesMemo.htm).
- [6] The West Virginia Radio Astronomy Zoning Act, Chapter 37A, Article 1 of the West Virginia State Code, at <http://www.legis.state.wv.us/WVCODE/code.cfm?chap=37a&art=1>.

## Annex 1

### Characteristics of radio quiet zones: Mexico's quiet zone around the large millimetre telescope (LMT)

#### **1 The Zona de silencio around the Gran Telescopio Milimetrico (GTM) or Large Millimetre Telescope (LMT)**

##### **a) Introduction and description**

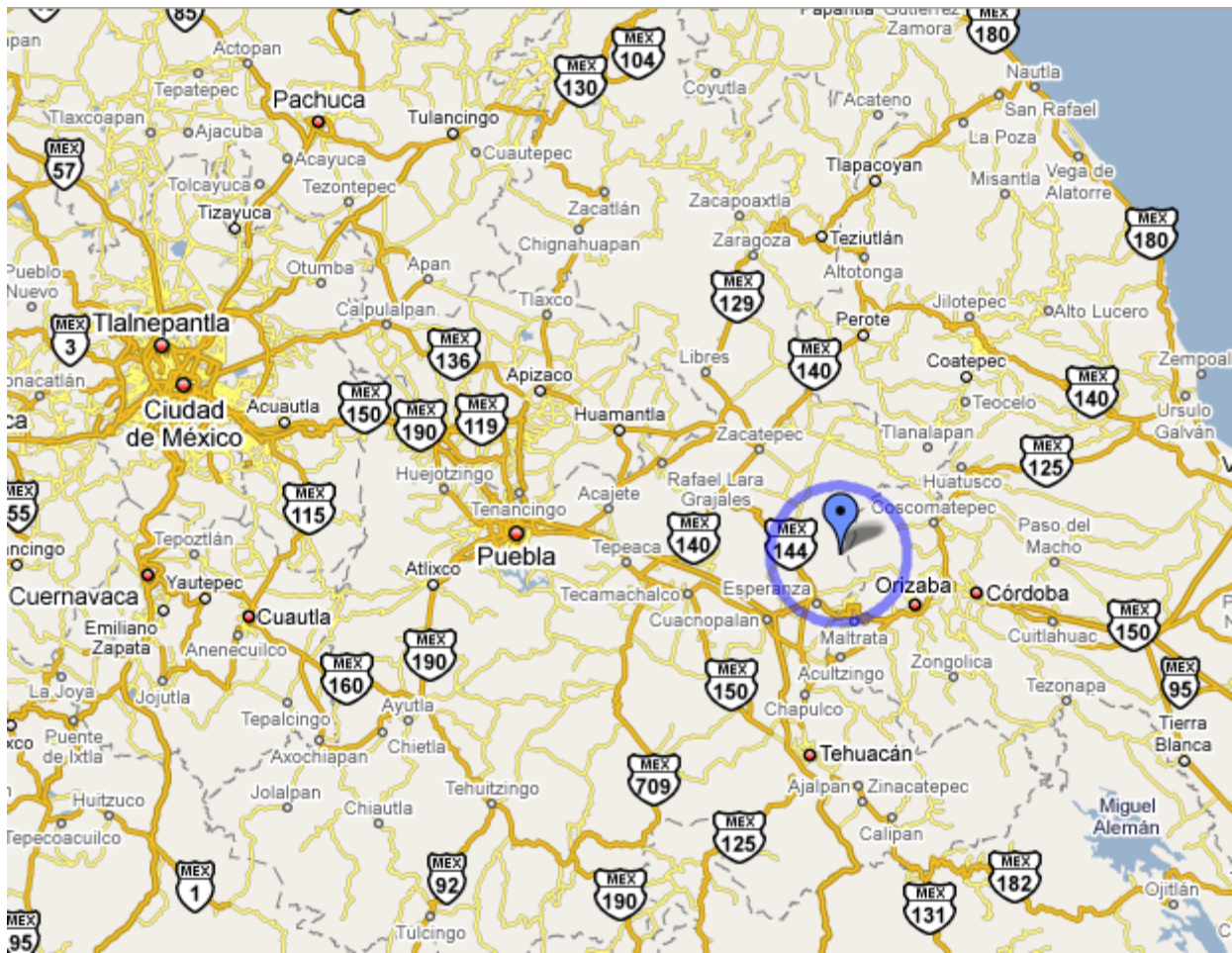
The Large Millimetre Telescope (LMT) or Gran Telescopio Milimetrico (GMT) has been erected in Mexico at longitude (West)  $-97^{\circ}18'48''$ , latitude (North)  $18^{\circ}59'06''$  at an elevation of 4 580 m. The construction of this instrument involved both US and Mexican participation and it is known as the LMT in English and the GTM in Spanish. The intended frequency range of operation is 80-345 GHz.

To protect the operation of this instrument from harmful interference, the Administration of Mexico has created a RQZ which is described by footnote Mex 163 to the (Mexican) Table of Frequency Allocations. An English-language translation of footnote Mex 163 is as follows:

“The radio telescope called the Large Millimetre Telescope (LMT) working initially in the range 85-115 GHz has been installed on Volcano Sierra Negra-Pico de Orizaba by the National Institute of Astrophysics, Optics and Electronics (INAOE). For its correct operation the LMT requires a quiet or silent zone extending 20 km in distance, and the operation of no other system of communication is permitted in this area.”

The Quiet Zone around the LMT is shown in Fig. 2.

FIGURE 2  
The RQZ around the LMT



A circle of radius 20 km about the telescope is shown, corresponding to the region established by the Administration of Mexico in footnote Mex 163 to their Table of Frequency Allocations. Within this quiet zone, no other communications system is allowed to operate.

## Annex 2

### Characteristics of radio quiet zones: the US National radio quiet zone

#### 1 The US National Radio Quiet Zone

##### a) Introduction and description

The US National Radio Quiet Zone (NRQZ) was established by the Federal Communications Commission (FCC) in Docket No. 11745 (19 November 1958) and by the Interdepartment Radio Advisory Committee (IRAC) in Document 3867/2 (26 March 1958) to minimize possible harmful interference to the US National Radio Astronomy Observatory (NRAO) in Green Bank, WV (<http://www.gb.nrao.edu>) and the radio receiving facilities for the United States Navy in Sugar Grove, WV. The rules regarding operation of the NRQZ are part of the US code, specifically Title 47, part 1.924 of the Consolidated Federal Register, i.e. 47 CFR 1.924. Information pertaining to the operation of the NRQZ on the part of the NRAO may be found at <http://www.gb.nrao.edu/nrqz/nrqz.html>.

Over the life of the Quiet Zone, several major telescopes have operated at the NRAO's Green Bank Observatory station, including; a since-collapsed 100 m meridian instrument operating up to 5 GHz from 1960-1988; an equatorially-mounted 43 m (140') steerable paraboloid usable up to 45 GHz since 1965; and many smaller telescopes, including a 4-element interferometer. At present, the main beneficiary of the NRQZ is the 100m Robert C. Byrd Green Bank Telescope (GBT), an off-axis, fully-steerable, 100m alt-az mounted paraboloid with an active (deformable) surface which has operated in the range 0.3-49 GHz since August 2000 and is presently being tested at 90 GHz. The reference point of the NRQZ operations is the position of the GBT's vertex at its maximum elevation.

The NRQZ is bounded by North American Datum 83 (NAD-83) meridians of longitude at 78d 29 m 59.0s W and 80d 29 m 59.2s W and latitudes of 37°30'0.4" N and 39°15'0.4" N, and encloses a land area of approximately 34,000 sq. km (13,100 sq. miles) centred near the state border between Virginia and West Virginia. Approximately 600,000 people live within the NRQZ. Its location within the United States of America is shown on the following map (Fig. 3), along with the locations of the radio telescopes found within the map borders.



FIGURE 3

The US NRQZ. The NRQZ is the blue rectangle near the map centre. Markers in the Zone represent the 100 m Robert C. Byrd Green Bank Telescope (GBT) in West Virginia (to the West) and NRAO HQ in Charlottesville, VA. Other radio astronomy stations are also shown outside the NRQZ

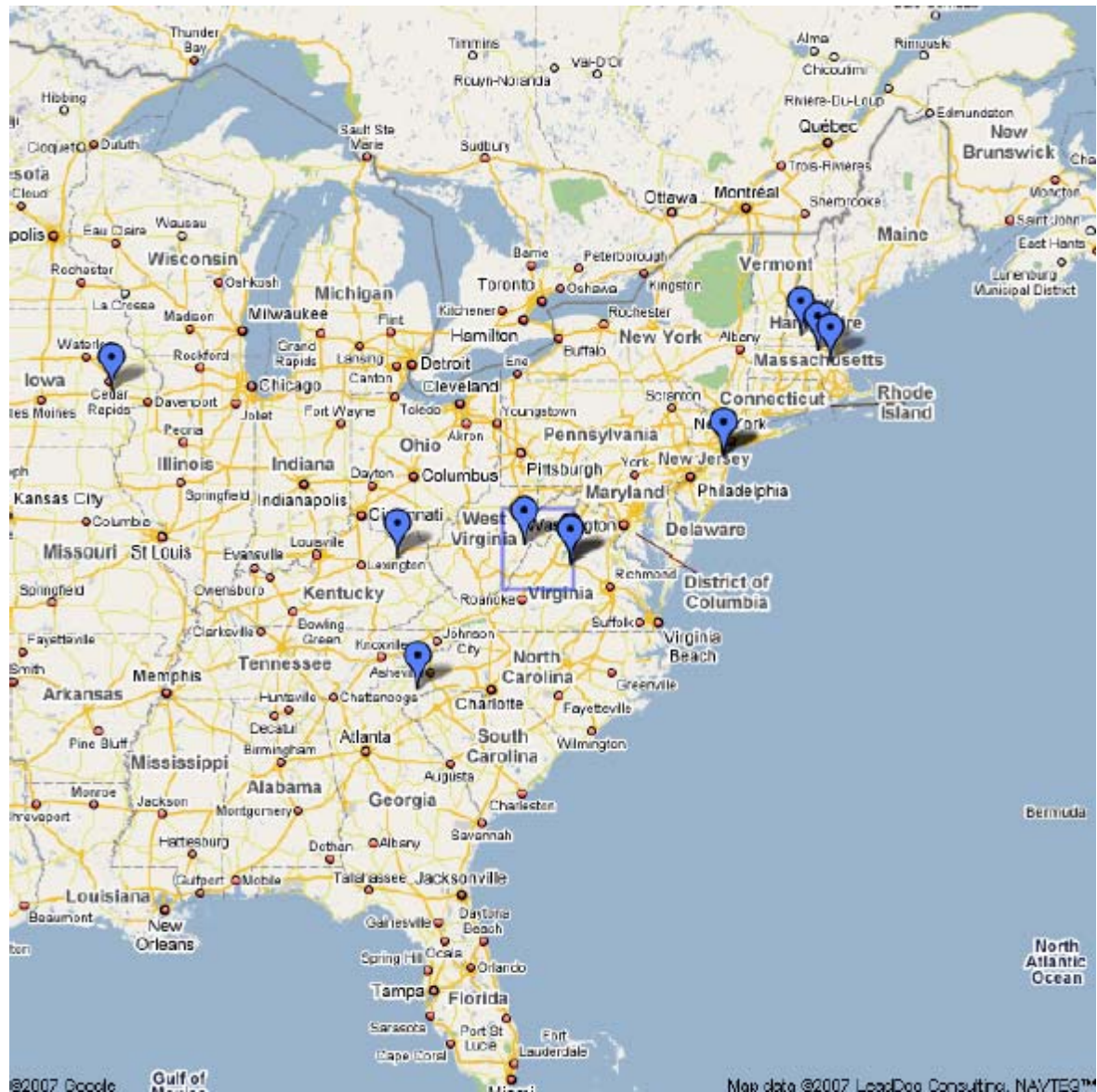
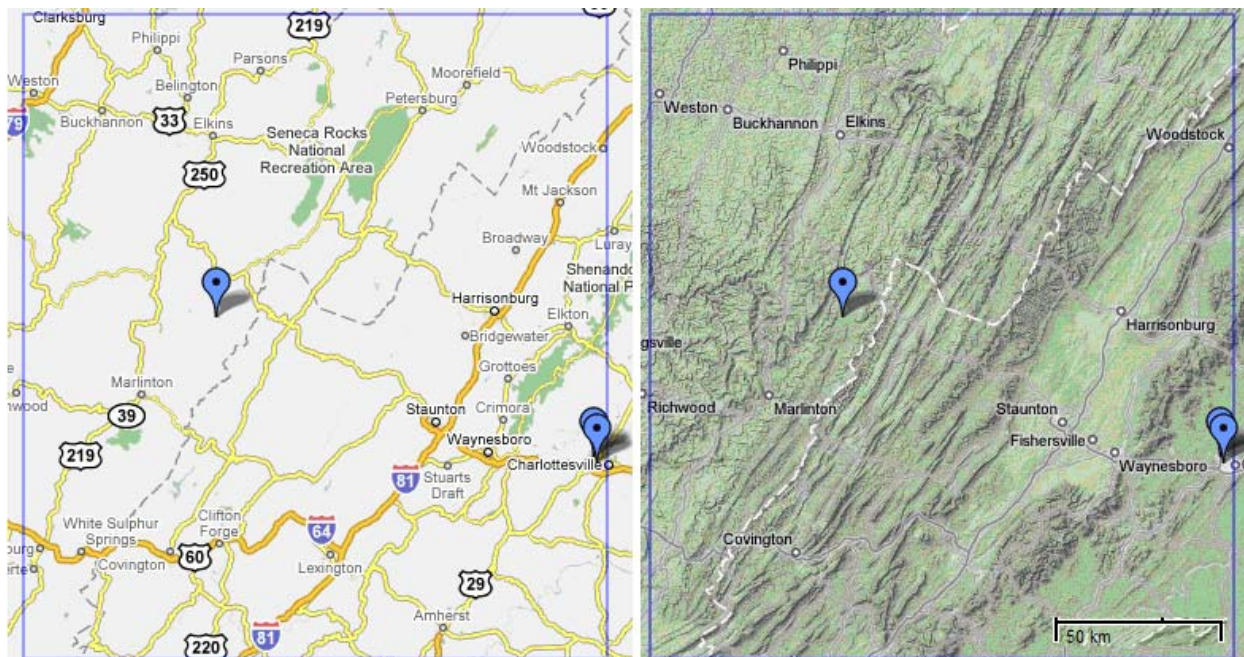


FIGURE 4

The US NRQZ in greater detail. Left: Major roads and cities within the NRQZ are shown. At right, the terrain is indicated. The hilly terrain surrounding the GBT shields the site. The GBT is indicated by the blue symbol to the West, NRAO administrative buildings in Charlottesville, VA are indicated at the Eastern boundary of the NROZ



**b) Transmitters which are required to coordinate**

Fixed, terrestrial transmitters that intend to locate within the NRQZ, (including, e.g. radio and TV stations), which are required to submit to coordination with the Interference Office of the National Radio Astronomy Observatory (NRAO) in Green Bank, West Virginia prior to receiving a government license. Transmitters generally must obtain a waiver from the NRAO if their signals are projected to exceed certain threshold signal levels when arriving at the NRQZ reference point, which is the prime focus of the 100 m Robert C. Byrd Green Bank Telescope (GBT). This reference point is shown in the NRQZ map in Figs. 2 and 3, near the western boundary of the Zone: its precise coordinates are 79°50'23.4"W, 38°25'59.2"N (NAD83), at ground 806 metres or 2644 Feet AMSL (NAVD88). Topographic maps and a Longley-Rice propagation model are used to calculate the arriving signal level.

Airborne and space-borne transmitters, and unintentional radiators such as power line communications (PLC; known in the US as BPL), are excluded from explicit Quiet Zone coordination although they are generally required to coordinate with the operator of the telescopes within the NRQZ under other rules which apply to all telescopes for operation within protected radio astronomy bands.

### c) Threshold levels for coordination

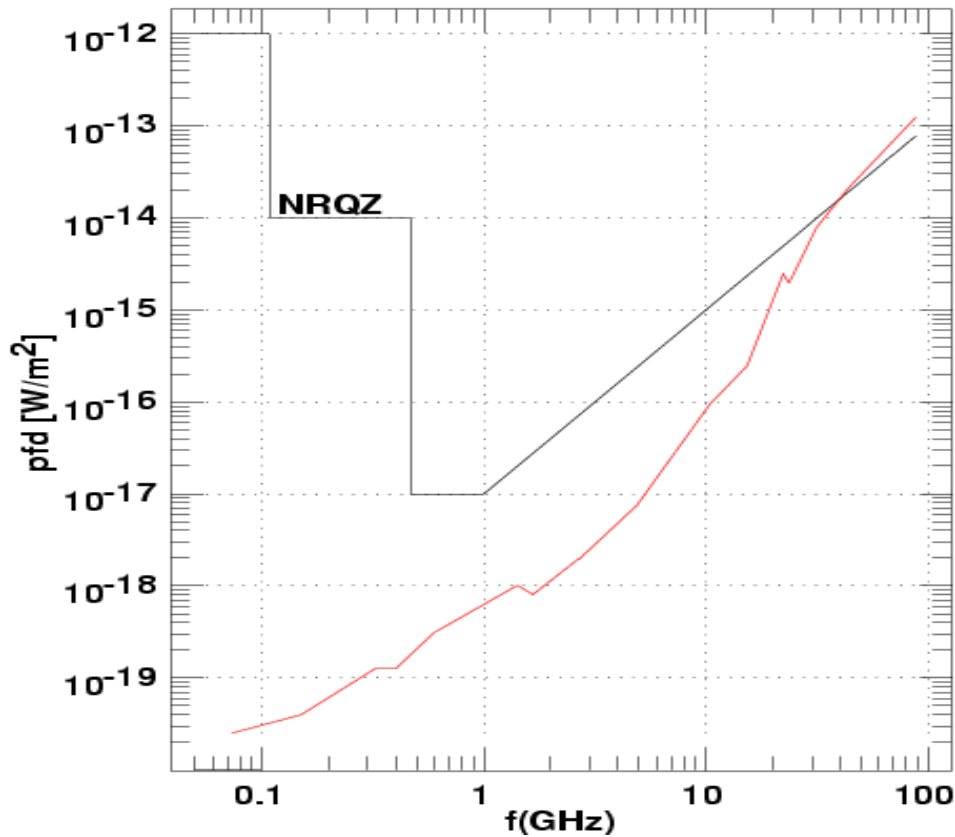
NRQZ thresholds for coordination exist at *all* frequencies. *Within protected radio astronomy bands, the threshold for coordination is that given in Recommendation ITU-R RA.769.* Outside those bands, the threshold level is given as a function of frequency. Based on a 20 kHz measurement bandwidth, the calculated power density of the transmitter at the reference point should be less than

- $1 \times 10^{-8}$  W/m<sup>2</sup> for frequencies below 54 MHz
- $1 \times 10^{-12}$  W/m<sup>2</sup> for frequencies from 54 MHz to 108 MHz
- $1 \times 10^{-14}$  W/m<sup>2</sup> for frequencies from 108 MHz to 470 MHz

- $1 \times 10^{-17} \text{ W/m}^2$  for frequencies from 470 MHz to 1 000 MHz
- $\text{freq}^2 \text{ (in GHz)} \times 10^{-17} \text{ W/m}^2$  for frequencies above 1 000 MHz.

FIGURE 5

Coordination threshold levels for the NRQZ. Black: applicable values outside protected radio astronomy bands.  
Red: ITU-R RA.769-2 levels applicable inside protected bands



#### d) Coordination mechanism

Applications for licences to transmit within the NRQZ are received by the US Government (the FCC or NTIA), following the same rules as any other application. Those applications that fall within the NRQZ are flagged upon reception and referred to the NRAO Green Bank Interference Office for comment. To speed coordination, applicants are encouraged to contact NRAO at or before the time of submission of the license application.

The following information is used by the NRAO in order to coordinate transmitters; name and address of the applicant, the radio service under which the transmitter operates, the frequency of the transmitter, the transmitter power, transmission line losses, the location (to an accuracy of 1 arcsecond) and site ground elevation(s) above mean sea level (AMSL), the antenna height above ground level, and the antenna gain or horizontal pattern and orientation in azimuth (in Planet Antenna File Format).

In some instances, the power level requested by an applicant is projected to exceed the levels shown in Fig. 5 at the reference point of the GBT. When this occurs, applicants may discuss possible modifications to their transmitters (e.g. using a directional antenna, relocating the antenna to an area that provides additional terrain shielding, or selecting a different frequency where the power density limits are different) with the Interference Office at NRAO. A technical solution can almost always be found to provide the area coverage desired by the applicant while simultaneously minimizing the



impact of the interference. In the extremely rare case when differences between the applicant's desires and NRAO's evaluation cannot be resolved, both the applicant and the NRAO would forward their comments on the transmitter installation to the appropriate US agency for a final resolution. In most cases the FCC (for private sector licenses) and or the NTIA (for government licenses) has sided with the NRAO in these disputes. If the applicant is unhappy with the decision, he/she may appeal to the FCC's Administrative Tribunal, and request relief.

**e) The West Virginia Radio Astronomy Zoning Act**

Only the US Federal Government has the authority to regulate the operation of transmitters. However, the State of West Virginia created the West Virginia Radio Astronomy Zoning Act to regulate the emissions of unshielded electrical equipment within 10 miles of radio astronomy receiving equipment anywhere within the State. With an exemption for equipment which pre-dates the operation of a telescope and its replacement, this act limits the permitted electric field of affected equipment, varying progressively with distance from the radio astronomy receiver. For equipment located three (ten) miles from the radio astronomy receiver the electric field must not exceed 2  $\mu\text{V/m}$  (9  $\mu\text{V/m}$ ) when measured at a distance of 10 (50) feet from the equipment. Intermediate limits for equipment located between three and ten miles are specified in the Act, along with monetary fines and mechanisms for relief from interfering equipment.

The West Virginia Radio Astronomy Zoning Act, Chapter 37A, Article 1 of the West Virginia State Code, is available online at <http://www.legis.state.wv.us/WVCODE/code.cfm?chap=37a&art=1>.

**f) Work effort required to administer and service the National Radio Quiet Zone**

The NRAO presently employs one person full-time to respond to transmitter applications (which in a typical year number 400 or more) but this effort is supplemented in various ways (secretarial, engineering) in order to do propagation analysis, make site visits to assist in coordination and RFI-mitigation and the like: the Quiet Zone administrator and two-three dedicated engineers form the so-called "Interference Protection Group" in Green Bank. The additional amount of work necessitated by the Quiet Zone but performed directly by the US administration, which receives transmitter applications before forwarding them to the NRAO for approval and awards or denies the license afterward, is unknown.

### Annex 3

## Characteristics of radio quiet zones: the ALMA radio quiet zone in Chile

### 1 The Radio Quiet and Radio Coordination Zones around ALMA and other telescopes in northern Chile

#### a) Introduction and description

Associated Universities Inc. (AUI), which operates the US National Radio Astronomy Observatory (NRAO) under a cooperative agreement with the US National Science Foundation (NSF), along with the European Southern Observatory (ESO) and the National Astronomical Observatory of Japan (NAOJ) are jointly constructing the Atacama Large Mm-submm Array (ALMA) radiotelescope in an uninhabited region of northern Chile at an elevation of 5 000 m. ALMA is a reconfigurable array of some fifty movable 12 m diameter dishes and approximately eighteen 7 m dishes which will observe in the frequency range 30-950 GHz on baselines ranging up to 35 km, see <http://www.alma.nrao.edu/>.

To protect the operations of the ALMA telescope, the Chilean national telecommunications authority SUBTEL issued identical Resolutions 1055 to AUI and 1056 to the European Southern Observatory (ESO) in August 2004. The English-language translation of Resolution 1055 is presented in Appendix 1 here, as it is the policy of SUBTEL that the publication of such decrees is left to the parties concerned.

The Government of Chile has designated two partly-overlapping zones for the purpose of protecting radio astronomy observations, both centered on 23° 01' S by 67° 45' W:

- i) **Protection Zone:** with a radius of 30 km, within Chilean national territory. Third-party transmitters operating within certain frequency bands may not be stationed within this zone.
- ii) **Coordination Zone:** with a radius of 120 km, within Chilean national territory. Operators wishing to station certain kinds of transmitters within this zone are subject to coordination with the operators of the ALMA telescope, within certain frequency bands.

These zones are represented in the map in Fig. 6.

#### b) Transmitters which are required to coordinate

The regulations generally apply to fixed, terrestrial transmitters which require licences. The following sorts of transmitters are explicitly exempted: those performing space radio communications; those performing terrestrial radio communications with installations authorized outside the protection zone and using mobile stations; systems using high altitude platform stations (HAPS).

FIGURE 6

The ALMA radio quiet and coordination zones. The two concentric circles centered in northeastern Chile have the radii of the ALMA Protection Zone (30 km) and Coordination Zone (120 km) created by Chile. Legal protections granted by Chile extend only within its national borders. Locations of several radio astronomy stations in Chile and Argentina are indicated



### c) Threshold levels for protection and coordination

#### i) Within the Protection Zone

Within the 30 km radius Protection Zone, transmitters operating in the bands listed in Table 2 will not be licensed to 3<sup>rd</sup> party operators. The bands in Table 2 correspond to the receiver bands at which ALMA operates or is expected to operate.

TABLE 2  
Frequency bands relevant to the ALMA Protection Zone

31.3-45 GHz
67-90 GHz
84-116 GHz
125-163 GHz
163-211 GHz
211-275 GHz
275-370 GHz
385-500 GHz
602-720 GHz
787-950 GHz

ii) Within the Coordination Zone

At frequencies higher than 31.3 GHz, any equipment authorized to third parties is required to limit its in-band and spurious emissions so as not to produce any harmful interference in the reception frequencies listed in Table 2, for which the protection criteria established in Recommendation ITU-R RA.769 apply.

Transmitters operating at frequencies below 31.3 GHz are required to limit their e.i.r.p. to a pfd of less than  $2 \times 10^{-6} \text{ W/m}^2$  within the observatory area, understood as a circle of 20 km radius whose centre coincides with the coordination zone. As an example, a transmitter located 10 km outside the observatory area would have a permissible e.i.r.p. of 2.5 kW. Furthermore, such equipment is required to limit any spurious emissions within the range of receiving frequencies authorized for the radio telescope (Table 2), for which the protection criteria established in Recommendation ITU-R RA.769 apply.

d) Implementation of the coordination zone

SUBTEL will require “Good Practices” regarding adjusting antenna beams, transmitter power and filtering of harmonic emissions. Authorization for any transmitter will be submitted to a coordination process, whereby SUBTEL will inform ESO and AUI about applications that could affect the operation of the radiotelescope, asking for their technical opinion. In the case that ESO and AUI would detect emissions affecting the radiotelescope operation, they will inform SUBTEL for their coordination. No formal mechanism for resolution of disputes is yet in place.

**Appendix 1 to Annex 3****English language text of Resolution 1055**

**Republic of Chile**

**Ministry of Transport and Telecommunications**

**Sub-Secretariat of Telecommunications**

**Modifies permit for Limited Telecommunications Service**

Exempt Resolution N° 1055

Santiago, 17 August 2004

On this date the following has been resolved:

*considering*

- a) decree Law N° 1.762 of 1977;
- b) law N° 18.168 of 1982, the General Telecommunications Law;
- c) the Technical Framework relating to Limited Telecommunications Services, Exempt Resolution N° 391 of 1985 modified by Exempt Resolution N° 524 of 1989 and Exempt Resolution N° 563 of 2003, all of the Sub-secretariat of Telecommunications;
- d) Resolution N° 520 of 1996 that established the rearranged, coordinated and systemized text of Resolution N° 55 of 1992, both of the General Comptroller of the Republic;
- e) exempt Resolution N° 1 of 1999 of the Sub-secretariat of Telecommunications that authorizes Heads of Divisions and Departments to sign “By order of the Sub-Secretary of Telecommunications” and delegates the powers mentioned therein,

*whereas*

what was requested by the petitioner with SUBTEL ingress N° 42111 of 10.06.2004. (SL-383/2004),

*I hereby resolve*

**1** to modify the Limited Telecommunications Service Permit granted to ASSOCIATED UNIVERSITIES INC (AUI), Tax N° 69.507.700-9 domiciled at Camino El Observatorio N° 1515 in the Municipality of Las Condes, Metropolitan Region, granted by means of Resolution N° 1096 of 08.09.2003 of the Sub-Secretariat of Telecommunications;

**2** the period of this modification expires on the same date as the one mentioned in the Resolution that granted the permit mentioned in N° 1;

**3** the deadline for commencing the works will be (2) two months and for completing them it will be (5) five months. Likewise, the deadline for beginning the service will be (6) six months. All of these deadlines will come into force as of the date this Resolution has been totally dealt with;

**4** the technical characteristics and the location of the facilities of the system granted, including this modification, are as follows:

**4.1** It is possible to accept what was requested, so use of the frequency bands is authorized with the technical characteristics that are mentioned hereafter:

Receiving frequency bands of the radio telescope:

31.3-45 GHz
67-90 GHz
84-116 GHz
125-163 GHz
163-211 GHz
211-275 GHz
275-370 GHz
385-500 GHz
602-720 GHz
787-950 GHz

The radio telescope may operate within all of the frequency bands mentioned; however, protection cannot be guaranteed in the frequency bands, or part of them, that are not allocated to radio astronomy on a primary basis.

Type of station: Radio astronomy station, an array of receiving only antennas

Location: Chajnantor Plain, Municipality of San Pedro de Atacama, 2<sup>nd</sup> Region.  
Area centered on 23° 01' S by 67° 45' W

Number of antennas: 64 Cassegrain type parabolic antennas

Diameter of antennas: 12 m

**4.2** For the purpose of protecting the radio telescope's reception, the following zones have been defined:

- a) Protection Zone centered on 23° 01' S by 67° 45' W and with a radius of 30 km within national territory, inside which the installation of any other radio communications system will not be authorized to any third parties operating on the receiving frequency bands mentioned in point 4.1.
- b) Coordination Zone; coordination being understood as the process whereby the opinion of the petitioners, ESO and AUI will be sought regarding certain requests by third parties that this Sub-secretariat deems could interfere or affect the operation of the radio telescope. Likewise, in case such petitioners detect any emissions that affect the operation of the radio telescope, they will notify this Sub-secretariat for its coordination. The deadlines involved for each coordination process will depend on each case.

The coordination zone will be centered at 23° 01' S by 67° 45' W with a radius of 120 km inside national territory. Within this zone, any emissions by other petitioners or licensees will be limited, bearing in mind the following cases:

- Any emissions from each equipment authorized to third parties and which transmit on frequencies lower than those of the radio telescope's reception ( $<31.3$  GHz), will limit their e.i.r.p. in accordance with the values included in Table 1, as a function of the distance measured from the emission source to the edge of the area of the observatory, which is equivalent to a power flow density of less than  $2 \times 10^{-6}$  W/m<sup>2</sup> within the observatory area. The area of the observatory will be understood as a circle of 20 km radius whose centre coincides with the coordination zone.

Furthermore, such equipment shall limit any out-of-band and non-essential emissions within the range of receiving frequencies authorized for the radio telescope, for which the protection criteria established in Recommendation ITU-R RA.769-1, or any other that replaces or complements it, will apply.

TABLE 1  
e.i.r.p. maximum acceptable as a function of distance

Distance $d$ (km)	e.i.r.p. (kW)
10	2,5
20	10,0
30	22,5
40	40,0
50	62,5
60	90,0
70	122,5
80	160,0
90	202,5
100	250,0

- At frequencies higher than 31.3 GHz, any equipment authorized to third parties shall limit their in-band, out-of-band and non-essential emissions, so as not to produce any harmful interference in the reception frequencies authorized for the radio telescope, for which the protection criteria established in Recommendation ITU-R RA.769-1, or any other that replaces or complements it, will apply.

**4.3** It is worth mentioning that it is not possible to guarantee protection against interferences generated by the following types of services or systems that operate on bands not allocated to radio astronomy:

- those performing space radio communications;
- those performing terrestrial radio communications with installations authorized outside the protection zone and using mobile stations;
- systems using high altitude platform stations (HAPS);

**5** the petitioner shall provide whatever information is necessary for undertaking the procedure of international coordination of frequencies with ITU. It is worth mentioning that such procedure will only allow the coordination of those frequencies included in the bands allocated to the radio astronomy service on a primary basis;

**6** the petitioner may not initiate services unless the works and installations required by the approved modification have been previously authorized by the Sub-secretariat. For this purpose he shall request by registered letter that it be checked that the works and installations have been properly executed and that they correspond to the project approved;

7 the petitioner is under the obligation to be aware of and comply with the provisions of the General Telecommunications Law, its Regulations and its amendments, in what they are applicable to him.

**BE IT NOTED, NOTIFIED AND COMMUNICATED.**

**BY ORDER OF THE SUB-SECRETARY OF TELECOMMUNICATIONS**

*(Signature and seal)*

**VICTOR GARAY SILVA**

**HEAD OF CONCESSIONS DIVISION**



## **Annex 4**

### **Characteristics of radio quiet zones: the radio coordination zone around the Arecibo telescope in Puerto Rico**

#### **1 The coordination zone around the Arecibo Telescope**

##### **a) Introduction and description**

The Arecibo Telescope is at longitude (West)  $-66^{\circ} 45' 11.1''$ , latitude (North)  $18^{\circ} 20' 36.6''$  at an elevation of 497 m above mean sea level, in Barrio Esperanza, of the Municipality of Arecibo. It was built in 1960-3 in what was then a remote site on the island of Puerto Rico. It is screened from most centres of population by low karst hills. In 1960 the island's population was about 2.35 million: it has since increased by 68%, so the population density of 1100 per square mile is now the 5<sup>th</sup> highest in the world. Consequently settled areas have moved a little closer to the telescope over the past 40 years, while there has been an accompanying and far more than commensurate increase in the use of the radio spectrum on the island, and in the vicinity of the telescope.

Initially the telescope's primary reflector was formed from chicken wire, as it was only intended to be used at frequencies in the range 50-700 MHz. It was subsequently upgraded in 1972-3 to have a reflecting surface of perforated aluminium panels set to about 3 mm rms (to enable it to be used to observe pulsars and the neutral hydrogen line at 21 cm). When used with the then extant set of slotted wave-guide line-feeds, it had a usable sensitivity to  $\sim 3$  GHz. More recently still, in the 1990s, the telescope was upgraded for the second time by installing a Gregorian reflector system, to remove the spherical aberration introduced by the spherical primary reflector. This provides a deployable sensitivity from 300 MHz-10 GHz.

The initial defence against radio-frequency interference (RFI) is provided by the rugged limestone karst country surrounding the telescope. This is shown in Fig. 7.

FIGURE 7

Aerial view of the Arecibo Telescope set in its surrounding karst countryside



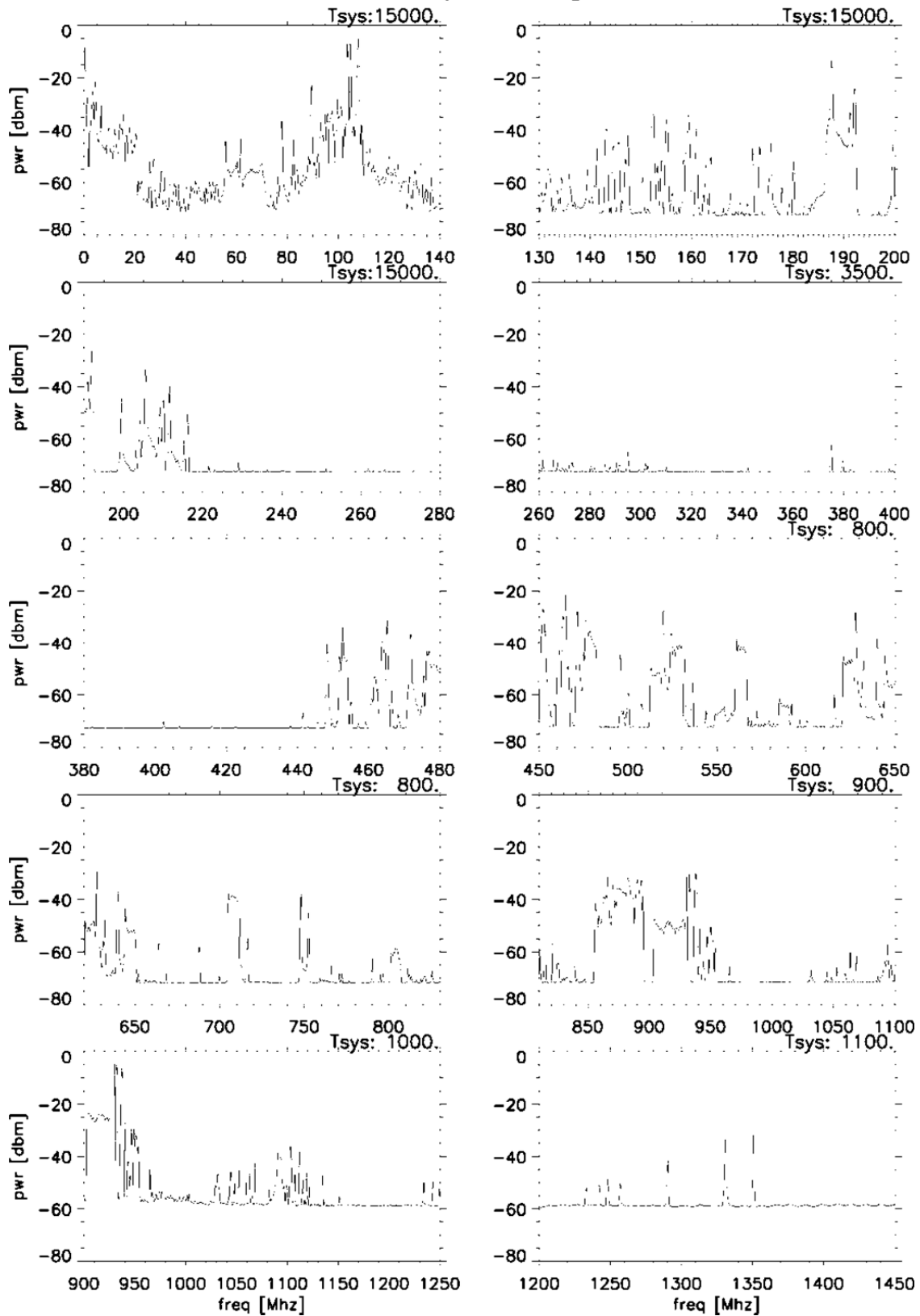
The approach road is clearly seen. Very few people dwell within the area covered by the picture.

Spectrum at frequencies of less than 10 GHz is well used on the island. Figure 8 shows the average power received over 24 hours by the Arecibo RFI monitoring system, which consists of an omnidirectional antenna covering 10-1 400 MHz, and a log periodic antenna that covers 1.7-10 GHz. The antennas are mounted on the hilltop above the control room. Most RFI signals reach the telescope's receivers after being scattered from the telescope structure into the primary reflector, and thence into the observing system. Nevertheless, the RFI reaching the receivers is much sparser than that appearing in Fig. 8, as the metallized radome protecting the secondary and tertiary mirrors from the weather greatly reduces the access of stray signals to the focus.

FIGURE 8a

Average daily spectra from the Arecibo hilltop monitor over the 24 hours of 15 July 2008

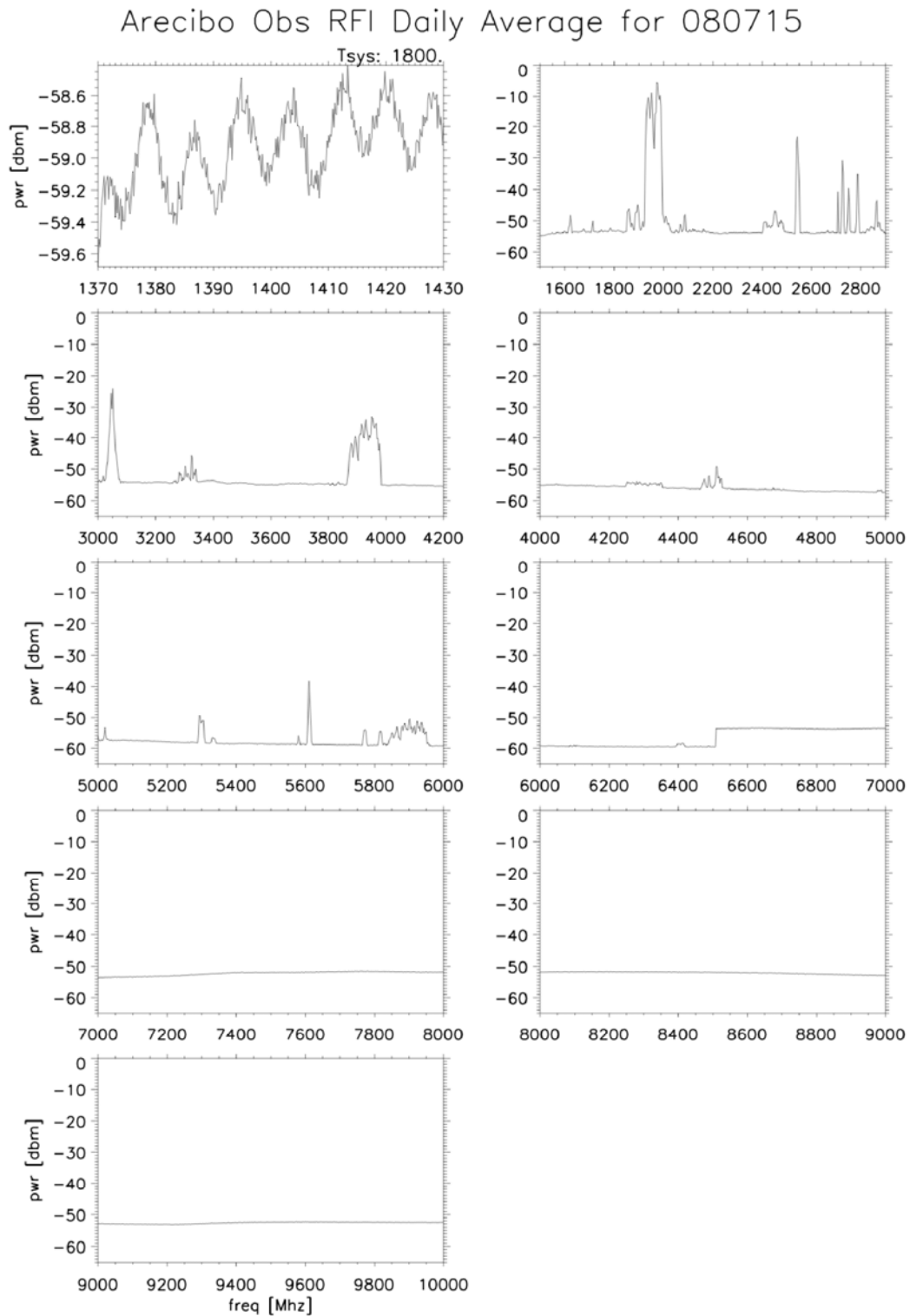
Arecibo Obs RFI Daily Average for 080715



The intensity scale is uncalibrated; panels cover frequencies from 20-1 450 MHz.

FIGURE 8b

Average daily spectra from the Arecibo hilltop monitor over the 24 hours of 15 July 2008



The intensity scale is uncalibrated; panels cover frequencies from 1.37-10 GHz.

## b) Local Legislation

To enable and protect the operation of the Arecibo Telescope, the Puerto Rican Government passed the Radio Astronomy Zoning Act, Act No. 88, on July 14, 1960. This provided for a four mile exclusion zone around the facility. Within this radius no machinery, mechanism, instrument or device, which may cause interference with electromagnetic or reception by the facility, can be established or operated.

With the evolution of technology and the increasingly common usage of more sophisticated equipment, it became necessary to amend the 1960 Act, to clarify its definition of “electrical machinery”. This is now understood to mean, as a result of Act No. 41 of August 5, 1989.

‘Electrical Equipment’ shall mean any machinery, mechanism, instrument, device or other facility capable of producing electromagnetic emissions which may damage or interfere with the operation or investigations at the Facility, such as, among others, (1) AM, FM, or TV transmitters or repeaters, or both, (2) commercial communications transmitters, repeaters, or both, (3) arc welding, (4) high voltage transmission or distribution power lines without adequate insulation, (5) radio control devices, (6) defective household appliances, (7) diathermic machines, (8) neon signs, (9) high power arc lights, (10) high power electric motors/generators with brushes, (11) high power microwave industrial equipment, and (12) industrial electric controls with electromagnetic radiation”.

Two further measures to protect the Observatory are in place. Scheduled airline flightpaths have been arranged so that they do not overfly the Observatory. And the Observatory has protection against the installation of microwave links that would pass too close to the Observatory under Article 4.02 of the June 19, 1992 Zoning Law on Telecommunication Facilities.

## c) FCC Dispensation – Puerto Rico Coordination Zone

The radio spectrum is heavily utilized in Puerto Rico, despite the small size of the island. The US Federal Communications Commission (FCC), which governs all non-federal government licensing concerns in Puerto Rico (and the continental United States of America) is ever concerned to see that broadcasting licensees cover as much of the population as possible. Under this dictum, it urges existing TV stations to increase their broadcast power to the maximum allowed by their licenses, and to locate their broadcast antennae on high ground. The relocation of the local Arecibo TV station from a coastal site to a mountain top under this policy resulted in the second harmonic of the station being broadcast LoS directly at the Observatory. This experience led to a federally mandated Radio Astronomy Coordination Zone being established in Puerto Rico, with the cooperation of the PR government and people.

Part 5 of Chapter I of Title 47 of the Code of Federal Regulations states:

### 5.70 Notification to the Arecibo Observatory.

Any applicant for a new permanent base or fixed station to be located on the islands of Puerto Rico, Desecheo, Mona, Vieques, and Culebra, or for a modification of an existing authorization which would change the frequency, power, antenna height, directivity, or location of a station on these islands and would increase the likelihood of the authorized facility causing interference, shall notify the *Interference Office of the Observatory* in writing or electronically to [prcz@naic.edu](mailto:prcz@naic.edu) the technical parameters of the proposal.

(1) The notification to the Interference Office, Arecibo Observatory shall be made prior to, or simultaneously with, the filing of the application with the Commission (FCC). The notification shall state the geographical coordinates of the antenna (NAD-83 datum), antenna height above ground, ground elevation at the antenna, antenna directivity and gain, proposed frequency and FCC Rule Part, type of emission, effective radiated power, and whether the proposed use is itinerant.

Generally, submission of the information in the technical portion of the FCC license application is adequate notification. In addition, the applicant shall indicate in its application to the Commission the date notification was made to the Arecibo Observatory.

(2) After receipt of such applications, the Commission will allow the Arecibo Observatory a period of 20 days for comments or objections in response to the notification indicated. The applicant will be required to make reasonable efforts in order to resolve or mitigate any potential interference problem with the Arecibo Observatory, and to file either an amendment to the application or a modified application, as appropriate. If the Commission determines that an applicant has satisfied its responsibility to make reasonable efforts to protect the Observatory from interference, its application may be granted.

(3) The provisions of this paragraph do not apply to operations that transmit on frequencies above 15 GHz.

Further, all amateur radio stations are excluded within a 10 mile radius, with the exception of repeaters and beacon station modifications or installations.

The majority of the license requests concern variations on the original license. The Observatory currently receives upwards of 200 requests a year, many of which have 20-30 entries. Processing and responding appropriately amounts to about 0.3 FTE (full time equivalent). Only a very few require coordination, though an important percentage with line-of-sight access require a warning that harmonics or errors in alignment of antennae can result in problems for the Observatory.

#### **d) Outreach**

The maintenance of a world-class radio Observatory on a crowded island depends on coordination and cooperation. This has always been forthcoming. It has been explicitly fostered over the last decade by the formation of an informal group, the Puerto Rico Spectrum Users Group (PRSUG). This convenes two meetings a year to foster cooperation and the exchange of information between public broadcasters and federal agencies on the island. The Observatory plays an active role in maintaining and supporting this group, and as a result has personal contact with many of the users. It has been particularly helpful in garnering concessions on the blanking of radar signals in the direction of the Observatory, and in coordination with frequency-agile radars on the island.

## Annex 5

### Radio notification zones around existing radio astronomical facilities in Australia

#### Introduction

The Australian Communications and Media Authority (ACMA) has implemented “*Notification zones for apparatus licensed services around radio astronomy facilities*”, which provide for voluntary consultation between radio astronomy telescopes and radio communication operators in their vicinity. The notification zones define a series of frequency bands and regions around a radio astronomy facility, inside which use of that spectrum has the potential to seriously degrade the performance of radio astronomy receivers.

#### Applicability

The notification zones described in this report apply to apparatus licensed, coordinated terrestrial service stations or earth stations only – no consideration is given, for example, to space or aeronautical services. Coordination of satellites with radio astronomy facilities is generally a matter dealt with by the International Telecommunication Union (ITU).

The zones have no bearing on existing apparatus licences, nor do they apply to transmitters that may be authorised for use by spectrum or class licences within the AUS87 bands.

The zones also do not apply to assignments whose details would be kept confidential under Section 152 of the *Radiocommunications Act 1992*.

#### Background

The radio astronomy service uses extremely sensitive radio receiving systems to detect very faint signals of cosmic origin, at much lower power levels than are generally used in other radio services. It is highly susceptible to interference from emissions from other radiocommunication services. To minimise such interference radio astronomy antennas are usually operated in geographically remote locations.

Specific frequency allocations to the radio astronomy service have been made in spectrum of particular importance to radio astronomers, such as the 1 660-1 670 MHz band. The operators of radio astronomy facilities may take out radiocommunications licences in these bands, giving them rights to protection from interference from other spectrum users. Radio astronomers also conduct observations in other bands, on a fortuitous basis, and cannot take out licences there because they do not have allocations in these bands. In these other bands, radio astronomy receivers are particularly vulnerable to interference from transmitters operating in the same spectrum bands.

Radio astronomy is regarded by the Australian Government as an important scientific undertaking, with value for the broader community. Considerable investment has been made in a number of radio astronomy and support facilities around Australia, and there is strong international involvement in radio astronomy science taking place in Australia. There is therefore a benefit to the Australian community in protecting radio astronomy facilities from interference that would otherwise diminish their capacity.

In recognition of the importance of radio astronomy to Australia, the ACA<sup>2</sup> increased the visibility of the service within planning documentation. Information is now provided in the Australian Radiofrequency Spectrum Plan (ARSP)<sup>3</sup>, by way of a chapter about radio astronomy use of the spectrum<sup>4</sup>. Radio astronomy use of spectrum is also made visible by the application of footnote AUS87 to appropriate bands (see Appendix 1). This footnote states that radio astronomy facilities operating in listed bands and at given locations use receivers that are highly sensitive to interference.

### **Australian Productivity Commission Recommendation**

In 2002 the Australian Productivity Commission (APC) conducted a public inquiry, review of Radiocommunications Acts and of the market based reforms and activities undertaken by the Australian Communications Authority. A submission by the Australia Telescope National Facility (ATNF) argued that footnote AUS87 is not effective in managing the interference with radio astronomers in these bands where no spectrum allocations to the radio astronomy service exist. The ATNF suggested that it would be more effective to designate major radio astronomy facilities as ‘radio sensitive zones’. Under this proposal, it would be mandatory to notify radio telescope facilities that another user has applied for a transmitter licence wholly or partially within the zone. This would provide the ATNF the opportunity to find a technical solution that overcomes any interference to radio astronomy facilities.

The APC did not receive any submissions arguing against this proposal. The ATNF did not suggest that other services be prohibited from using the spectrum. Further, the ATNF stated it would be responsible for finding a solution to interference.

The inquiry report, “Radiocommunications” released on 5 December 2002<sup>5</sup> made the following recommendation:

*“Radio astronomy facilities should be designated as ‘radio sensitive sites’ under the Australian Radiofrequency Spectrum Plan. These facilities must be notified that another user has applied for a transmitter licence wholly or partially within the bands specified in footnote AUS87.”*

### **Implementing the APC Recommendation**

The Australian Communications Authority (ACA) advised the APC that it would implement the recommendation, but it would need to be done in a different manner from that suggested.

The ARSP is not an appropriate vehicle to convey the concept described by the APC. Its prescribed purpose, as defined in Section 30 of the *Radiocommunications Act 1992*, is to partition the radio spectrum into bands and define the general purposes for which these bands may be used. It has no mechanism to trigger a notification that a user has applied for a radiocommunications licence within a particular band.

The recommendation is more usefully implemented in the frequency assignment instructions that the Australian Communications and Media Authority (ACMA) uses to convey its frequency coordination procedures. The ACMA maintains a suite of documents called Radiocommunications Assignment and Licensing Instructions (RALIs), that establish and codify the relationships that

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<sup>2</sup> The Australian Communications Authority was merged with the Australian Broadcasting Authority on 1 July 2005 to form the Australian Communications and Media Authority.

<sup>3</sup> The ARSP sets out the purposes for which bands of spectrum may be used by apparatus-licensed transmitters and radio astronomy receivers.

<sup>4</sup> Australian Radiofrequency Spectrum Plan General Information Chapter 1 Part 4 Section 13.

<sup>5</sup> See <http://www.pc.gov.au/inquiry/radiocomms/finalreport/index.html> for details.



enable interference to be avoided and successful frequency assignments to be made. These instructions are followed by suitably accredited persons who have the power to assign frequencies for new radiocommunications transmitters.

The frequency assignment process is usually followed by the application for, and issuing of, a radiocommunications licence that authorises the use of a radio transmitter. Once a licence is issued a transmitter is generally installed and enabled. A RALI, then, has the ability to trigger notification to radio astronomy facilities of potentially interfering transmitters, before they are turned on.

### **An appropriate zone**

One must consider the question of what is an appropriate way to protect the radio astronomy service in bands where there is no radio astronomy allocation (and other services have allocations and pay for licences offering protection from interference). To gain an understanding of how other administrations are dealing with the issue of RQZs, the ACMA examined the use of declared RQZs in the United States of America (US) and Europe<sup>6</sup>.

The ACMA found that RQZs around radio astronomy facilities in Europe were mainly notification zones only, and the zones were typically from 0.1 to 3 km in radius, centred on a radio astronomy facility. The zones were implemented through a patchwork of legislative arrangements at state and national levels of government.

In the US, the ACMA found notification zones mainly based on EMC requirements, implemented through FCC arrangements, and one large geographical area used to control the “radio quietness” within it: the National Radio Quiet Zone (NRQZ)<sup>7</sup>.

There appears to be two requirements: a zone that restricts all transmitters that might overload a radio astronomy receiver and render it useless, and a zone within which signals have the potential to degrade the performance of a radio astronomy receiver.

The European and US experience suggests that the “overload” zone would typically be of the order of a few kilometres and cover the entire radio spectrum. The degradation zone would extend to 100 km and beyond, depending on the receiver’s protection requirement. When reception of undesirable signals cannot be prevented, various methods to mitigate against these signals will need to be employed.

### **Dimensioning of the notification zones**

The natural tension in dimensioning a notification zone is between the zone being large enough to capture any potentially undesirable signals, and not too large as to cause too great an impost on the radiocommunications community.

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<sup>6</sup> See ACA Planning Report SP 13/02, “Radio quiet zones in the United States of America and Europe” for details.

<sup>7</sup> The NRQZ is a 13000 square mile region in West Virginia and Virginia in which US federal regulations place extra constraints on the location and power of radio frequency transmitters in order to protect the radio environment around the Green Bank site. One of the major communications stations for military use is also located within the boundaries of the NRQZ, some 50 miles away in Pendleton County, West Virginia. The combination of low population density and the natural shielding from man-made transmissions that the mountains offer was the main motivation for locating the Observatory in Green Bank in the first place. Its continued “radio quietness” makes it a unique environment for the study of faint signals from the distant universe. Proposals to locate radio transmitters in the NRQZ are reviewed for their potential to cause RFI. In many instances, negotiations between the proposer and the observatory lead to a solution that satisfies both.

### Notification zone methodology

The following methodology is used to determine the size of a notification zone around a radio astronomy facility.

- Establish system models for potentially interfering apparatus licensed transmitters, i.e. service types and quantities, antenna heights, bandwidths and e.i.r.p.s.
- Establish levels of signals, in dBm/Hz, emanating from terrestrial transmitters proposed by ACMA or external accredited persons to be apparatus-licensed by the ACMA.
- Establish technical characteristics for radio astronomy receivers, i.e. locations, antenna (gain, beam pattern, effective height), likely bandwidths and receiver performance parameters.
- Calculate the required propagation loss so that the level of a potentially interfering signal falls below that which could degrade a radio astronomy receiver beyond an agreed value.
- Apply an appropriate path-loss model to determine the corresponding minimum separation distances for the various bands and received levels.
- Determine the most appropriate dimensioning of exclusion zones reflecting the findings of the analysis above.
- Analyse the potential number of affected frequency assignment applications within the zones.

### Terrestrial transmitters – Technical characteristics

Reasonable assumptions on the technical characteristics of likely terrestrial transmitters can be made by examining the existing frequency assignments within the AUS87 bands. These assumptions may be refined by considering factors such as the locations of these assignments relative to any of the listed radio astronomy facilities.

Following is a summary of the relevant technical parameters of the most likely interferer, based on power spectral density and the number of existing assignments, for each of the bands of interest. Appendix 1 provides detailed data and the analysis used to determine the characteristics of the most significant interferer type for each band.

TABLE 3

#### Indicative interferer parameters

Band (MHz)	e.i.r.p. (dBm/Hz)	Antenna height (m)
1 250-1 780	0.6	30
2 200-2 550	–8.1	30
4 350-6 700	0.0	20
8 000-9 200	0.5	20
16 000-26 000	–6.0	20

**Radio astronomy receivers – Technical characteristics****System model – Radio astronomy receiver****Radio astronomy receiver antenna**

TABLE 4  
Effective antenna heights

Effective antenna height (m)					
Narrabri	Parkes	Mopra	Mt Pleasant	Ceduna	Tidbinbilla
18	30	13	15	12	30

For the assessment of potential interference to radio astronomy from transmitters used for terrestrial radiocommunications a value of 0 dBi is assumed for the gain of the radio astronomy antenna in the direction of the horizon, as per the radio astronomy reference antenna described in Recommendation ITU-R SA.509. An increase in the levels of 10 dB for Parkes and 15 dB for Narrabri may be used to more accurately reflect antenna pattern roll-off<sup>8</sup>.

**Receiver degradation levels**

At a meeting between ACA and CSIRO staff on 13 February 2004 it was agreed to use the levels provided in Recommendation ITU-R RA.769-1 for VLBI observations to model the threshold interference levels of radio astronomy receiving systems.

Later material from CSIRO (15 June 2004) refined the threshold interference levels to figures consistent with the spectral line specification for Parkes at 1 250-1 780 MHz and the continuum specification for all other bands, and use of the continuum specification for all bands at Narrabri.

Combining the limits given in Table 4 of Recommendation ITU-R RA.769-1 with the information above, and converting to power spectral density<sup>9</sup> (dBm/Hz) yields the values shown in Table 5:

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<sup>8</sup> These values were provided by the CSIRO. The Parkes antenna has an effective elevation limit of 30° from the horizon. The gain of the antenna at 30° from the main beam is given as –10 dBi from Recommendation ITU-R S.1428. Thus for Parkes an antenna mitigating factor of 10 dB is used. Figures for other dishes (e.g. Tidbinbilla) were not provided.

<sup>9</sup> A power spectral density threshold in dBm/Hz may be determined by adding 30 dB (Watts to milliwatts) and subtracting an effective area value ( $20\log(f_{\text{MHz}}) - 38.6$ ) dB.

TABLE 5  
Threshold levels (dBm/Hz)

Band (MHz)	Threshold levels (dBm/Hz)								
	Recommendation ITU-R RA.769			Narrabri	Parkes	Mopra	Mt Pleasant	Ceduna	Tidbinbilla
	<i>Cont</i>	<i>Spec</i>	<i>VLBI</i>	<i>+15 dB</i>	<i>+10 dB</i>	<i>VLBI</i>	<i>VLBI</i>	<i>VLBI</i>	<i>VLBI</i>
1 250-1 780	−249	−233	−204	−234	−223	−204	−204	x	−204
2 200-2 550	−247	x	−204	−232	−237	−204	−204	−204	−204
4 350-6 700	−247	−235	−204	−232	−237	−204	−204	−204	−204
8 000-9 200	−250	x	−204	−235	−240	−204	−204	−204	−204
16 000-26 000	−251	−234	−200	−236	−241	−200	−200	−200	−200

### Propagation model

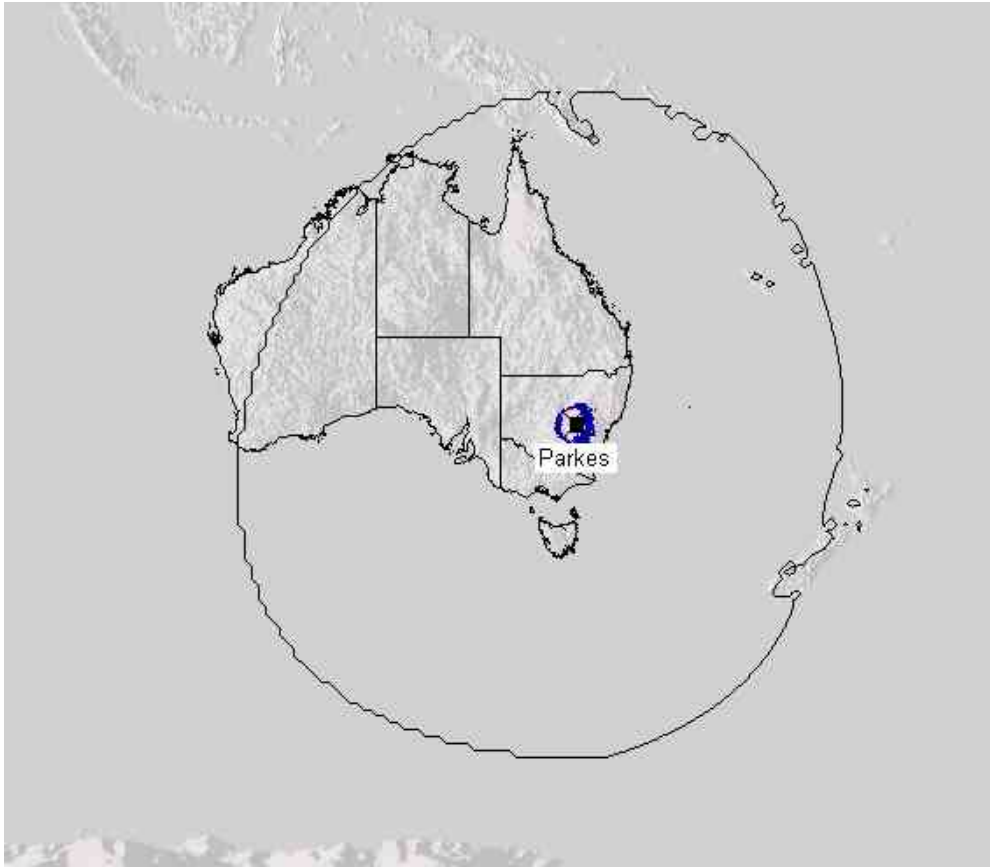
Because of the sensitivity of radio astronomy receivers, interfering signals are likely to originate from beyond the radio horizon. Long-term interference may propagate through the mechanisms of LoS, diffraction and tropospheric scatter. Short-term interference may propagate through the mechanisms of surface ducting, elevated layer reflection/refraction and hydrometeor scatter. There are a number of propagation models that can be used in this scenario to appropriately determine transmission path loss. Some of these are:

- Recommendation ITU-R P.526 is a general method for diffraction over one or more obstacles.
- Recommendation ITU-R P.452 is a combination model which is particularly adapted to the various propagation mechanisms giving rise to over-the-horizon situations. Amongst other things, this model accounts for diffraction, hydrometeor scatter and tropospheric scatter. This model uses the general method described in Recommendation ITU-R P.526 for diffraction.
- Recommendation ITU-R P.1546 is a method using curves based on measurements for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3 000 MHz.

The Recommendation ITU-R P.526 method appears to be most appropriate in this case. The Recommendation ITU-R P.1546 method does not account for specific terrain and would generally be less accurate than a model that takes specific terrain into account. The Recommendation ITU-R P.452 model is also suitable except the hydrometeor scatter and tropospheric scatter propagation modes which yield “unhelpful” results<sup>10</sup>. Figure 1 depicts the zone of potential interference for Parkes at 1 250 MHz when tropospheric scatter is the mode of propagation. It is simply not practical or meaningful to implement zones of this size. The effect of anomalous nodes of propagation will therefore be noted, but will not be included in the determination of notification zones.

<sup>10</sup> However the 526 model is for a time percentage of 50%. Adding 3.9 dB to the required loss (as per P.452-12 equation 15) adjusts the time percentage to 10%.

FIGURE 9

**Zone of potential interference at 1 250 MHz – Tropospheric Scatter<sup>11</sup>****Interference zone analysis**

The size of zones of potential interference can be determined using the interferer parameters of Table 4 and the threshold levels given in Table 5. A time percentage of 10% is typically used for radio astronomy facilities<sup>12</sup>.

The analysis involves the use of a complex propagation model and a terrain database to predict the coverage area.

The terrain data used is the GEODATA 9 Second DEM, Version 2. It is a gridded digital elevation model computed from topographic information including point elevation data, elevation contours, stream lines and cliff lines. The grid spacing is 9 seconds in longitude and latitude (approximately 250 metres).

<sup>11</sup> Assuming Recommendation ITU-R P.452 Tropospheric Scatter Propagation Path 10% time and a  $-29.7$  dBm/Hz interferer.

<sup>12</sup> As per Recommendation ITU-R RA.1031.

Results  
Parkes

TABLE 6  
Parkes notification zone results

Band (MHz)	Zone (radius of circle, centred on Parkes facility)
1 250-1 780	200 km
2 200-2 550	180 km
4 350-6 700	160 km
8 000-9 200	150 km
16 000-26 000	110 km

FIGURE 10  
Parkes 1 250 MHz and 200 km circle

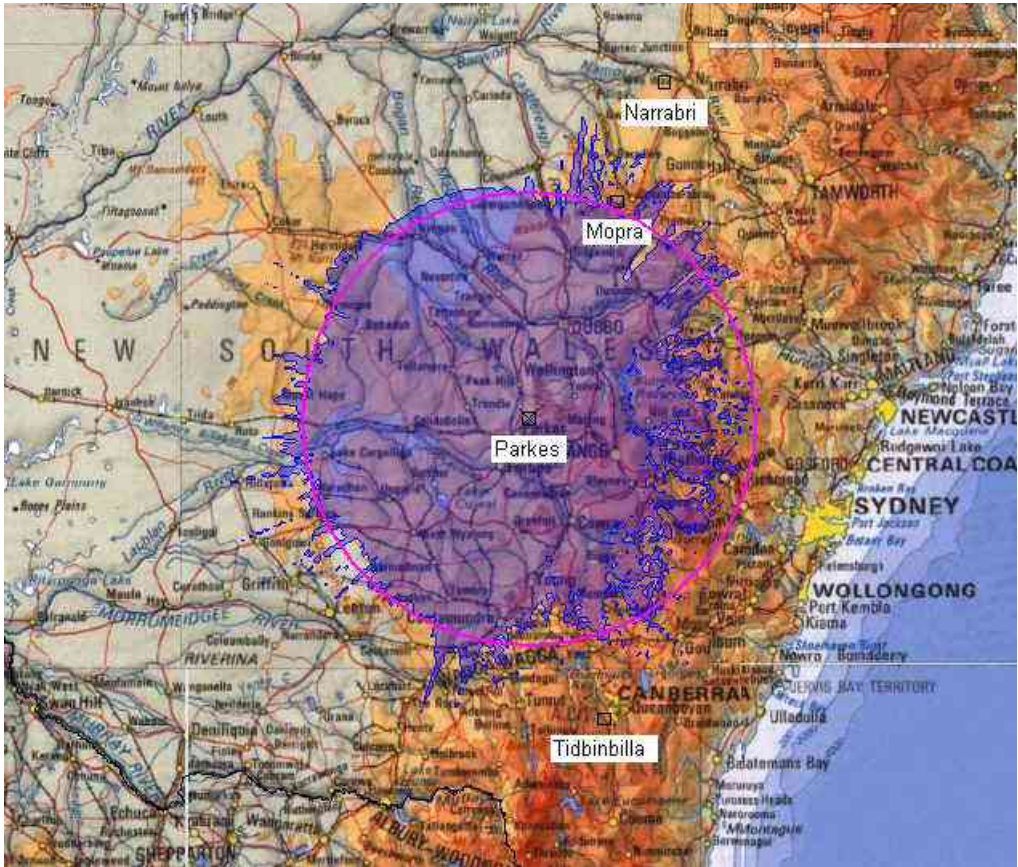




FIGURE 11

Parkes 2 250 MHz and 180 km circle

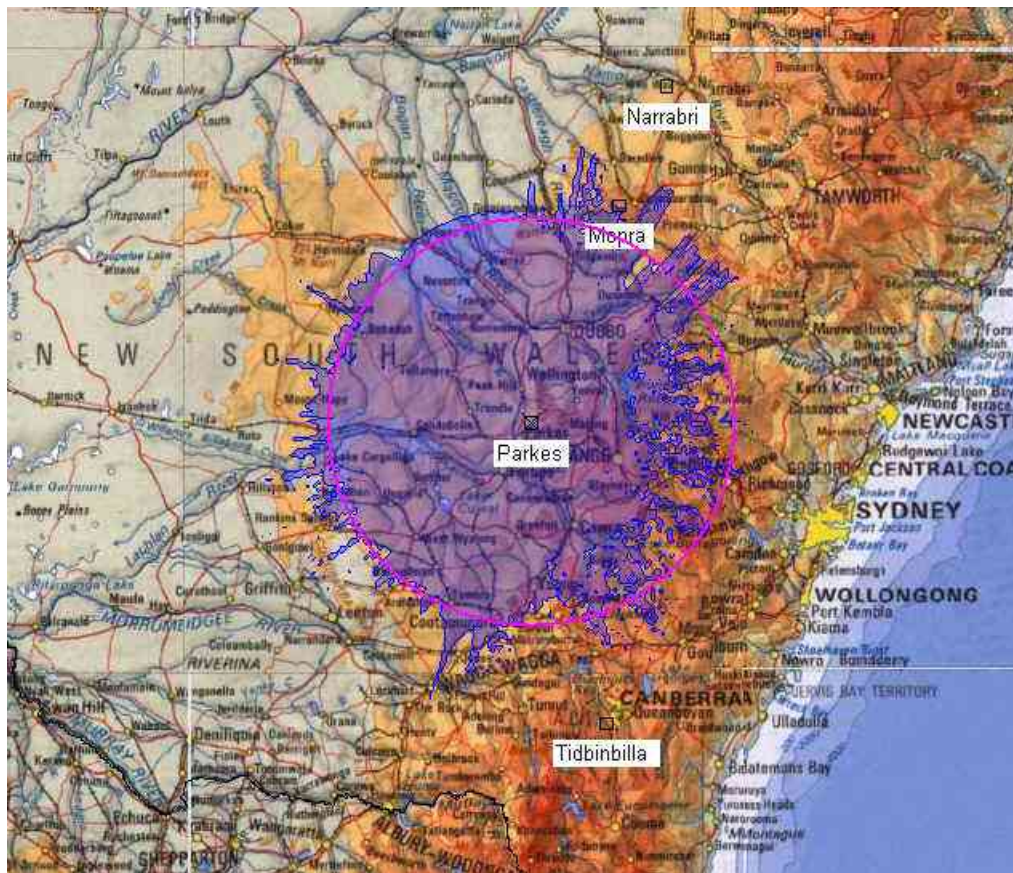


FIGURE 12

Parkes 4 GHz and 160 km circle

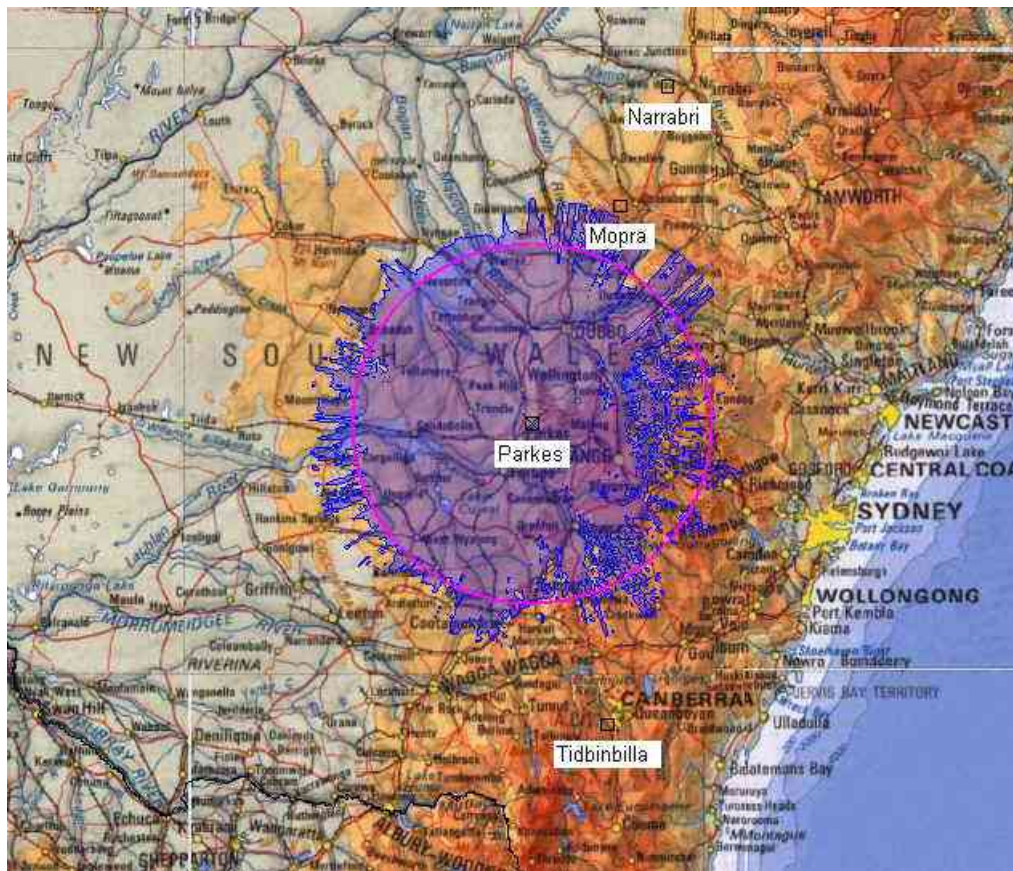




FIGURE 13  
Parkes 8 GHz and 150 km circle

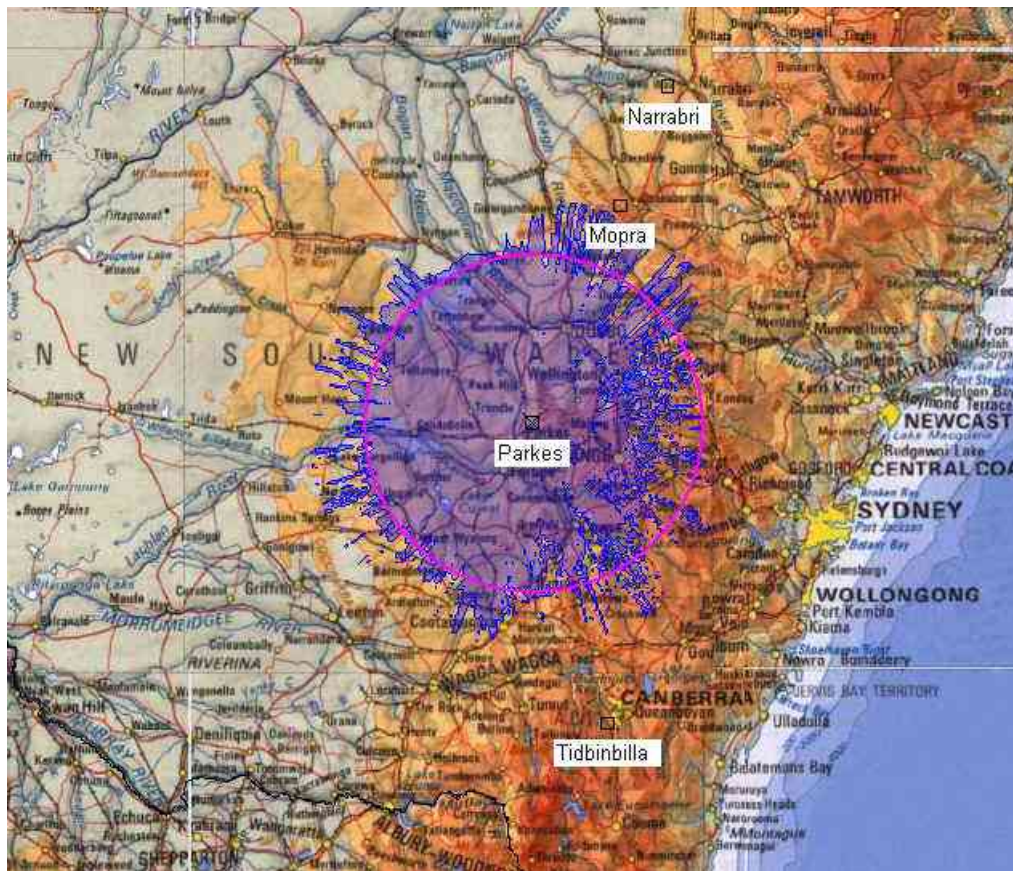
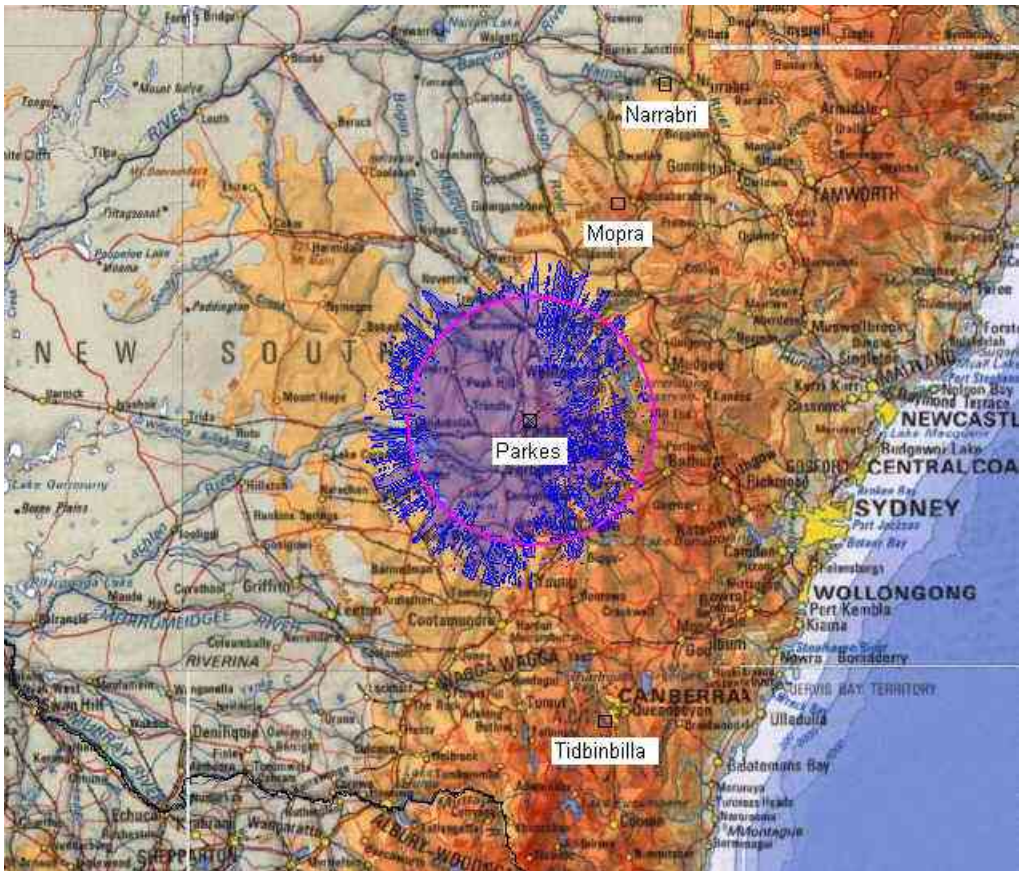


FIGURE 14  
Parkes 16 GHz and 110 km circle



Narrabri

TABLE 7  
Narrabri notification zone results

Band (MHz)	Zone (radius of circle, centred on Narrabri facility)
1 250-1 780	250 km
2 200-2 550	180 km
4 350-6 700	160 km
8 000-9 200	110 km
16 000-26 000	90 km



FIGURE 15

Narrabri 1 250 MHz and 250 km circle

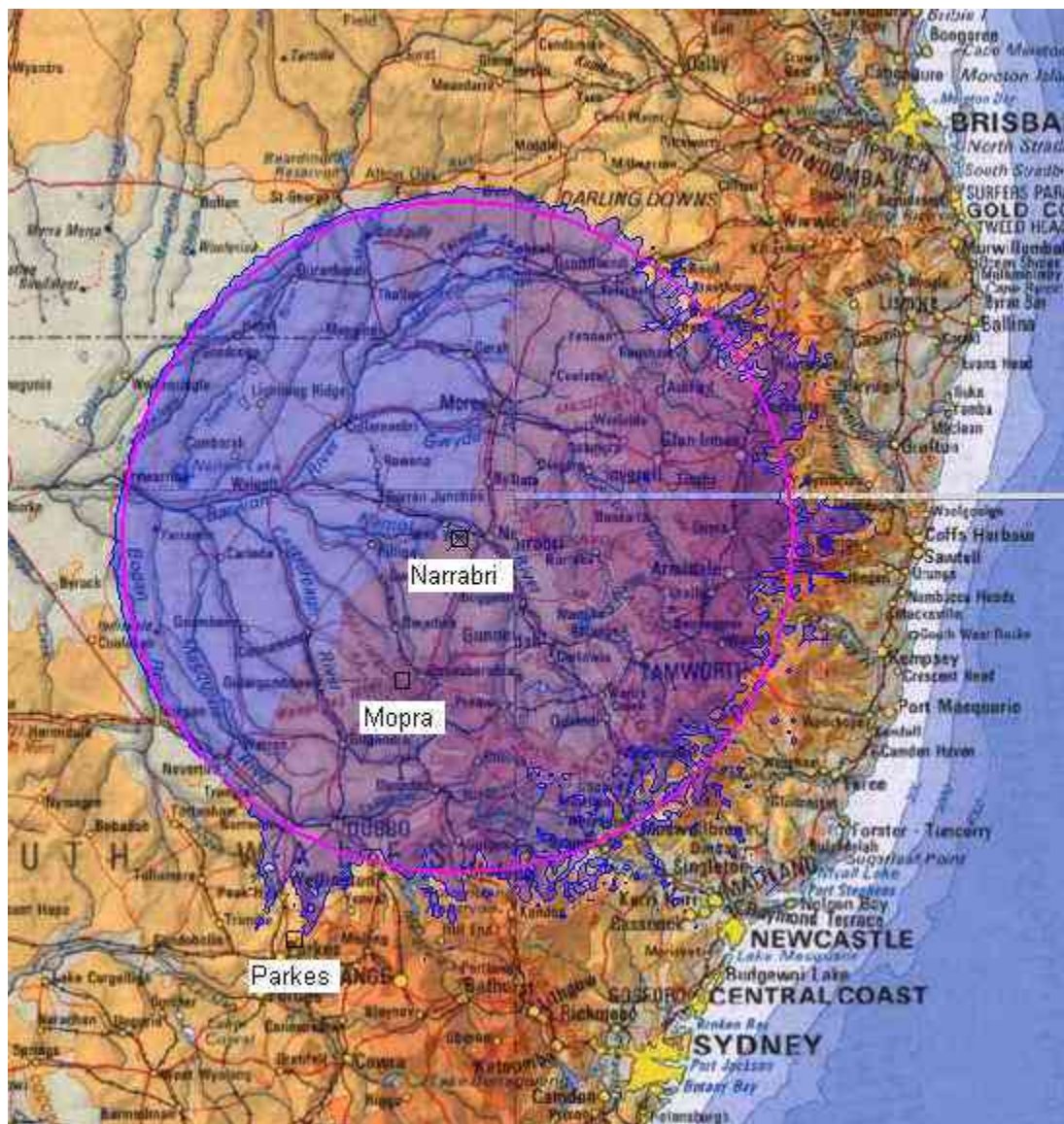


FIGURE 16

Narrabri 2 250 MHz and 180 km circle

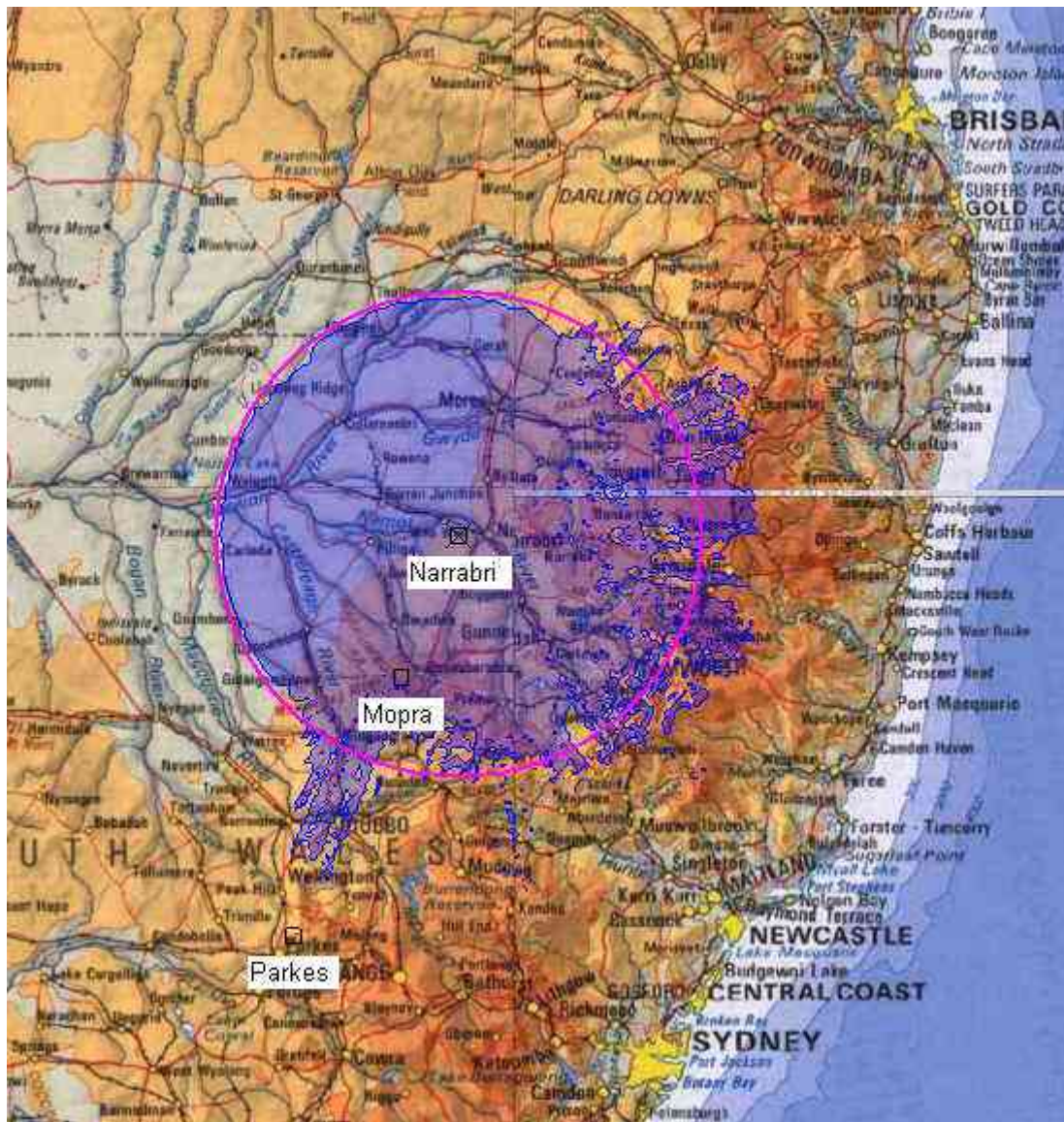




FIGURE 17

Narrabri 4 GHz and 160 km circle

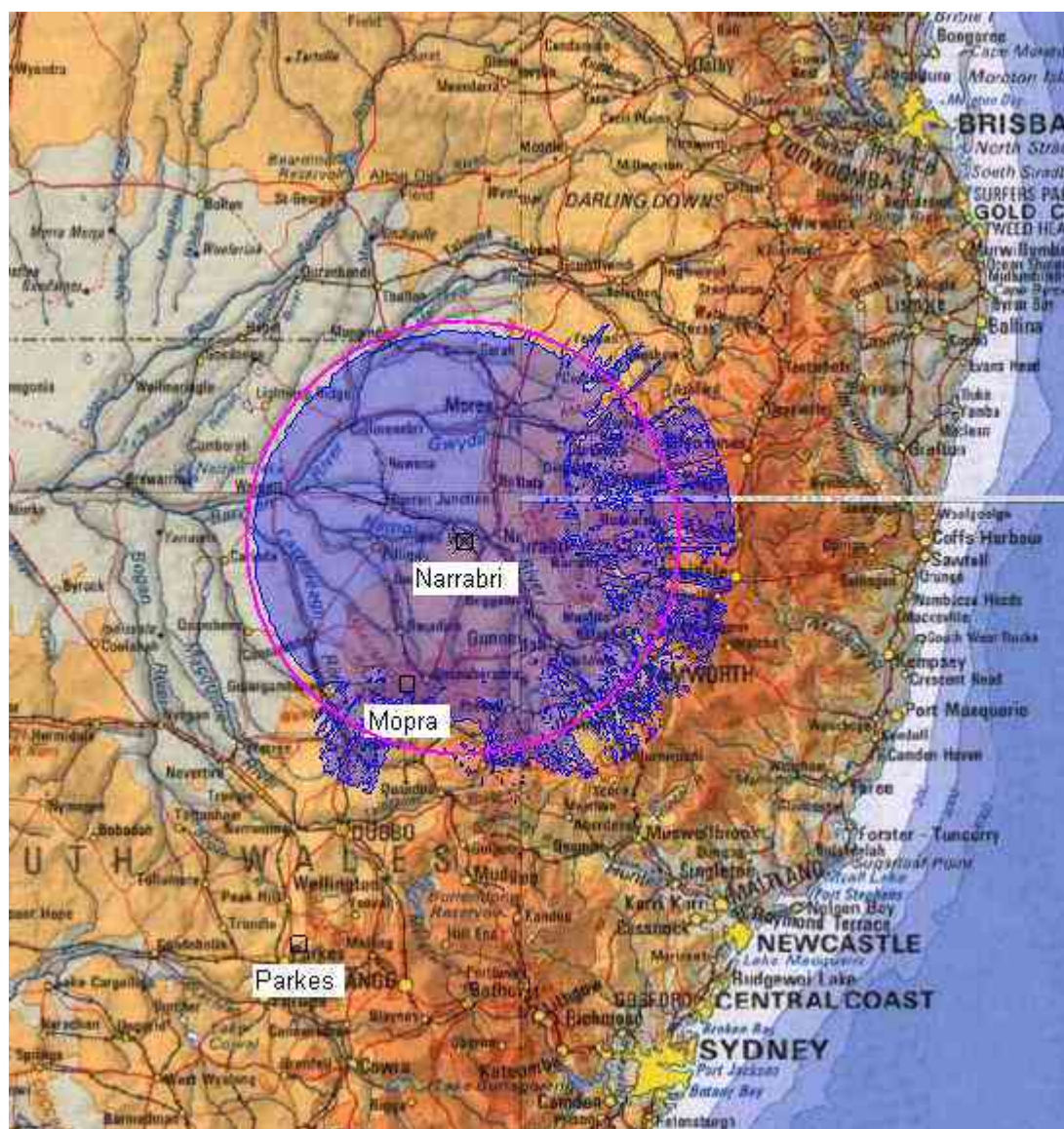


FIGURE 18  
Narrabri 8 GHz and 110 km circle

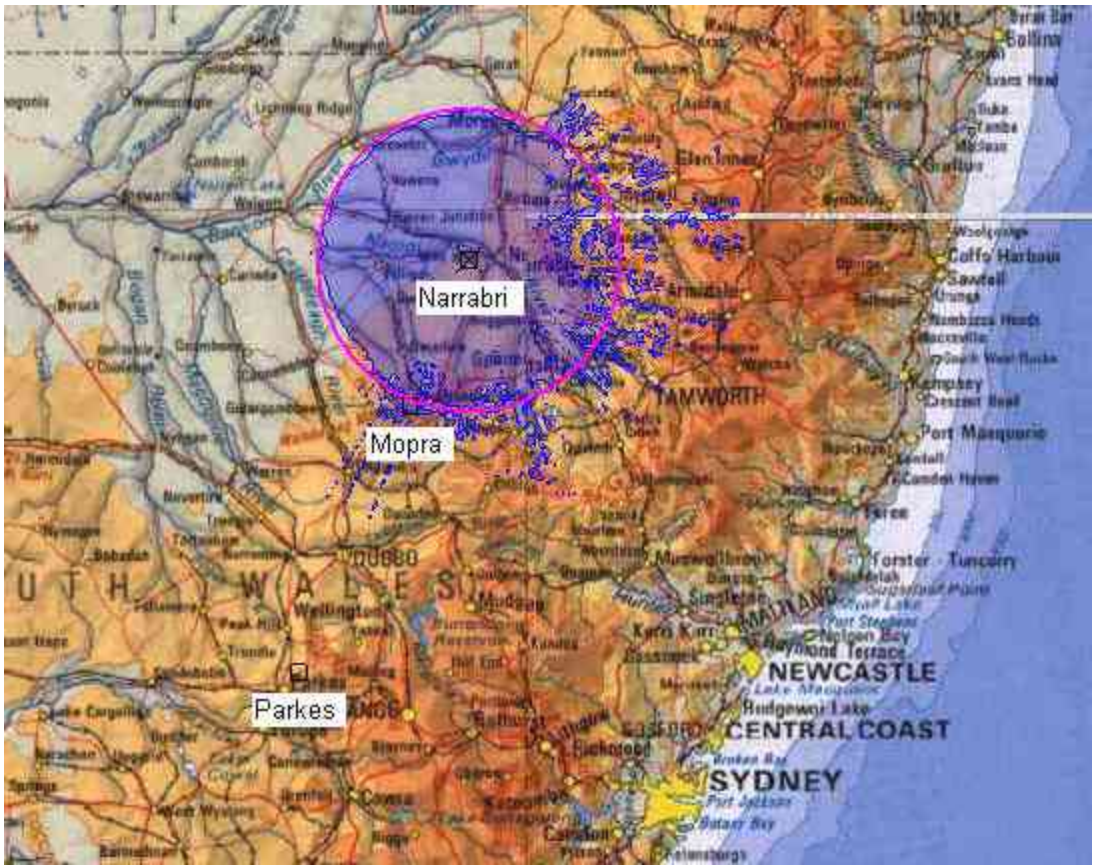
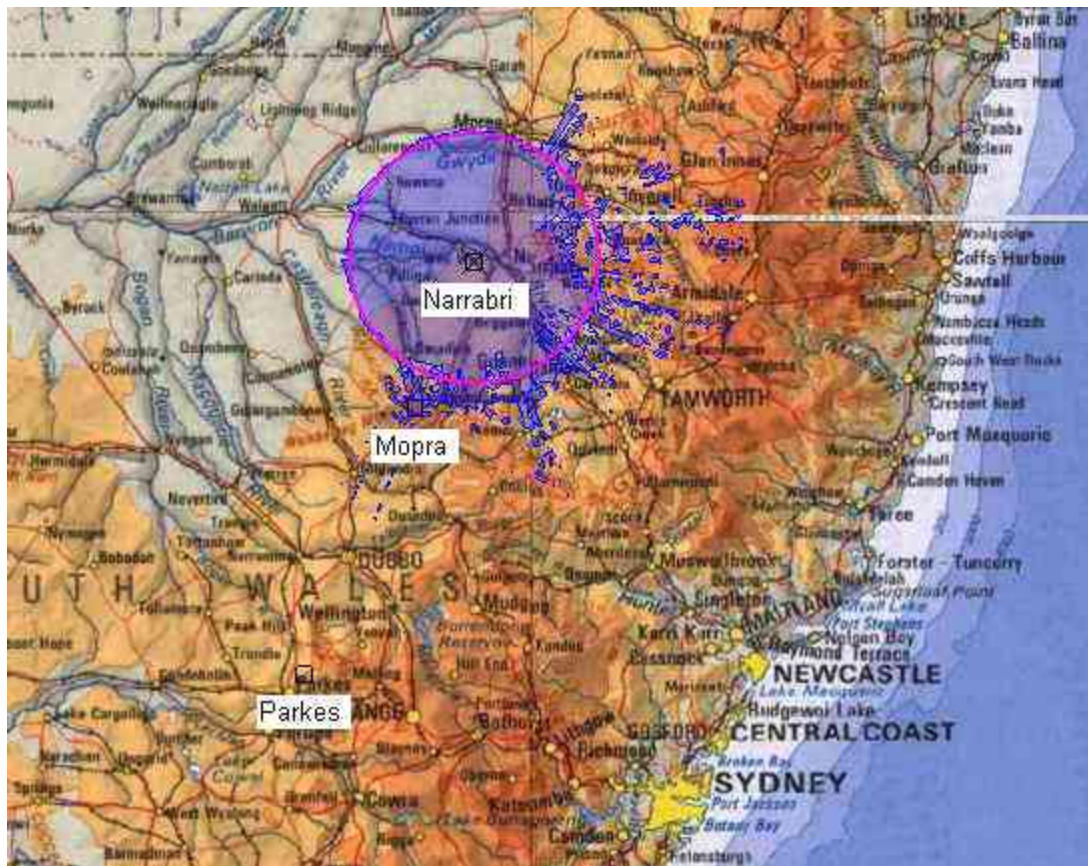




FIGURE 19  
Narrabri 16 GHz and 90 km circle



Mopra

TABLE 8  
Mopra notification zone results

Band (MHz)	Zone (radius of circle, centred on Mopra facility)
1 250-1 780	150 km
2 200-2 550	130 km
4 350-6 700	120 km
8 000-9 200	100 km
16 000-26 000	80 km

FIGURE 20  
Mopra 1 250 MHz and 150 km circle

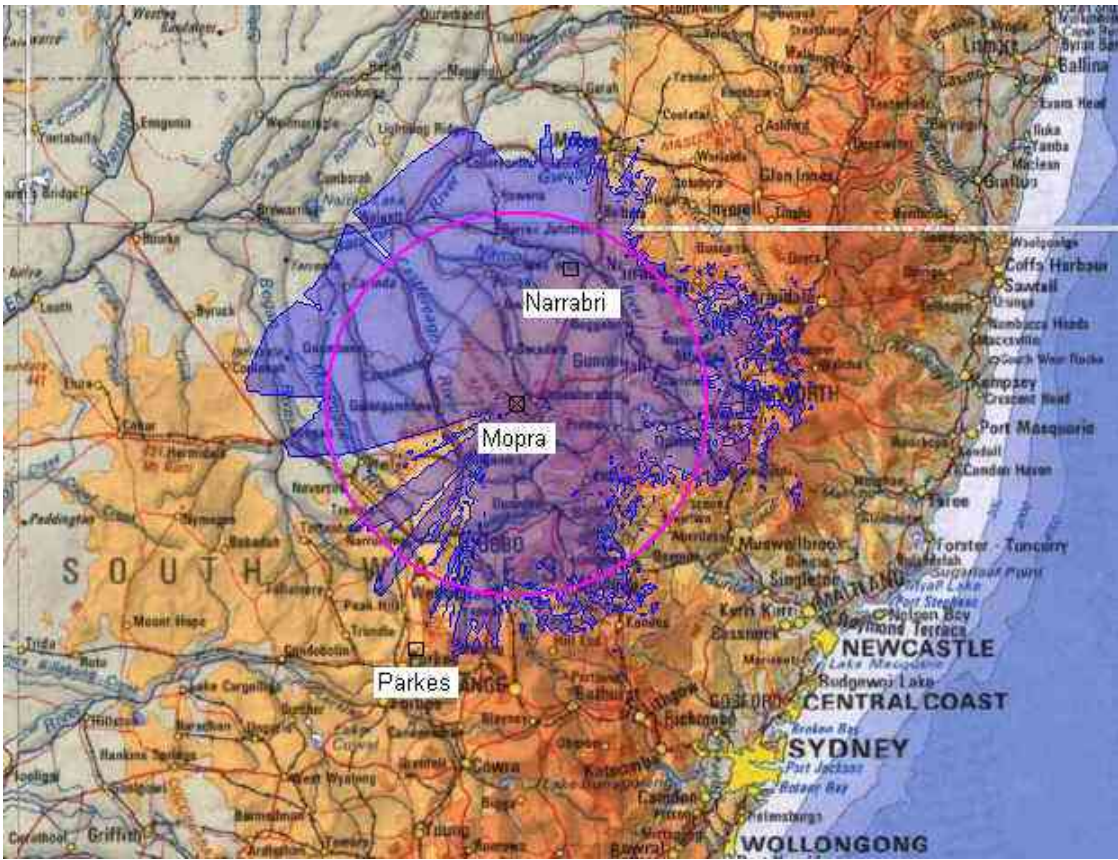




FIGURE 21

Mopra 2 250 MHz and 130 km circle

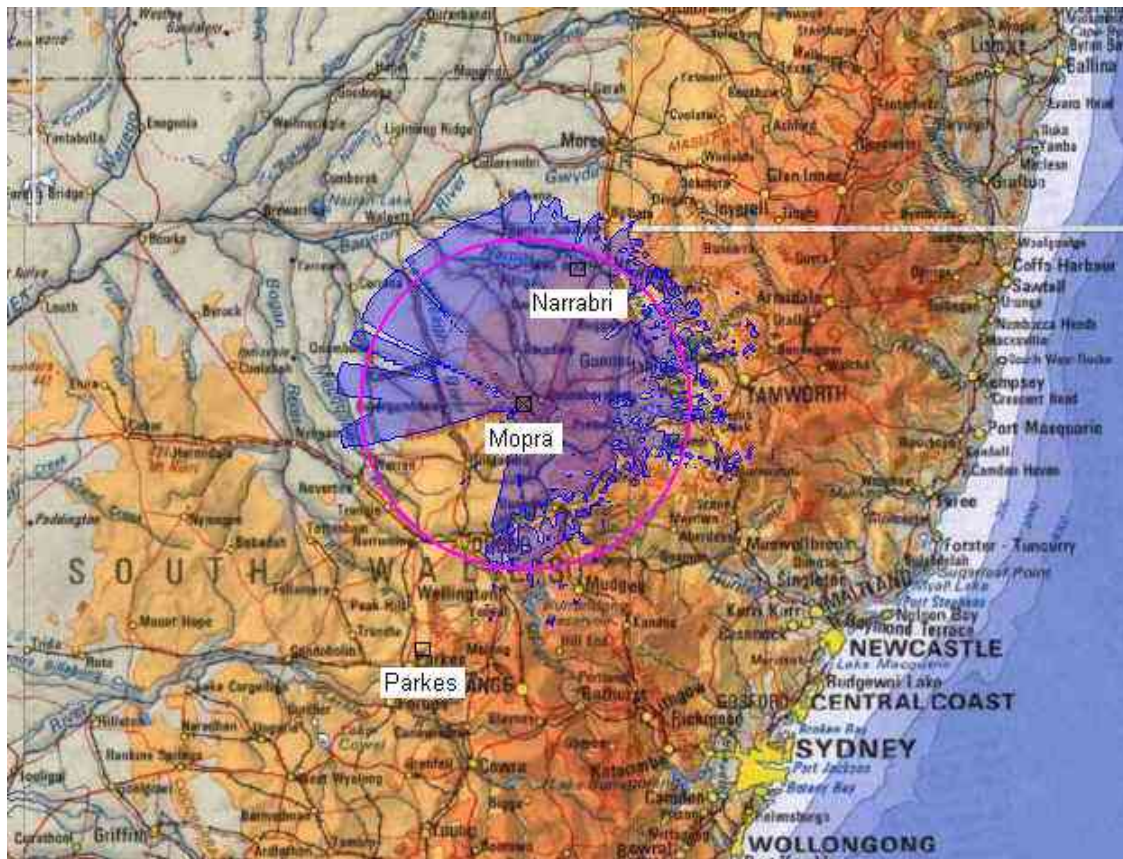


FIGURE 22

Mopra 4 GHz and 120 km circle

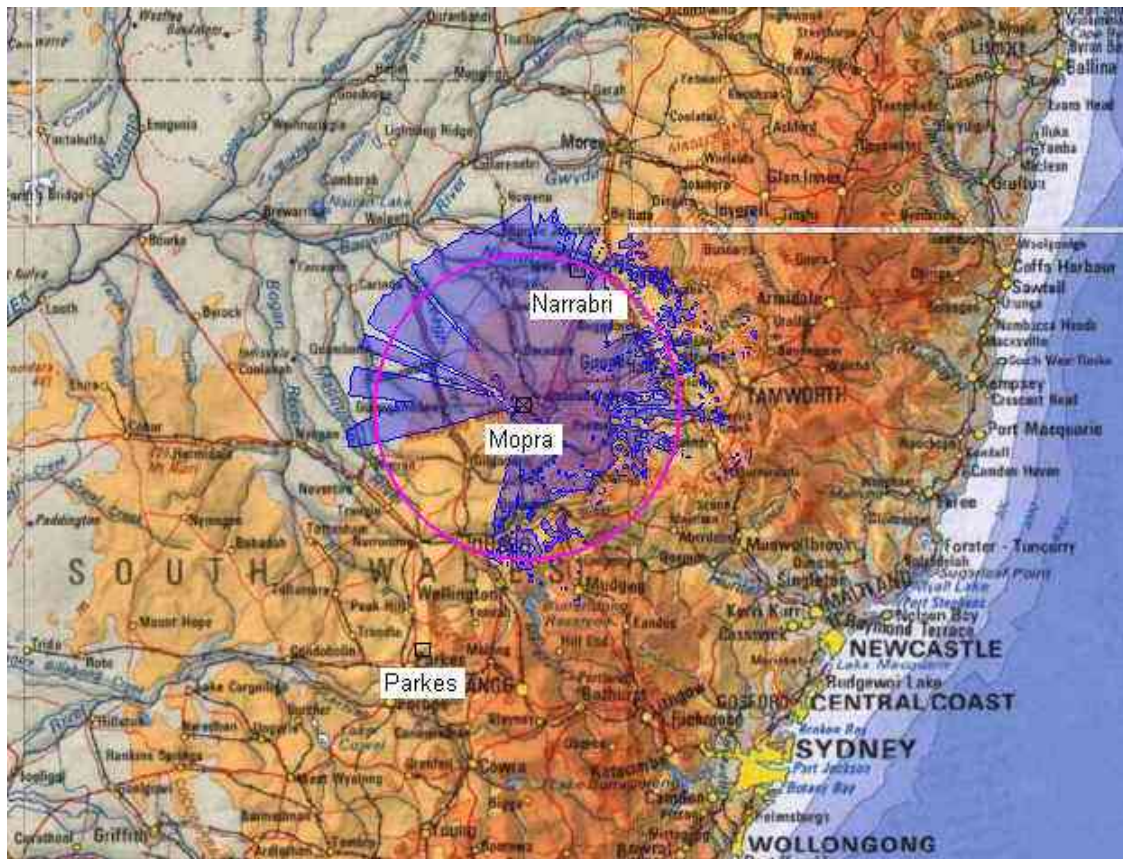




FIGURE 23

Mopra 8 GHz and 100 km circle

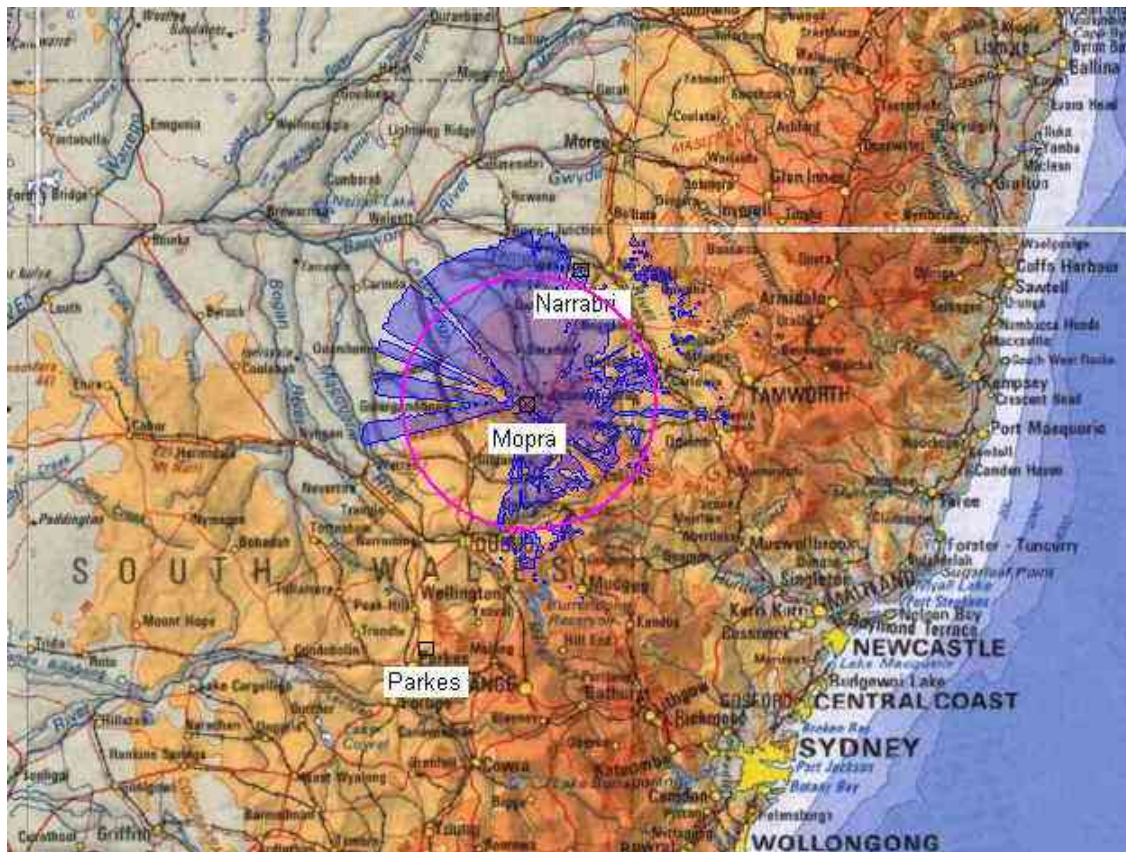
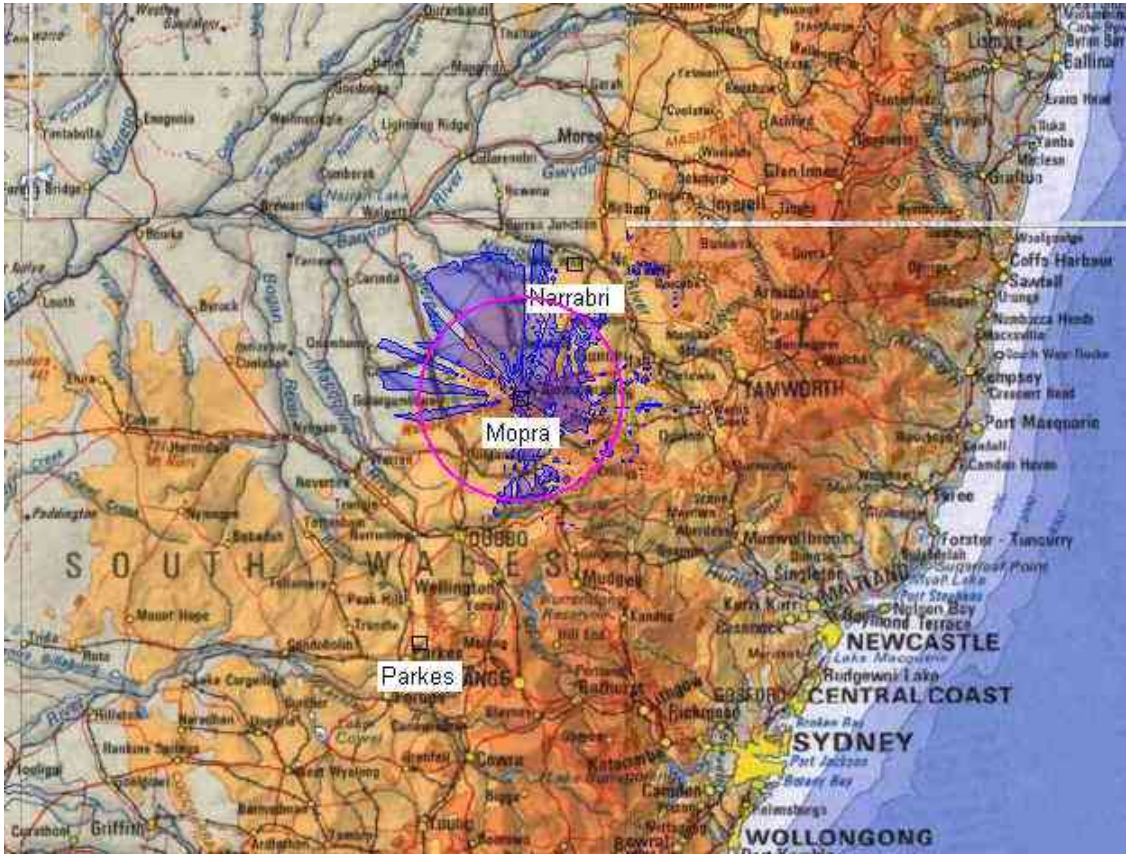


FIGURE 24  
Mopra 16 GHz and 80 km circle



Ceduna

TABLE 9  
Ceduna notification zone results

Band (MHz)	Zone (radius of circle, centred on Ceduna facility)
1 250-1 780	(not used)
2 200-2 550	120 km
4 350-6 700	120 km
8 000-9 200	120 km
16 000-26 000	80 km



FIGURE 25

Ceduna 2 250 MHz and 120 km circle

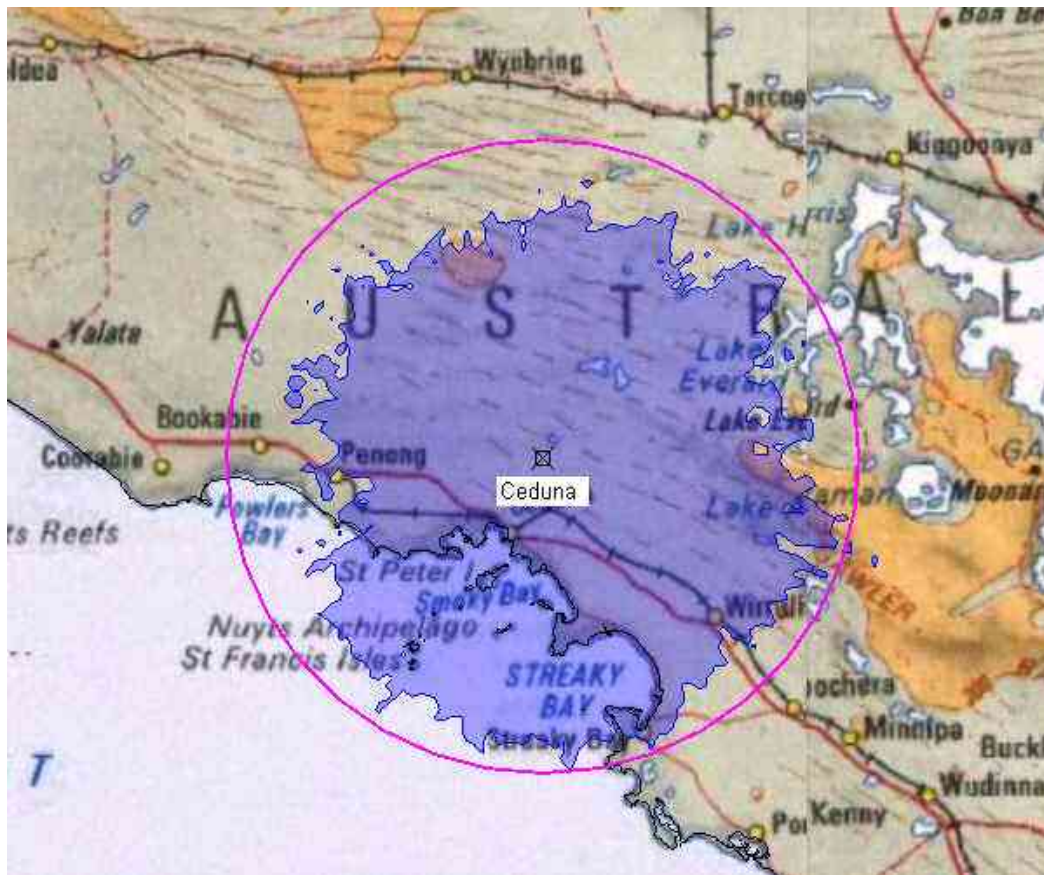


FIGURE 26

Ceduna 4 GHz and 120 km circle

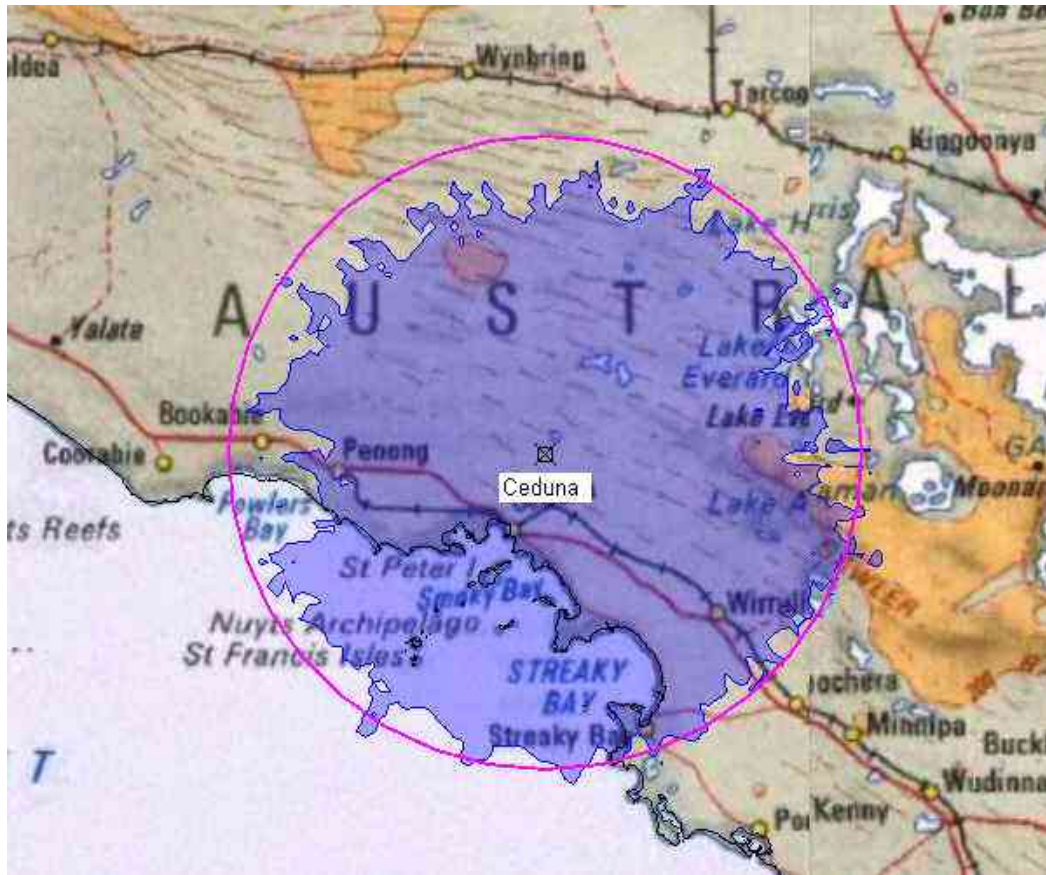


FIGURE 27

Ceduna 8 GHz and 120 km circle

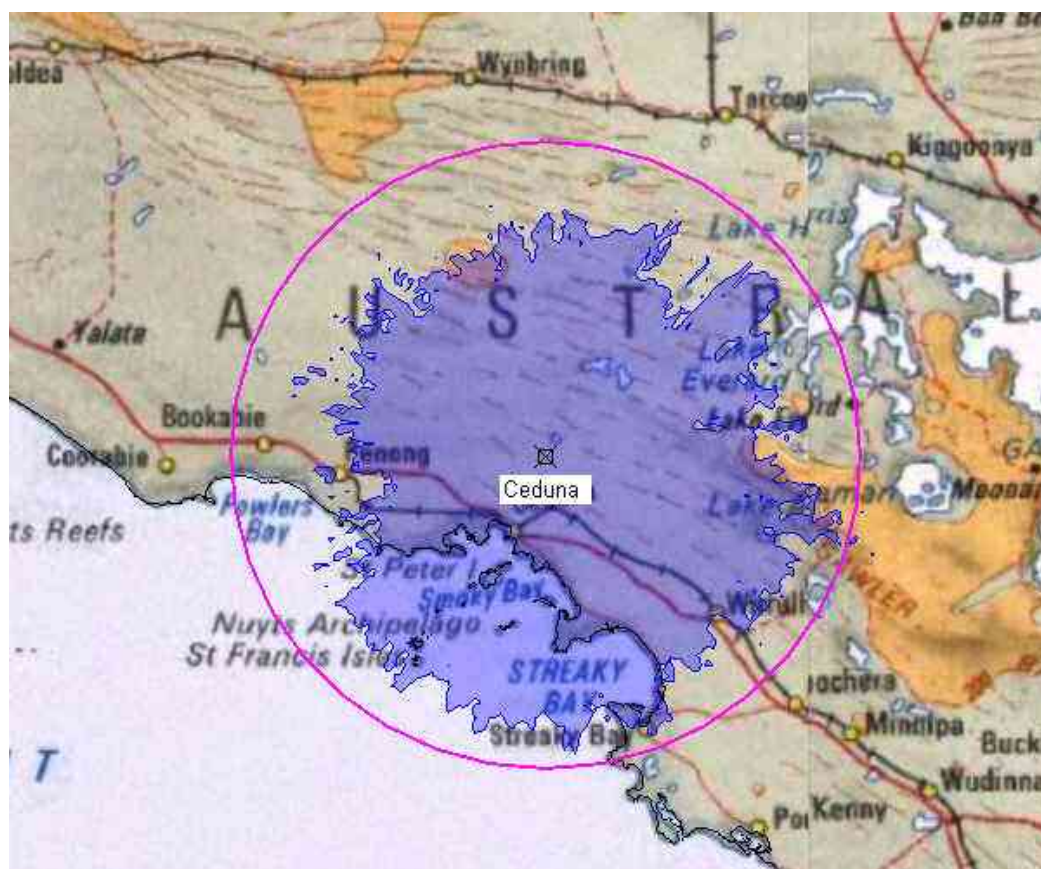
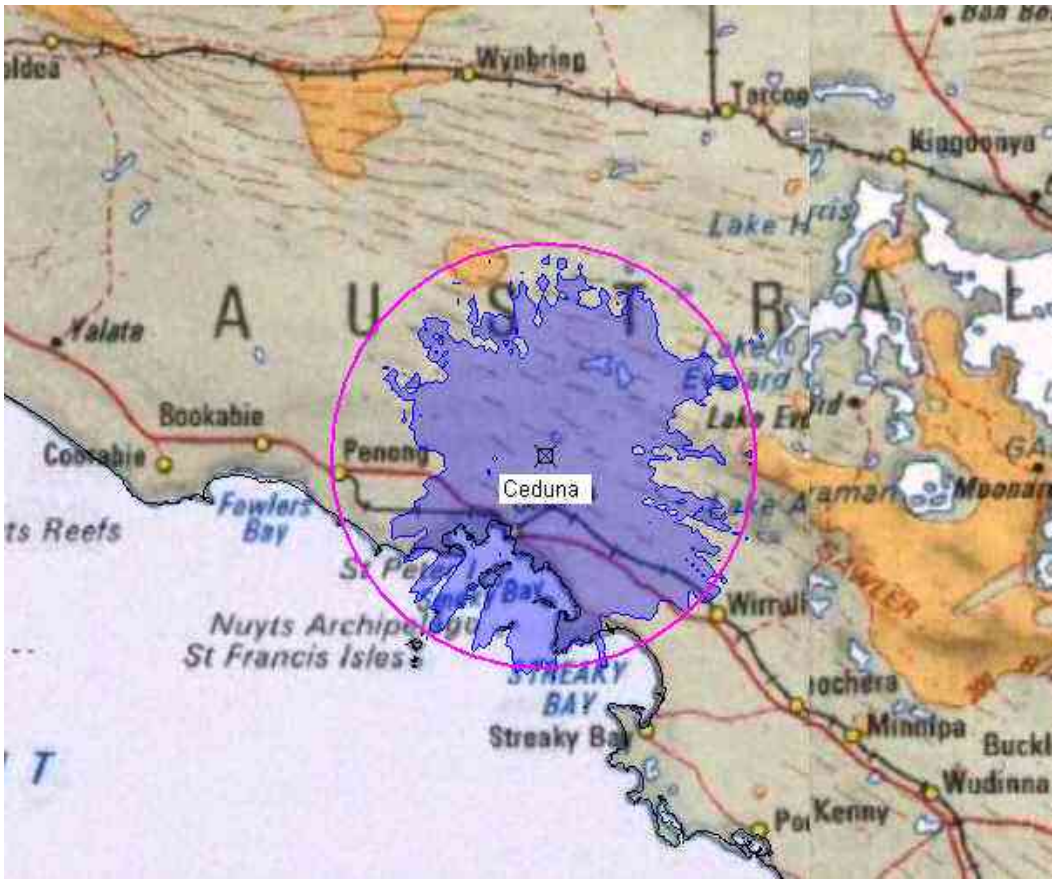




FIGURE 28  
Ceduna 16 GHz and 80 km circle



Hobart – Mount Pleasant

TABLE 10  
Mount Pleasant notification zone results

Band (MHz)	Zone (radius of circle, centred on Mount Pleasant facility)
1 250-1 780	100 km
2 200-2 550	80 km
4 350-6 700	70 km
8 000-9 200	50 km
16 000-26 000	30 km



FIGURE 29

Mount Pleasant 1 250 MHz and 100 km circle

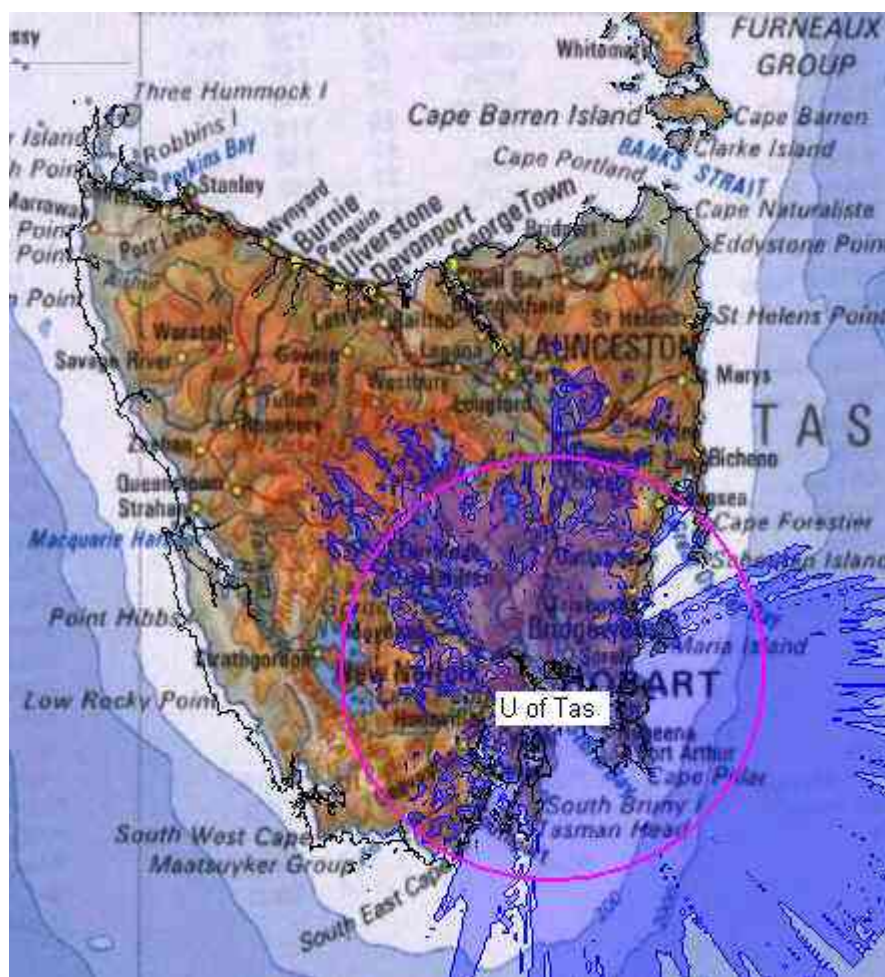


FIGURE 30

Mount Pleasant 2 250 MHz and 80 km circle

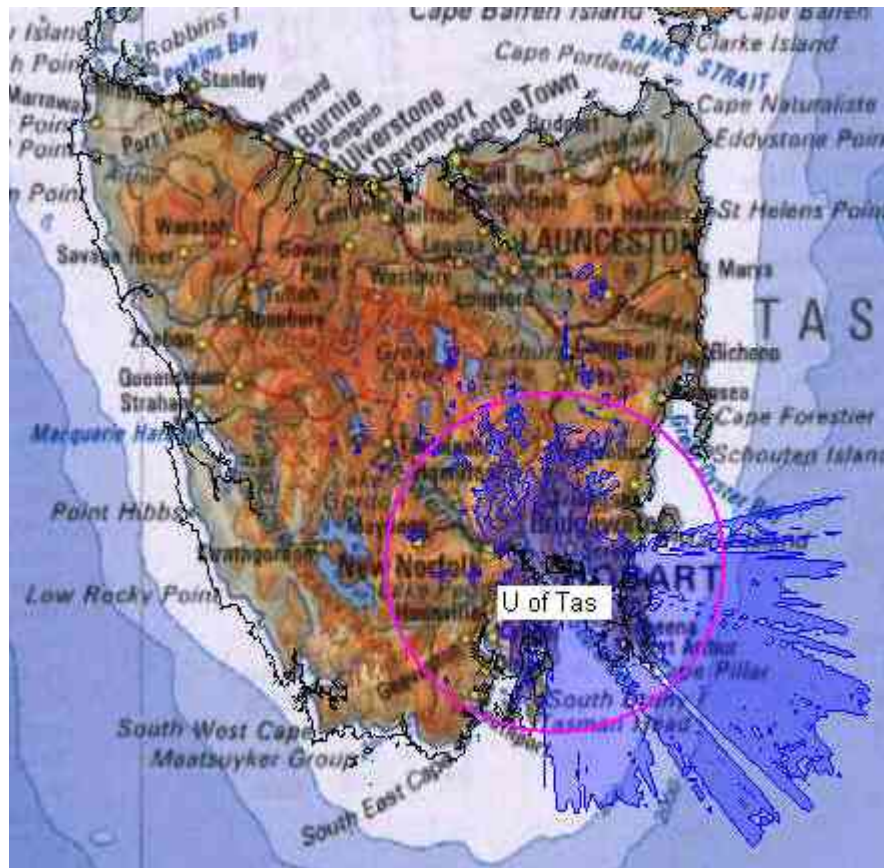


FIGURE 31

Mount Pleasant 4 GHz and 70 km circle

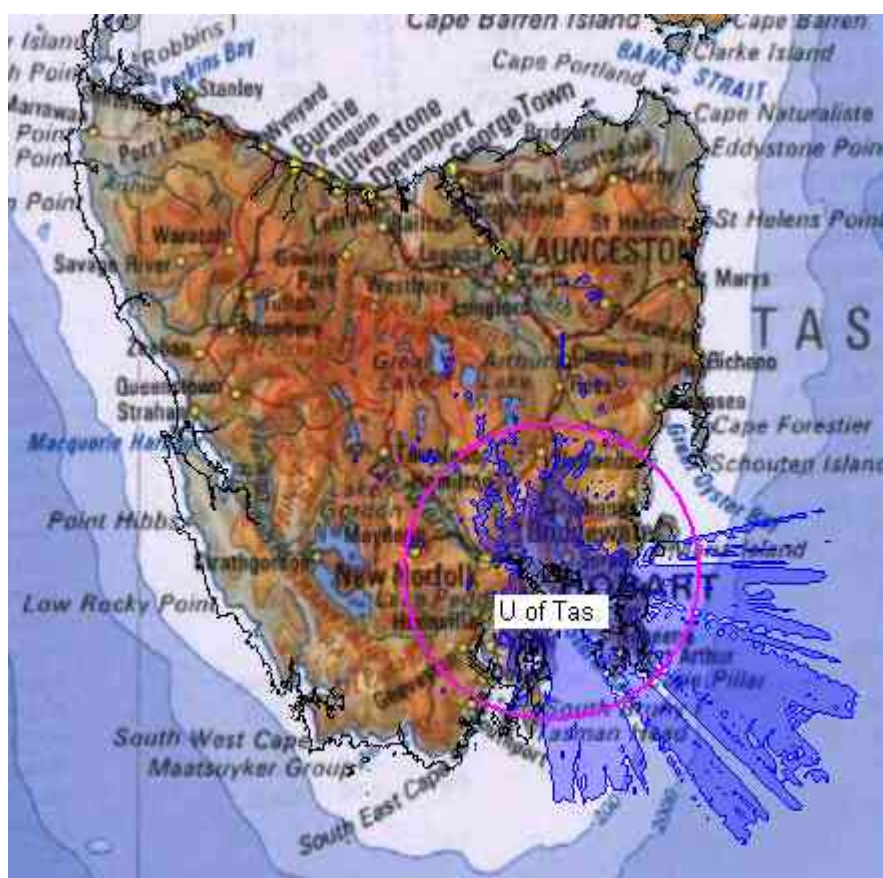




FIGURE 32

Mount Pleasant 8 GHz and 50 km circle

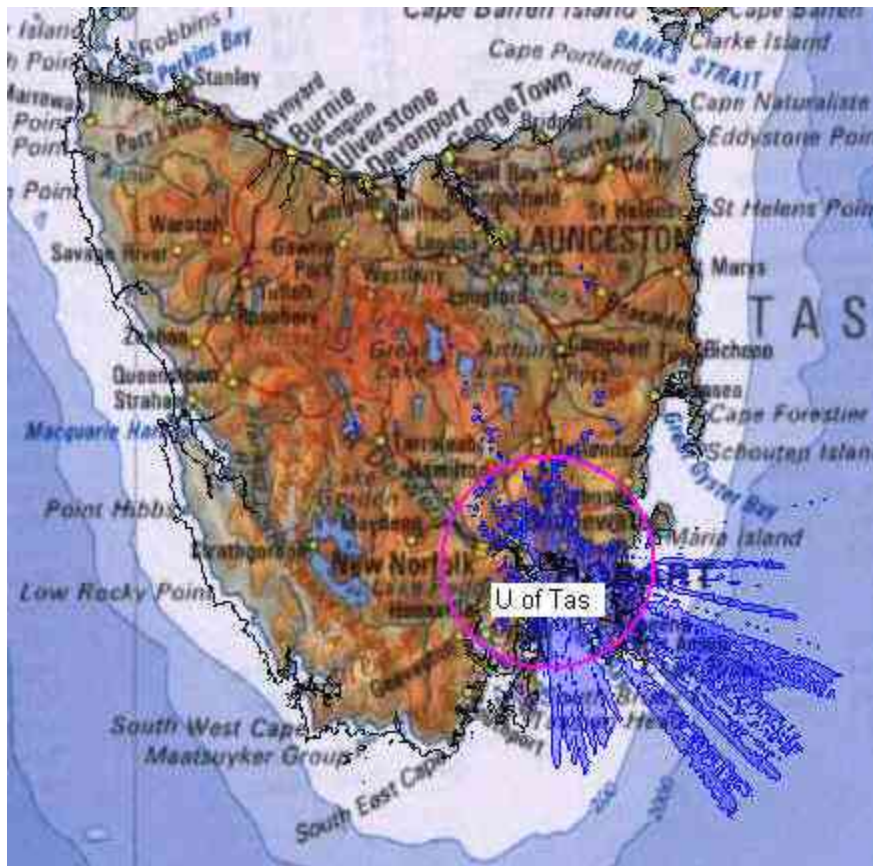


FIGURE 33

Mount Pleasant 16 GHz and 30 km circle



## Tidbinbilla

TABLE 11

Tidbinbilla notification zone results

Band (MHz)	Zone (radius of circle, centred on Tidbinbilla facility)
1 250-1 780	120 km
2 200-2 550	80 km
4 350-6 700	70 km
8 000-9 200	50 km
16 000-26 000	30 km

FIGURE 34

Tidbinbilla 1 250 MHz and 120 km circle

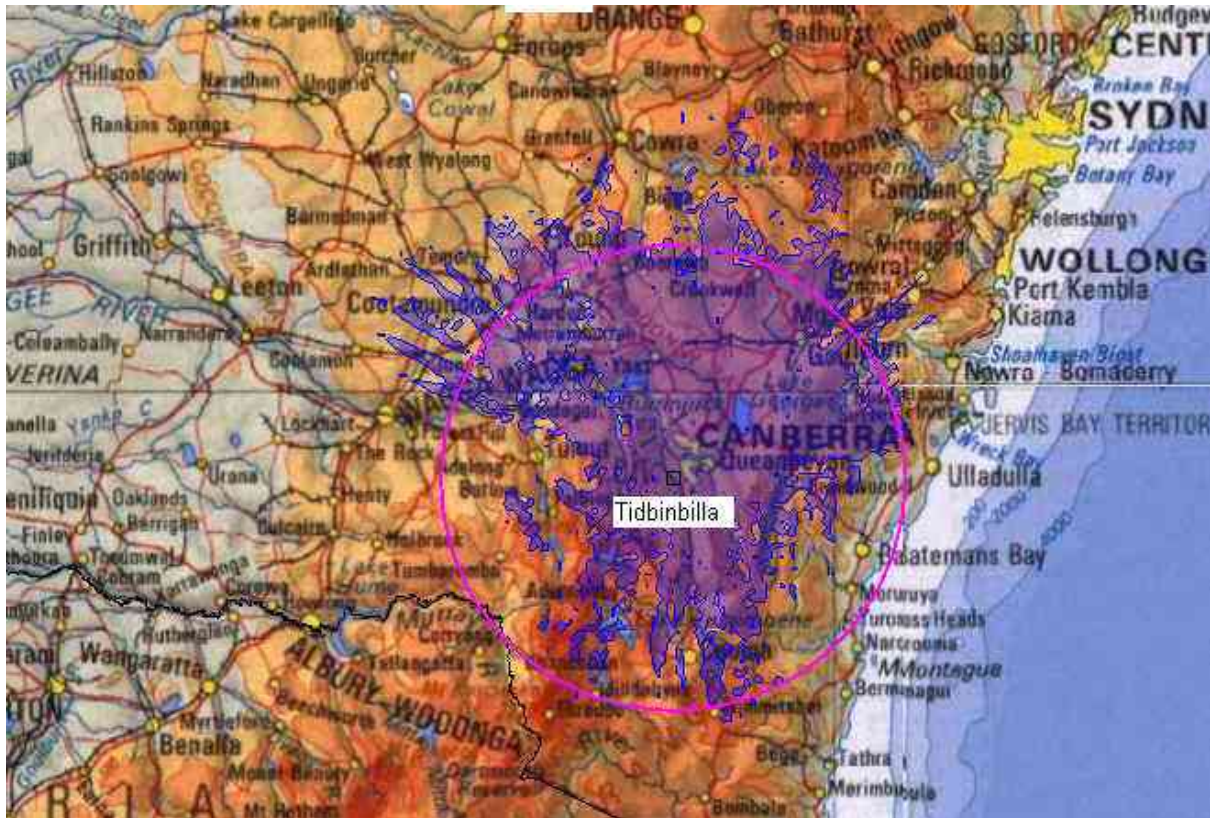




FIGURE 35

Tidbinbilla 2 250 MHz and 80 km circle

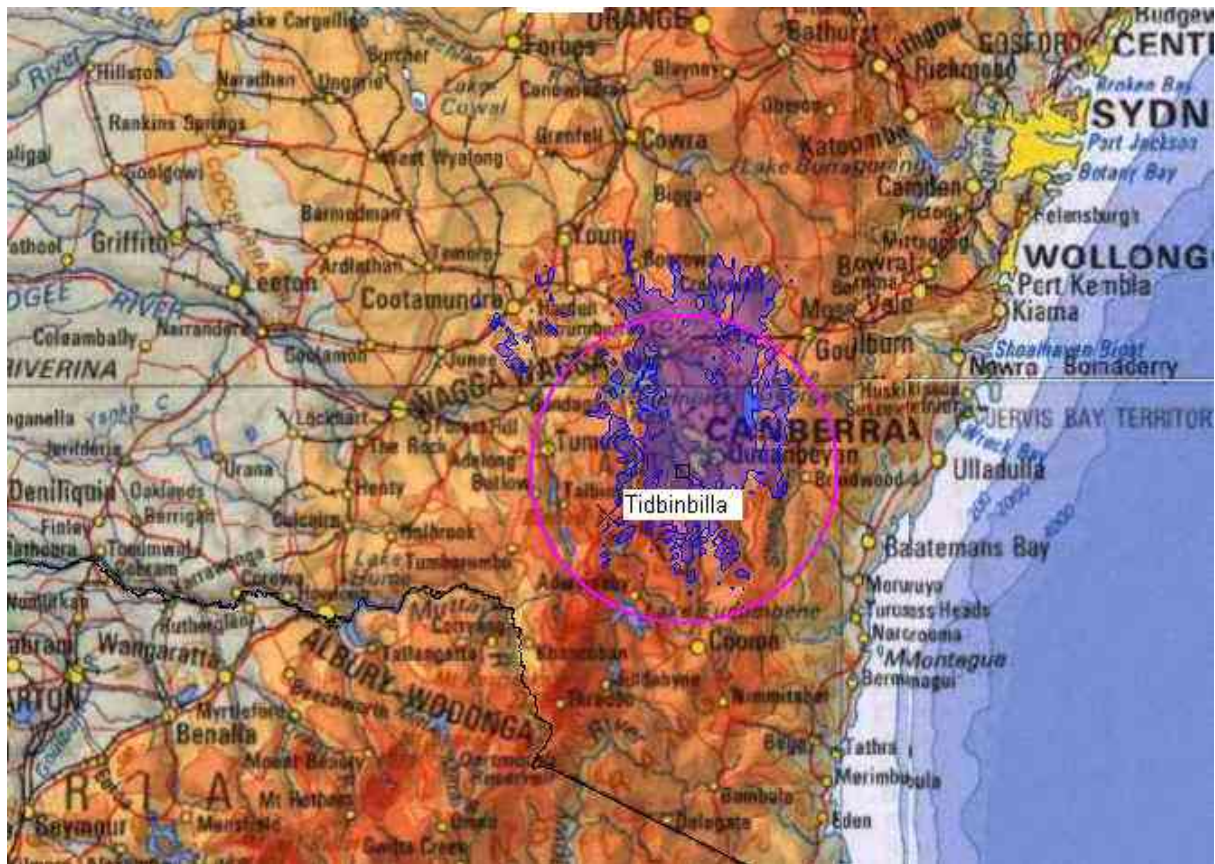


FIGURE 36

Tidbinbilla 4 GHz and 70 km circle

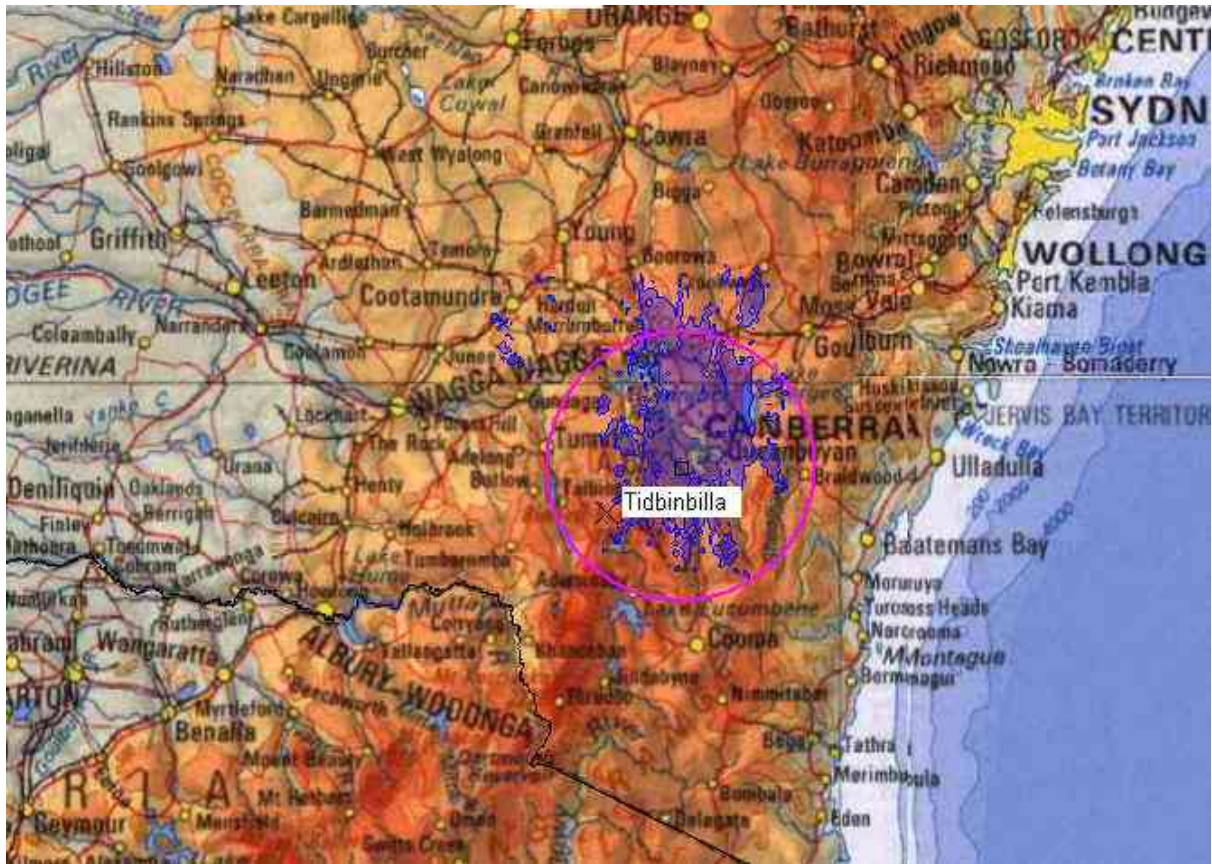




FIGURE 37

Tidbinbilla 8 GHz and 50 km circle

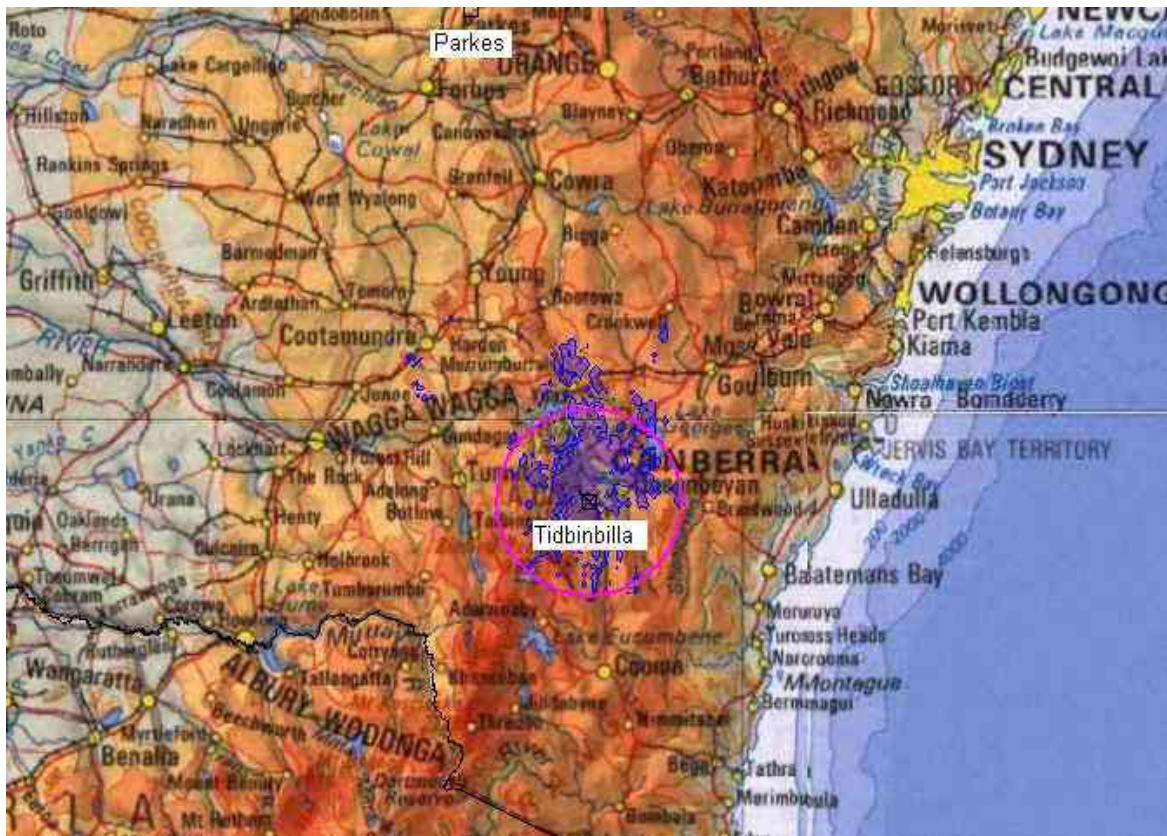
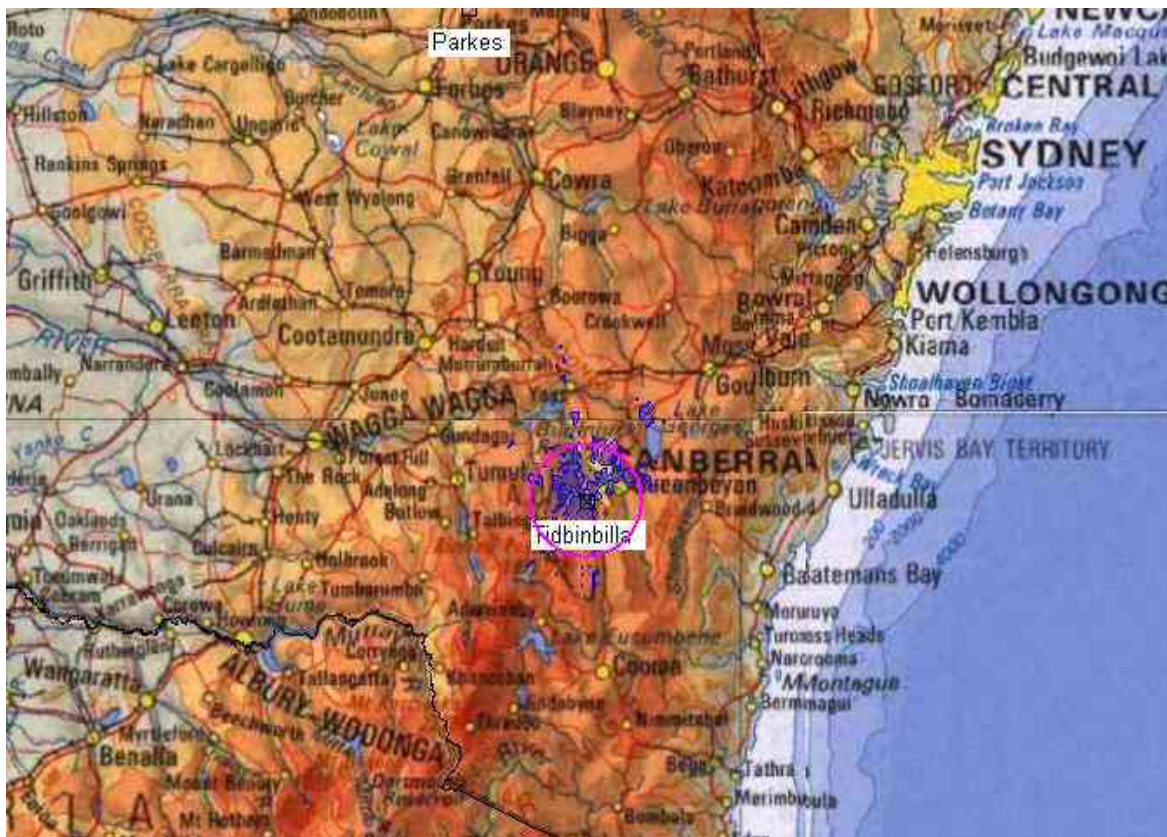


FIGURE 38

Tidbinbilla 16 GHz and 30 km circle



### Impact of zones

To assess the impact of the zones on future frequency assignment activity it is useful to examine recent apparatus licensing activity to estimate future activity. The tables below show the number of frequency assignments approved within each of the zones between the years 2000 and 2004.

TABLE 12

#### Parkes area – Assignment activity

Band (MHz)	D (km)	2000	2001	2002	2003	2004
1 250-1 780	200	2	2	2	0	1
2 200-2 550	180	0	0	0	0	0
4 350-6 700	160	0	0	20	4	0
8 000-9 200	150	0	0	2	0	1
16 000-26 000	110	0	2	6	20	0

TABLE 13

#### Narrabri area – Assignment activity

Band (MHz)	D (km)	2000	2001	2002	2003	2004
1 250-1 780	250	14	8	6	6	4
2 200-2 550	180	0	0	0	0	0
4 350-6 700	160	6	1	7	4	0
8 000-9 200	110	0	1	2	0	4
16 000-26 000	90	0	0	0	0	2

TABLE 14

#### Mopra area – Assignment activity

Band (MHz)	D (km)	2000	2001	2002	2003	2004
1 250-1 780	150	0	2	4	2	0
2 200-2 550	130	0	0	0	0	0
4 350-6 700	120	0	0	12	1	0
8 000-9 200	100	0	0	0	0	0
16 000-26 000	80	2	0	0	2	0

TABLE 15  
Mt Pleasant area – Assignment activity

Band (MHz)	D (km)	2000	2001	2002	2003	2004
1 250-1 780	100	0	5	0	0	0
2 200-2 550	80	0	1	0	0	0
4 350-6 700	70	31	0	33	0	0
8 000-9 200	50	0	0	0	0	0
16 000-26 000	30	4	6	0	0	6

TABLE 16  
Ceduna area – Assignment activity

Band (MHz)	D (km)	2000	2001	2002	2003	2004
1 250-1 780	–	–	–	–	–	–
2 200-2 550	120	0	0	0	0	1
4 350-6 700	120	0	0	0	0	1
8 000-9 200	120	0	0	0	0	0
16 000-26 000	80	0	0	0	0	0

TABLE 17  
Tidbinbilla area – Assignment activity

Band (MHz)	D (km)	2000	2001	2002	2003	2004
1 250-1 780	120	1	0	3	6	12
2 200-2 550	80	0	0	0	0	0
4 350-6 700	70	0	3	0	5	1
8 000-9 200	50	0	0	4	4	0
16 000-26 000	30	18	10	16	22	12

Assignment activity within the zones is low for all the zones, with the exceptions of the 4 350-6 700 MHz band around Mt Pleasant and the 16-26 GHz band around Tidbinbilla.

Assignment activity in the 4 350-6 700 MHz band around Mt Pleasant occurs in the 5 GHz band (4.4-5 GHz), the 6 GHz band (5.925-6.425 GHz) and the 6.7 GHz band (6.425-7.11 GHz). Excluding these bands from any notification zone would minimize the impost on the radiocommunications community around Mt Pleasant.

Assignment activity in the 16-26 GHz band around Tidbinbilla occurs in the 18 GHz band (17.7-19.7 GHz) and the 22 GHz band (21.2-23.6 GHz). Excluding these bands from any notification zone would minimize the impost on the radiocommunications community around Tidbinbilla.

## Conclusions

This report derives proposed radii and frequency bands for notification zones around the radio astronomy facilities listed in AUS87. The following factors have been considered:

- the characteristics of radio astronomy receivers;
- the most likely interferer;
- propagation path loss accounting for terrain; and
- the likely number of affected future frequency assignments.

## Summary of Recommendations

The following dimensions are recommended for notification zones for the given locations and frequency bands.

TABLE 18  
Summary of proposed notification zones

Band (MHz)	Notification zones (km radius)					
	Parkes	Narrabri	Mopra	Mt Pleasant	Ceduna	Tidbinbilla
1 250-1 780	200	250	150	100	n/a	120
2 200-2 550	180	180	130	80	120	80
4 350-6 700	160	160	120	70 <sup>13</sup>	120	70
8 000-9 200	150	110	100	50	120	50
16 000-26 000	110	90	80	30	80	30 <sup>14</sup>

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<sup>13</sup> Excluding the 5 GHz band (4.4-5 GHz), the 6 GHz band (5.925-6.425 GHz) and the 6.7 GHz band (6.425-7.11 GHz).

<sup>14</sup> Excluding the 18 GHz band (17.7-19.7 GHz) and the 22 GHz band (21.2-23.6 GHz).



## Appendix 1 to Annex 5

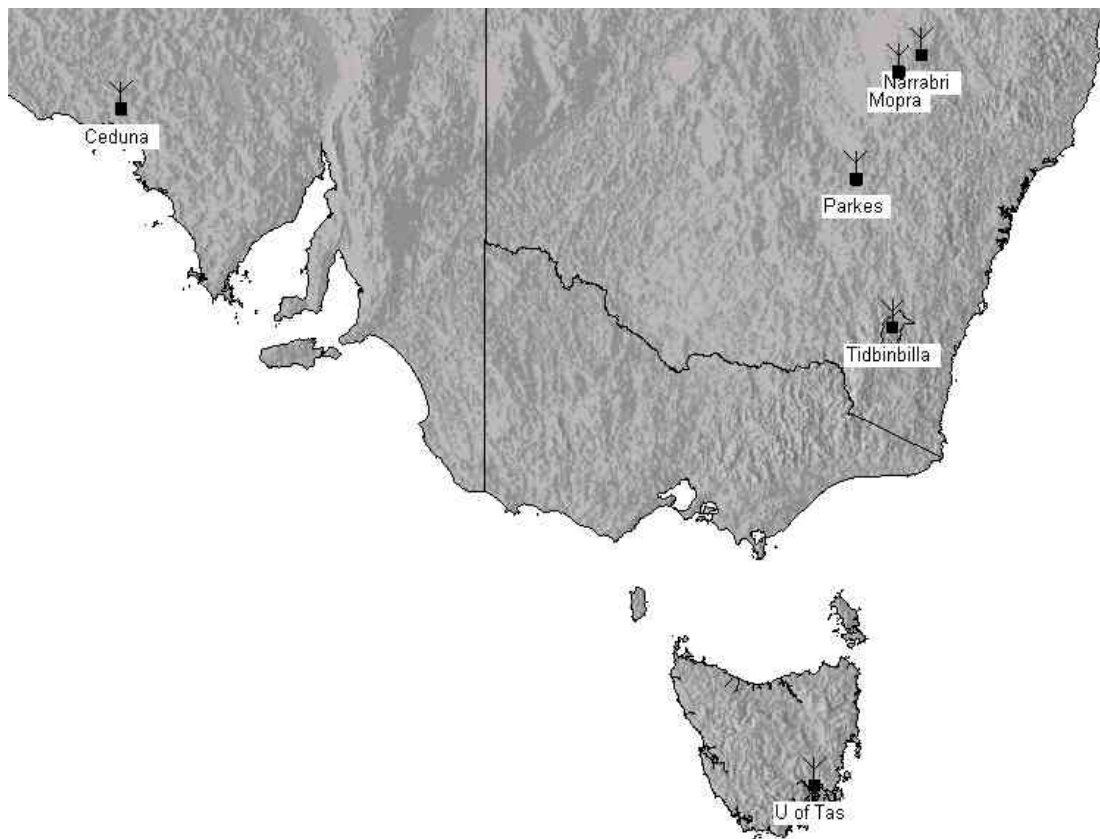
### Australian radio-frequency spectrum plan footnote AUS87

AUS87 Radio astronomy facilities operated by the CSIRO at the Paul Wild Observatory Narrabri (latitude  $30^{\circ} 59' 52.048''$  S, longitude  $149^{\circ} 32' 56.327''$  E), the Parkes Observatory (latitude  $32^{\circ} 59' 59.8657''$  S, longitude  $148^{\circ} 15' 44.3591''$  E), and the Mopra Observatory Coonabarabran (latitude  $31^{\circ} 16' 4.451''$  S, longitude  $149^{\circ} 5' 58.732''$  E) and by the University of Tasmania at the Mount Pleasant Observatory Hobart (latitude  $42^{\circ} 48' 12.9207''$  S, longitude  $147^{\circ} 26' 25.854''$  E) and the Ceduna Observatory (latitude  $31^{\circ} 52' 08.8269''$  S, longitude  $133^{\circ} 48' 35.3748''$  E), and at the Canberra Deep Space Communication Complex (latitude  $35^{\circ} 23' 54''$  S, longitude  $148^{\circ} 58' 40''$  E) conduct passive observations in the frequency bands 1 250-1 780 MHz, 2 200-2 550 MHz, 4 350-6 700 MHz, 8 000-9 200 MHz and 16-26 GHz using receivers that are highly sensitive to interference.

Figure 39 shows the locations of these facilities.

FIGURE 39

AUS87 radio astronomy facility locations



## AUS87 band use survey

## 1 Frequency assignments survey: 1 250-1 780 MHz

FIGURE 40  
Apparatus licensed services: 1 250-1 780 MHz

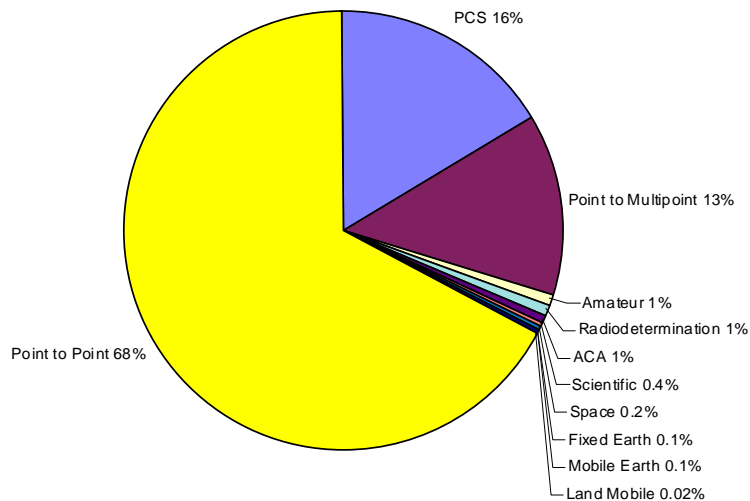


TABLE 19  
Service quantities, e.i.r.p., bandwidth and power spectral density 1 250-1 780 MHz

Assignment type	Qty	e.i.r.p. (W)	BW (Hz)	PSD (dBm/Hz <sup>15</sup> )
CTS	1020	23.2	2200000	-19.7693
Point to multipoint	836	50	1750000	-15.4407
Amateur	52	60	16000	5.740313
Radiodetermination	51	1200000	1000000	30.79181
ACMA	38	NA	NA	NA
Scientific	22	20000	1250000	12.0412
Space	12	1400	350000	6.0206
Fixed Earth	8	20	10000	3.0103
Mobile Earth	5	50	10000	6.9897
Land mobile	1	8.3	16000	-2.85042
Point-to-point (P-P)	4210	2000	1750000	0.579919

<sup>15</sup> Assumes the transmitter has uniform power spectral density.

### Analysis of applicable PSD

Assignments to the radiodetermination service appear to be of significance. Six of these assignments have the PSD indicated, the rest have a PSD of  $-17$  dBm or less. The six assignments are located at Tindal (Lat 14.512423 S, Long 132.445755 E) and Dutson (Lat 38.189581 S, 147.181224 E) and are associated with Department of Defence activity at these locations. None of the radio astronomy facilities listed in AUS87 are located near Tindal. The radio astronomy facility at the Mount Pleasant Observatory Hobart (latitude  $42^{\circ} 48' 12.9207''$  S, longitude  $147^{\circ} 26' 25.854''$  E) is the only facility that may be affected by new radiodetermination installations in the 1 250-1 780 MHz band at Dutson.

The next most significant assignment type is to the fixed (P-P) service. The PSD of the fixed (P-P) service is typically 0.6 dBm/Hz. Antenna height for stations in the fixed (P-P) service in this band is typically 30 metres.

## 2 Frequency assignments survey: 2 200-2 550 MHz

FIGURE 41  
Apparatus licensed services: 2 200-2 550 MHz

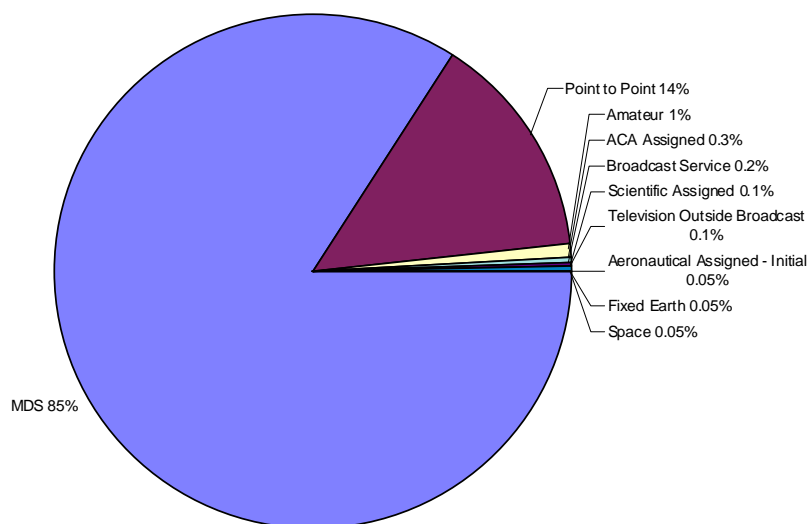




TABLE 20

Service quantities, e.i.r.p., bandwidth and power spectral density 2 200-2 550 MHz

Assignment type	Qty	e.i.r.p. (W)	BW (Hz)	(dBm/Hz)
MDS	1852	1000	6250000	−8.0
P-P	313	4000	25600000	−8.1
Amateur	16	120	850000	−8.5
ACMA assigned	7			
Broadcast service	4	20	6250000	−25.0
Scientific assigned	3	3	850	5.5
Television outside broadcast	3	10	24000000	−33.8
Aeronautical assigned – Initial	1	4.5	12000000	−34.3
Fixed Earth	1	800	5000000	−8.0
Space	1	4	1230000	−24.9

### Analysis of applicable PSD

MDS is by far the predominant assignment type, however use of MDS is supported by Spectrum licensing, not apparatus licensing and therefore falls outside of the scope of this RALI. The next most significant assignment type is to the fixed (P-P) service. The PSD of the fixed (P-P) service is typically −8.0 dBm/Hz. Antenna height for stations in the fixed (P-P) service in this band is typically 30 metres.

### 3 Frequency assignments survey: 4 350-6 700 MHz

FIGURE 42  
Apparatus licensed services: 4 350-6 700 MHz

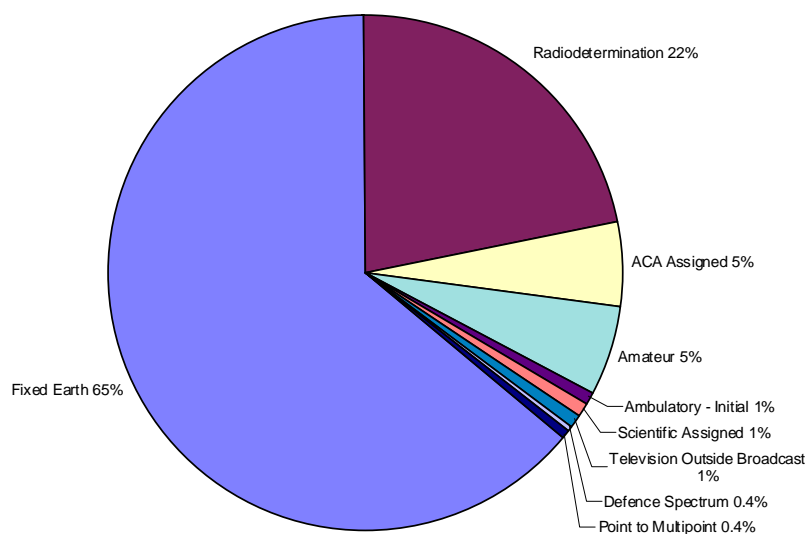


TABLE 21

Service quantities, e.i.r.p., bandwidth and power spectral density 4 350-6 700 MHz

Assignment type	Qty	e.i.r.p. (W)	BW (Hz)	(dBm/Hz)
Fixed Earth	152	32000	200000	22.0
Radiodetermination	52	250000	1000000	24.0
ACMA assigned	13			
Amateur	13	120	500	23.8
Ambulatory – Initial	2	160	25000000	–21.9
Scientific assigned	2			
Television outside broadcast	2	10	18000000	–32.6
Defence spectrum	1			
Point to Multipoint	1	1	35000000	–45.4
P-P	3384	35000	35000000	0.0

### Analysis of applicable PSD

The most significant assignment type in this band is to the fixed (P-P) service. The PSD of a station in this service is typically 0 dBm/Hz. Antenna height for stations in the fixed (P-P) service in this band is typically 20 metres.

## 4 Frequency assignments survey: 8-9.2 GHz

FIGURE 43

Apparatus licensed services: 8-9.2 GHz

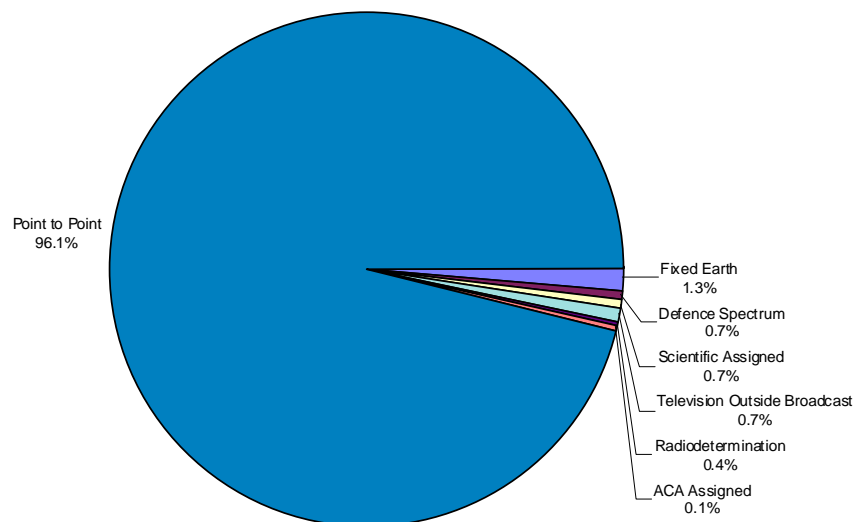


TABLE 22

**Service quantities, e.i.r.p., bandwidth and power spectral density 8-9.2 GHz**

Assignment type	Qty	e.i.r.p. (W)	BW (Hz)	(dBm/Hz)
Fixed Earth	17	2000	60000000	-14.8
Defence spectrum	9	551	1800000	-5.1
Scientific assigned	9	2000000	2500000	29.0
Television outside broadcast	9	2	8000000	-36.0
Radiodetermination	6	300000	17900000	12.2
ACMA assigned	2			
P-P	1287	19000	17000000	0.5

**Analysis of applicable PSD**

The most significant assignment type in this band is to the fixed (P-P) service. The PSD of a station in this service is typically 0.5 dBm/Hz. Antenna height for stations in the fixed (P-P) service in this band is typically 20 metres.

**5 Frequency assignments survey 16-26 GHz**

FIGURE 44

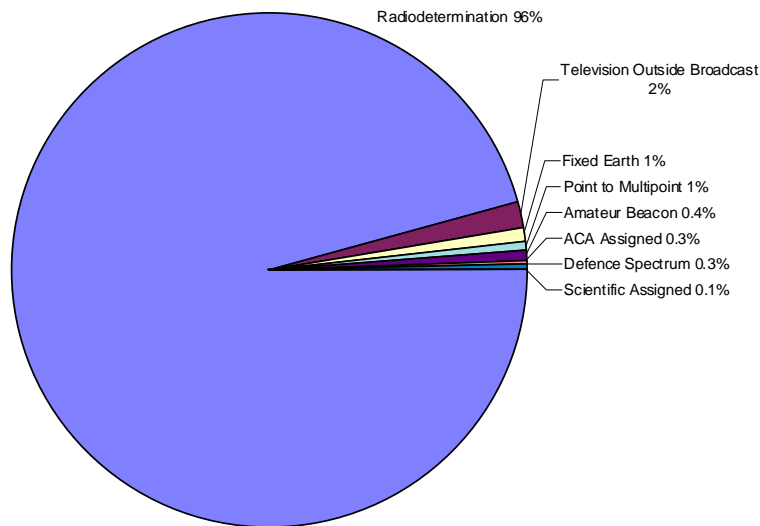
**Apparatus licensed services: 16-26 GHz**

TABLE 23

**Service quantities, e.i.r.p., bandwidth and power spectral density 16-26 GHz**

Assignment type	Qty	e.i.r.p. (W)	BW (Hz)	(dBm/Hz)
Radiodetermination	763	0.1	4000000	−46.0
Television outside broadcast	14	1000	24000000	−13.8
Fixed Earth	6	130000000	1000000	51.1
Point to Multipoint	5	4500	18000000	−6.0
Amateur beacon	3	10	800	11.0
ACMA assigned	2			
Defence spectrum	2	65000	16000000	6.1
Scientific assigned	1	0.005	110000000	−73.4
P-P	10228	1500	6000000	−6.0

**Analysis of applicable PSD**

The most significant assignment type in this band is to the fixed (P-P) service. The PSD of a station in this service is typically −6 dBm/Hz. Antenna height for stations in the fixed (P-P) service in this band is typically 20 metres.



## **Annex 6**

### **A radio quiet zone in Western Australia**

#### **1 A radio quiet zone in WA**

The Australian Government, through the Australian Communications and Media Authority (ACMA), has implemented a “radio astronomy park” in Western Australia (WA), which will cater for new radio astronomy facilities such as the Square Kilometre Array (SKA) in a very radio quiet environment. A key component of this radio astronomy park is the establishment of a RQZ. The planning and implementation reports for this RQZ in WA are of direct relevance to Question ITU-R 242/7 on existing radio quiet zones, and are attached as annexes to this document. This material may be useful in developing a Report in response to Question ITU-R 242/7.

Appendix 1 contains the planning and implementation report from ACMA on the RQZ in WA. Please note that the location of the RQZ has changed since the report was prepared. The location of the RQZ is a site near Boolardy Station, WA; its central coordinates are latitude 26° 42’ 15” South, longitude 116° 39’ 32” East.

Appendix 2 is a report about managing RFI from mining operations near the RQZ in WA. It includes an attachment describing the procedures for assessment of proposed mining activities which could produce RFI. This attachment has two appendices, one listing the required information for the assessment process, and the other providing very basic radio power calculations and propagation models.

Appendix 3 is a report on RFI standards to be met by equipment installed in the RQZ as part of the development of the radiotelescopes and supporting infrastructure. This work is still under development.

## Appendix 1 to Annex 6

### A radio quiet zone for Western Australia

#### Introduction

This Report quantifies the implementation of a RQZ around a site in Mileura Station<sup>16</sup> in Western Australia. This site has been identified as an area of excellent radio-quietness, and is the proposed site for a “radio astronomy park”. The CSIRO has indicated that, should an RQZ be implemented in WA, it will place significant facilities there in the coming years.

The CSIRO is also bidding to host the SKA an international undertaking to build the world’s premier radio telescope. The Australian Government supports this bid, and the creation of an RQZ, with appropriate regulatory support from ACMA and the WA Government, will strengthen Australia’s bid.

#### Background

##### What is a radio quiet zone?

An RQZ is an area within which levels of radiation from stations are restricted in some way, with a view to minimizing the strength of electromagnetic energy within the zone.

RQZs exist in other parts of the world. The United States of America established the National Radio Quiet Zone (NRQZ) in 1958, to minimize possible harmful interference to the National Radio Astronomy Observatory (NRAO) in Green Bank, West Virginia, and the radio receiving facilities for the United States Navy in Sugar Grove, West Virginia. Rectangular in shape, the NRQZ has an area of approximately 13,000 square miles.

An RQZ also exists around the Arecibo Observatory in Puerto Rico. Licensees must make reasonable efforts to protect the Observatory from interference.

##### Radio astronomy – General

Many of the issues faced in establishing an RQZ also apply to existing radio astronomy facilities. The choice of remote sites away from sources of degradation has meant that radio astronomy systems have been able to maintain their performance. With the general increase in use of the spectrum, interference to radio astronomy receivers has increased over the years, and radio astronomers have been gradually seeking further regulatory support from ACMA, and internationally through the ITU, to preserve their ability to operate effectively.

ACMA, with the CSIRO’s support, is currently in the final stages of implementing a number of “radio sensitive” zones<sup>17</sup>, within which potential new radiocommunications activity triggers a process whereby the CSIRO can seek to have their needs considered when new radiocommunications transmitters are planned.

##### The square kilometre array

The Square Kilometre Array (SKA) is a radio telescope with a collecting area of one square kilometre. The design criteria call for a large central collecting array and additional receivers spread over continental distances. The SKA is planned to operate over a frequency range of around 100 MHz to 25 GHz and have 50 to 100 times the sensitivity of the best radio astronomy receivers currently in use. The broad mission of the SKA is to address fundamental questions in research on

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<sup>16</sup> The centre of the proposed RQZ is located at 117.5111 E, 26.6204 S.

<sup>17</sup> See [http://www.acma.gov.au/ACMAINTER.65690:STANDARD:842221617:pc=PC\\_100102](http://www.acma.gov.au/ACMAINTER.65690:STANDARD:842221617:pc=PC_100102) for details.

the origin and evolution of the universe. Groups in several countries around the world have put in proposals to host the SKA: Australia has proposed a site near Mileura Station, in remote Western Australia. At present, the SKA steering committee plans to either rank the sites or choose one by early 2006.

#### Protection of the SKA from terrestrial radio interference

The CSIRO Australia Telescope National Facility (ATNF), in its role as coordinating organisation for the Australian SKA effort, has been exploring ways of protecting the central core of an SKA from radio interference from terrestrial sources. ACMA has been engaged with advocates of an Australian SKA since the inception of the project, exploring ways that ACMA could assist in managing the potential interference issues that would come with an SKA sited in Australia. Early in this process, ACMA injected the realisation that the creation of an RQZ was about managing land use, as well as spectrum use. The SKA group subsequently engaged State and Local government bodies on land use issues, and continues to work with ACMA on spectrum issues.

#### **Dimensioning of the RQZ**

Radio astronomy receiver interference thresholds, technical parameters of the potential interferer and the facilities, and the application of a suitable propagation model may be used to determine appropriate dimensioning for the RQZ.

The natural balance in dimensioning the RQZ is between the zone being of sufficient size to achieve the objective of realistic protection of the site, and the zone being not so large as to cause too great an impost on the community through denial of radiocommunications services. Radio astronomers may need to use interference mitigation techniques where interference cannot be avoided.

#### **Notification zone methodology**

The following methodology is used to determine the size of a notification zone around a radio astronomy facility.

- Establish system models for potentially interfering apparatus licensed transmitters, i.e. service types and quantities, antenna heights, bandwidths and e.i.r.p.s.
- Establish levels of signals emanating from existing terrestrial transmitters in the area and use these parameters as a basis for modelling potential interferers.
- Establish technical characteristics for radio astronomy receivers, i.e. antenna (gain, beam pattern, effective height), likely bandwidths and receiver performance parameters.
- Calculate the required propagation loss so that the level of a potentially interfering signal falls below that which could degrade a radio astronomy receiver beyond an agreed value.
- Apply an appropriate path-loss model to determine the corresponding minimum separation distances for the various bands and received levels.
- Determine the most appropriate dimensioning of the RQZ reflecting the findings of the analysis above.

Analyse the potential number of affected frequency assignment applications within the zones.

#### **Terrestrial transmitters – Technical characteristics**

Reasonable assumptions on the technical characteristics of likely terrestrial transmitters can be made by examining the existing frequency assignments within the 100 MHz to 25 GHz range. These assumptions may be refined by considering factors such as the locations of these assignments relative to any of the listed radio astronomy facilities.

Following is a summary of the relevant technical parameters of the most likely interferer, based on power spectral density and the number of existing assignments, for a series of bands in the range 100 MHz to 25 GHz. Band divisions have been created so that transmitters with similar technical parameters are grouped together.

TABLE 24  
Indicative interferer parameters

Band (MHz)	e.i.r.p. (dBm/Hz)	Service	Antenna height (m)
100-230	20.1	FM and TV broadcasting	50
230-400	9.2	Land mobile	10 <sup>18</sup>
400-470	7.1	Land mobile	30
470-520	7.1	Land mobile	30
520-820	25	TV broadcasting	50
820-890	10.7	P-P	30
890-1 000	13.8	P-P	30
1 000-2 300	6.8	P-P	30
2 300-6 000	19.7	Earth station <sup>19</sup>	10
6 000-10 000	7.9	P-P	30
10 000-25 000	-5.2	P-P	20

### Radio astronomy receivers – Technical characteristics

#### System model – Radio astronomy receiver

##### *Radio astronomy receiver antenna*

An effective antenna height of 15 metres has been provided by the CSIRO.

For the assessment of potential interference to radio astronomy from transmitters used for terrestrial radiocommunications a value of -15 dBi is assumed for the gain of the radio astronomy antenna in the direction of the horizon.

##### *Receiver degradation levels*

CSIRO has recommended that the levels provided in Table 3 of Recommendation ITU-R RA.769-1 should be used to model the threshold interference levels of radio astronomy receiving systems within the RQZ.

<sup>18</sup> Typical defence nomadic land mobile operations would have an antenna height of 10 metres or less.

<sup>19</sup> Only one licensed.

Combining the limits given in Table 3 of Recommendation ITU-R RA.769-1 with the information above, and converting to power spectral density<sup>20</sup> (dBm/Hz) yields the interference threshold values shown in Table 25:

TABLE 25  
Interference threshold levels dBm/Hz

Frequency (MHz)	Interference threshold (dBm/Hz)
100	–214
230	–222
400	–224
470	–224
520	–224
820	–228
890	–228
1 000	–230
2 300	–232
6 000	–232
10 000	–236

#### Propagation model

Because of the sensitivity of radio astronomy receivers, interfering signals are likely to originate from well beyond the radio horizon. Long-term interference will propagate through the modes of diffraction and tropospheric scatter. Short-term interference may propagate through the mechanisms of surface ducting, elevated layer reflection/refraction and hydrometeor scatter. There are a number of propagation models that can be used in this scenario to appropriately determine transmission path loss. Some commonly used models are:

- Recommendation ITU-R P.526 is a general method for diffraction over one or more obstacles. This model does not account for more than three diffraction obstacles.
- Recommendation ITU-R P.452-9 is a combination model which is particularly adapted to the various propagation mechanisms giving rise to over-the-horizon situations. Amongst other things, this model accounts for diffraction, hydrometeor scatter and tropospheric scatter. This model uses the general method described in Recommendation ITU-R P.526 for diffraction. The model is valid for frequencies of 700 MHz to 30 GHz, and as such, is not a valid propagation model for the lower frequencies involved (100 to 700 MHz).

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<sup>20</sup> A power spectral density threshold in dBm/Hz may be determined by adding 30 dB (Watts to milliwatts) and subtracting an effective area value ( $20\log(f_{\text{MHz}}) - 38.6$ ) dB.



- DETVAG-90/FOA ... Developed by the Swedish Defence Research Establishment, this model includes options to use several diffraction models, including Vogler's method for the calculation of multiple knife edge diffraction<sup>21</sup> (which can handle large numbers of diffraction edges). This model is suitable for frequencies between 10 kHz and 10 GHz.

### *Diffraction*

A survey of path profiles for an array of points around the centre of the RQZ shows the number of diffraction obstacles encountered:

TABLE 26  
Diffraction obstacles around the RQZ core

Direction from RQZ centre	Lat. Long (degrees)	Approx distance (km)	Number of obstacles
N	–25.6204, 117.5111	110	12
S	–27.6204, 117.5111	110	4
E	–26.6204, 118.5111	100	9
W	–26.6204, 116.5111	100	7
NE	–25.6204, 118.5111	150	9
NW	–25.6204, 116.5111	150	7
SE	–27.6204, 118.5111	150	10
SW	–27.6204, 116.5111	150	9

The Recommendation ITU-R P.526 model accounts for up to three diffractions. This model is therefore not suitable for this application.

The Recommendation ITU-R P.452-9 model uses the Recommendation ITU-R P.526 model for diffraction and is therefore also not suitable for this application. The effect of anomalous modes of propagation as per Recommendation ITU-R P.452-9 will not be included in the determination of the RQZ.

Use of DETGAG-90/FOA (with Vogler's method for diffraction) appears to be suitable for the frequency range 100 MHz-10 GHz, and is used in the analysis below.

### **Determining the RQZ size**

The size of zones of potential interference can be determined using the interferer parameters of Table 24 and the threshold levels given in Table 25, and applying the DETVAG-90/FOA propagation model<sup>22</sup>. A time percentage of 10% shall be used for radio astronomy facilities<sup>23</sup>.

<sup>21</sup> Extensive comparison tests have been conducted with the most commonly used diffraction models, using the database of some 20,000 measurements and terrain path profile information supplied by the UK Radiocommunications Agency. The Vogler method produces the most accurate results of the diffraction methods available in the DETVAG-90/FOA model.

<sup>22</sup> The terrain data used is the GEODATA 9 Second DEM, Version 2. It is a gridded digital elevation model computed from topographic information including point elevation data, elevation contours, stream lines and cliff lines. The grid spacing is 9 seconds in longitude and latitude (approximately 250 metres).

<sup>23</sup> As per Recommendation ITU-R RA.1031 and as agreed with CSIRO.

## Results

Table 27 lists the radii of the restricted and coordination zones for various frequency bands:

TABLE 27  
RQZ Zone Radii

Band (MHz)	RQZ restricted zone radius (km)	RQZ coordination zone radius (km)
100-230	150	260
230-400	100	180
400-520	100	165
520-820	100	190 <sup>24</sup>
820-890	100	145
890-1 000	100	145
1 000-2 300	100	140
2 300-6 000	100	120
6 000-10 000	100	Not required
10 000-25 000	100	Not required

Appendix 3 provides map images of these zones.

### Impact of zones

To assess the impact of the zones on future frequency assignment activity it is useful to examine recent apparatus licensing activity to estimate future activity. The tables below show the number of frequency assignments approved within each of the zones between the years 2000 and 2004.

Table 28 below shows the total number of existing services within the zones listed, and the number of new frequency assignments over the years 2000 to 2005.

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<sup>24</sup> Licensing in this band is fully controlled by ACMA.

TABLE 28  
Zone survey

Band (MHz)	Radius of zone (km)	Assignments within zone	New assignments by year					
			2000	2001	2002	2003	2004	2005
100-230	260	220	2	14	4	18	9	2
230-400	180	0	0	0	0	0	0	0
400-520	165	71	8	3	0	2	6	2
520-820 <sup>25</sup>	190	48	3	12	0	12	0	0
820-890	145	9	1	0	0	0	0	2
890-1 000	145	5	0	0	0	0	0	2
1 000-2 300	140	61	0	1	7	4	0	0
2 300-6 000	120	1	0	0	0	0	0	0
6 000-10 000	100	0	0	0	0	0	0	0
10 000-25 000	100	2	0	0	0	0	0	0

The frequency assignments currently within each zone are listed in Appendix 3.

### Conclusion

This planning Report sets out the rationale behind the dimensioning of the proposed RQZ and makes recommendations on the radii of the zones for various frequency bands.

A survey of frequency assignments within the zones, and figures on assignment trends in the last six years shows a low level of activity in the zones. The RQZ would therefore have a low impost on the radiocommunications community.

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<sup>25</sup> Analogue television channels contain three assignments per channel. The 48 assignments in this row correspond to 16 television channels.

## Appendix 2 to Annex 6

### Band usage survey

The following tables list the types of frequency assignments currently using the frequency bands indicated. For frequencies between 100 and 1 200 MHz a radius of 500 km around the RQZ core has been used. For frequencies between 1 200 MHz and 25 GHz a radius of 300 km around the RQZ core has been used.

TABLE 29  
100 to 230 MHz

Assignment type	Qty	e.i.r.p. (W)	BW (kHz)	(dBm/Hz)
Aeronautical	63	83	6	11.4
Amateur repeater	8	120	16	8.8
Ambulatory	35	41	10	6.1
FM Radio broadcast	123	984	200	6.9
TV Broadcast (picture)	38	262 295	6250	16.2
TV Broadcast (1 <sup>st</sup> sound carrier)	38	13 115	130	20.1
TV Broadcast (digital)	2	205	6 700	−15.1
Land mobile	1 001	83	10	9.2
Major coast A	6	83	16	7.1
Narrowcasting	3	82	200	−3.9
Paging system (exterior)	23	500	16	14.9
Paging system (interior)	9	8.3	16	−2.9
Point-to-multipoint	34	8.3	7	0.7
P-P	425	372	16	13.7
Radiodetermination	7	50	10	7.0
Limited coast assigned system	4	83	10	9.2

TABLE 30  
230 to 400 MHz

Assignment type	Qty	e.i.r.p. (W)	BW (kHz)	(dBm/Hz)
Land mobile	Nil registered <sup>26</sup>	83	10	9.2

<sup>26</sup> There are no assignments registered in this band, but this band is used Australia-wide by the Department of Defence, and it is reasonable to assume the use of land mobile systems.

TABLE 31  
400 to 470 MHz

Assignment type	Qty	e.i.r.p. (W)	BW (kHz)	(dBm/Hz)
Amateur repeater	4	120	16	8.8
Ambulatory	25	8.3	16	−2.9
Fixed Earth	1	5	25	−7.0
Land mobile	244	83	16	7.1
Paging system (exterior)	1	8.3	16	−2.9
Paging system (interior)	9	8.3	16	−2.9
Point-to-multipoint	90	8.3	16	−2.9
Point-to-multipoint – Land mobile	6	8.3	16	−2.9
P-P	592	63	16	5.9

TABLE 32  
470 to 520 MHz

Assignment type	Qty	e.i.r.p. (W)	BW (kHz)	(dBm/Hz)
Ambulatory	44	83	16	7.1
CBRS Repeater	80	21	16	1.2
Land mobile	565	83	16	7.1
Point-to-multipoint	45	8.3	16	−2.9
Point-to-multipoint – Land mobile	6	8.3	16	−2.9
P-P	149	20	16	1.0

TABLE 33  
520 to 820 MHz

Assignment type	Qty	e.i.r.p. (W)	BW (kHz)	(dBm/Hz)
Digital TV	2	245 901	6 700	15.6
Analogue TV – Vision carrier	129	819 672	6 250	21.2
Analogue TV – First sound carrier	129	40 984	130	25.0



TABLE 34  
820 to 890 MHz

Assignment type	Qty	e.i.r.p. (W)	BW (kHz)	(dBm/Hz)
800 MHz lower band	17	47	1 440	−14.8
Point-to-multipoint	49	8.3	10	−0.8
P-P	58	186	16	10.7
Land mobile	1	1	10	−10
800 MHz upper band	87	54	7 700	−21.5

TABLE 35  
890 to 1 000 MHz

Assignment type	Qty	e.i.r.p. (W)	BW (kHz)	(dBm/Hz)
Land mobile	1	1	10	−10
Point-to-multipoint	51	8.3	16	−2.9
P-P	49	380	16	13.8

TABLE 36  
1 000 to 2 300 MHz

Assignment type	Qty	e.i.r.p. (W)	BW (kHz)	(dBm/Hz)
Radiodetermination	10	1 200	500	3.8
Point-to-multipoint	64	50	1 750	−15.4
P-P	144	8 357	1 750	6.8

TABLE 37  
2.3 to 6 GHz

Assignment type	Qty	e.i.r.p. (W)	BW (kHz)	(dBm/Hz)
Earth-to-satellite	1	14 802 385	159 000	19.7

TABLE 38  
6 to 10 GHz

Assignment type	Qty	e.i.r.p. (W)	BW (kHz)	(dBm/Hz)
P-P	98	46 774	7 500	7.9
Earth-to-satellite	1	38 904	2 000	12.9

TABLE 39  
10 to 25 GHz

Assignment type	Qty	e.i.r.p. (W)	BW (kHz)	(dBm/Hz)
P-P	14	1 205	4 000	−5.2

### Appendix 3 to Annex 6

#### Map images of zones

FIGURE 45  
Zone for 100-230 MHz (circle radius: 260 km)

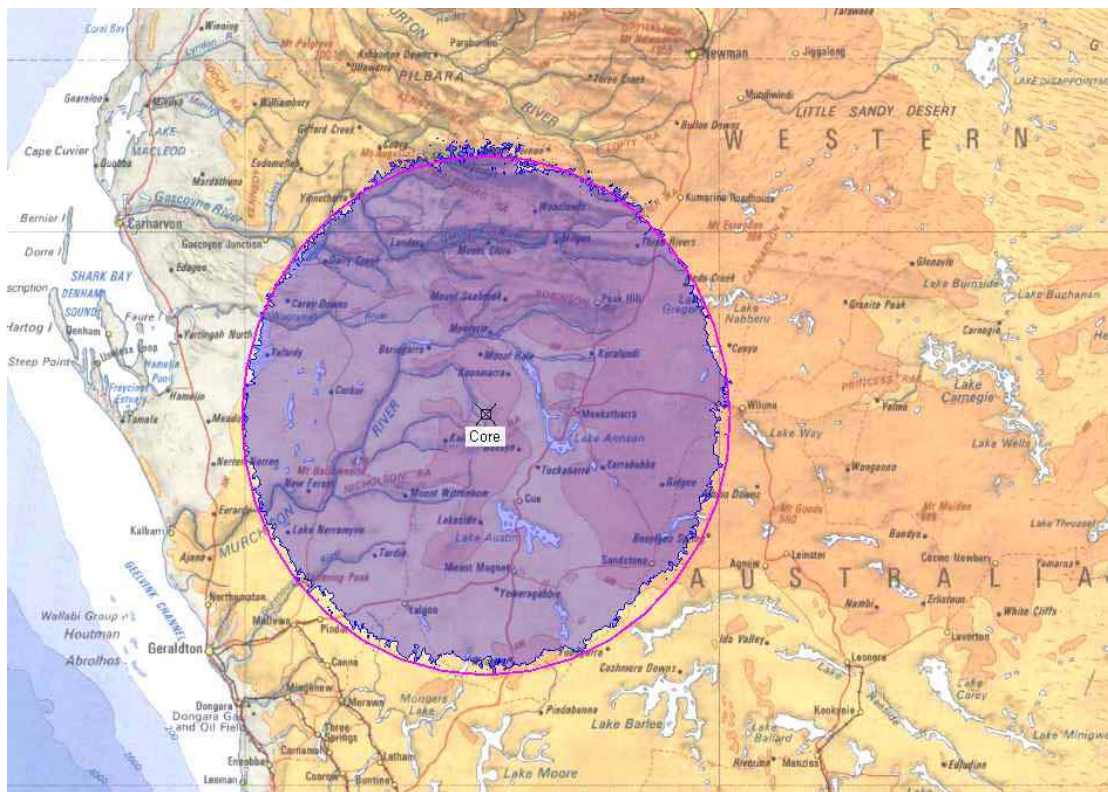




FIGURE 46

Zone for 230-400 MHz (circle radius: 180 km)

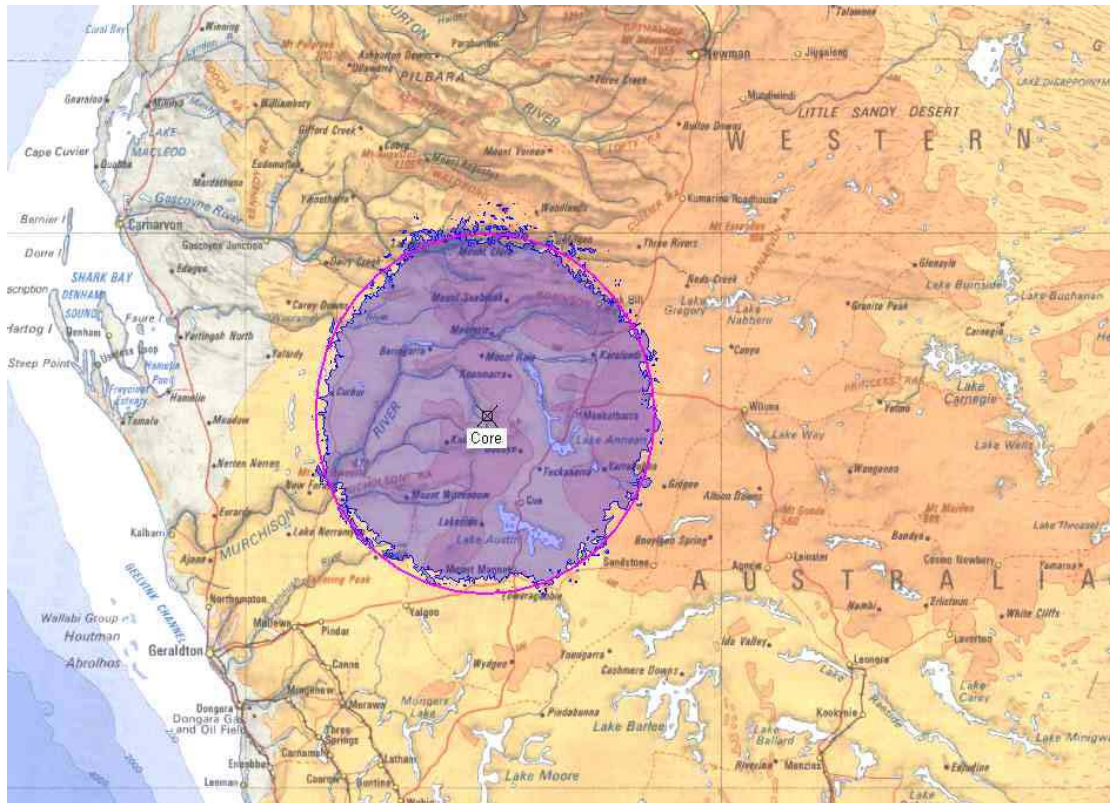


FIGURE 47

Zone for 400-520 MHz (circle radius: 165 km)

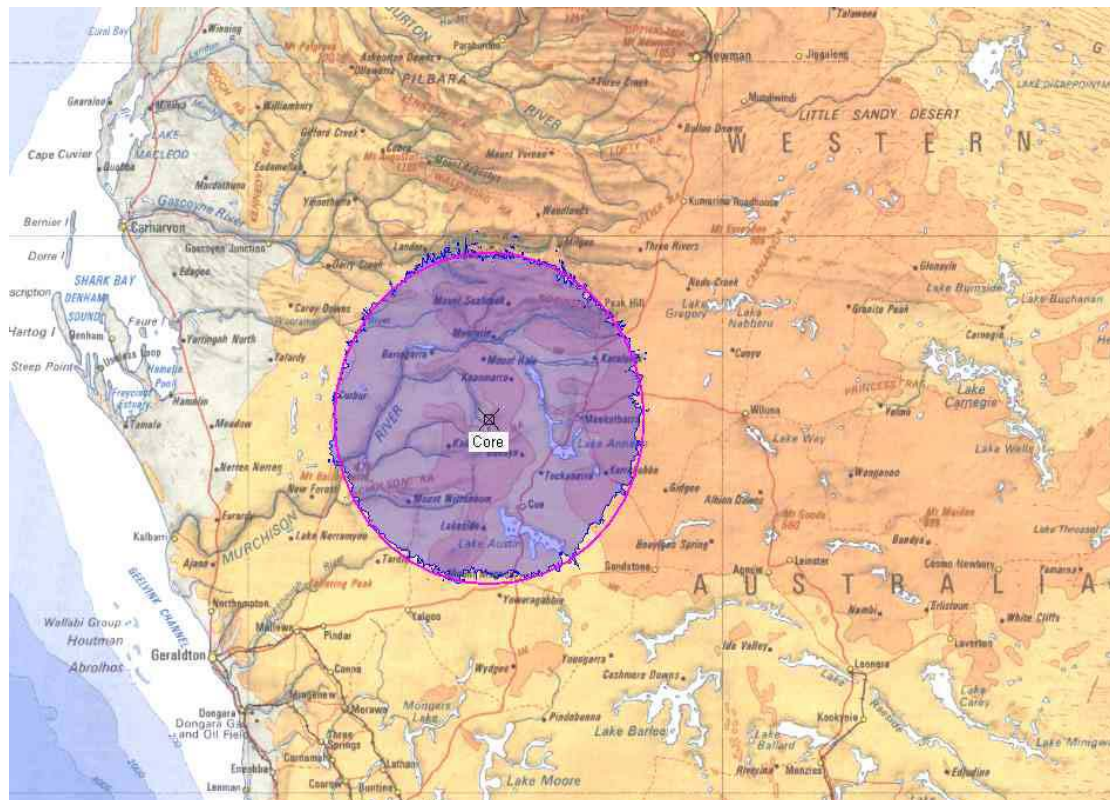




FIGURE 48

Zone for 520-820 MHz (circle radius: 190 km)

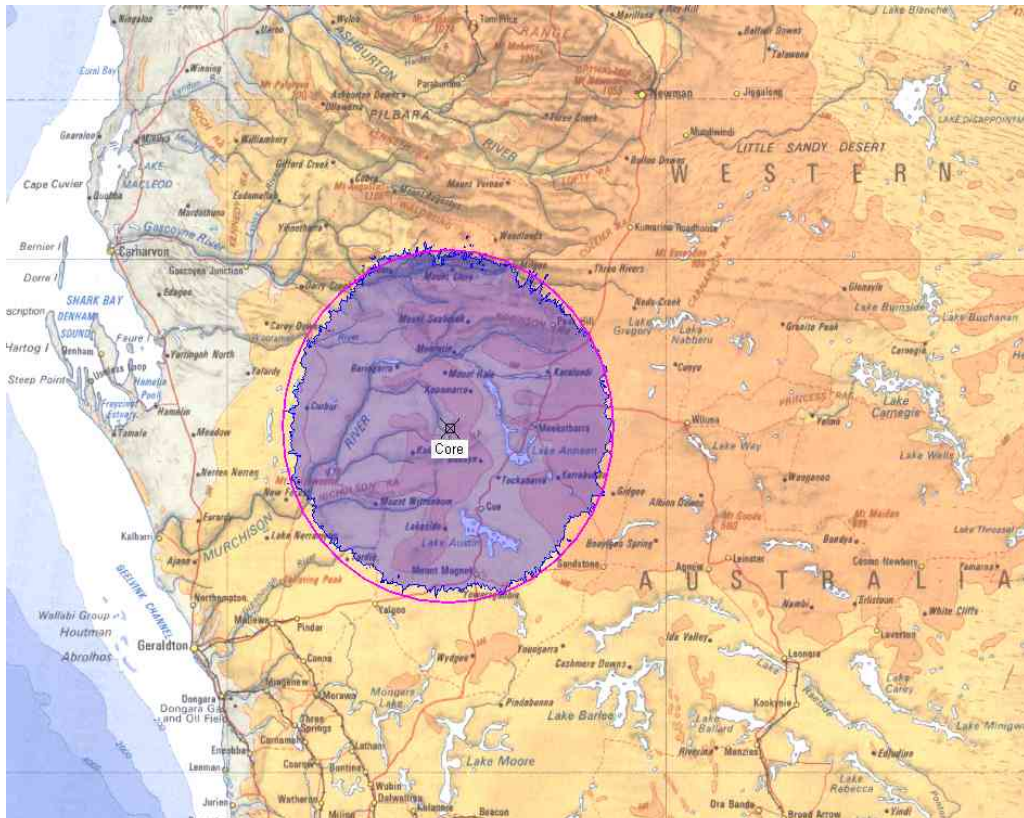


FIGURE 49

Zone for 820-890 MHz (circle radius: 145 km)

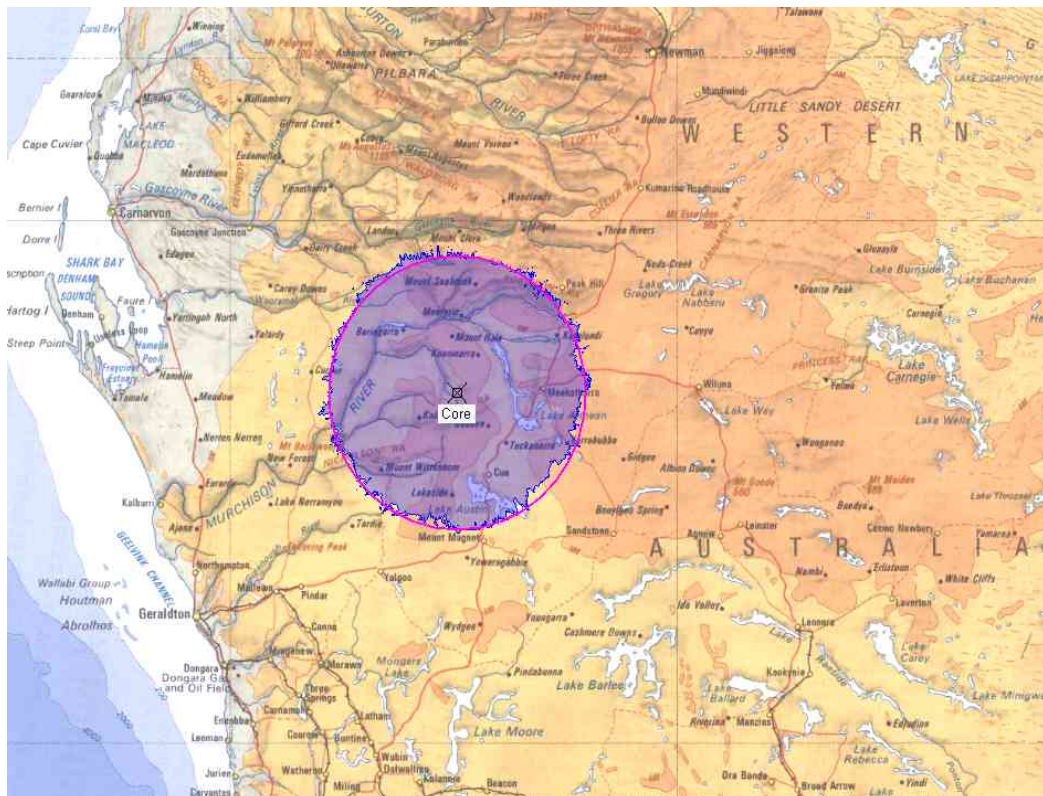




FIGURE 50

Zone for 890-1 000 MHz (circle radius: 145 km)

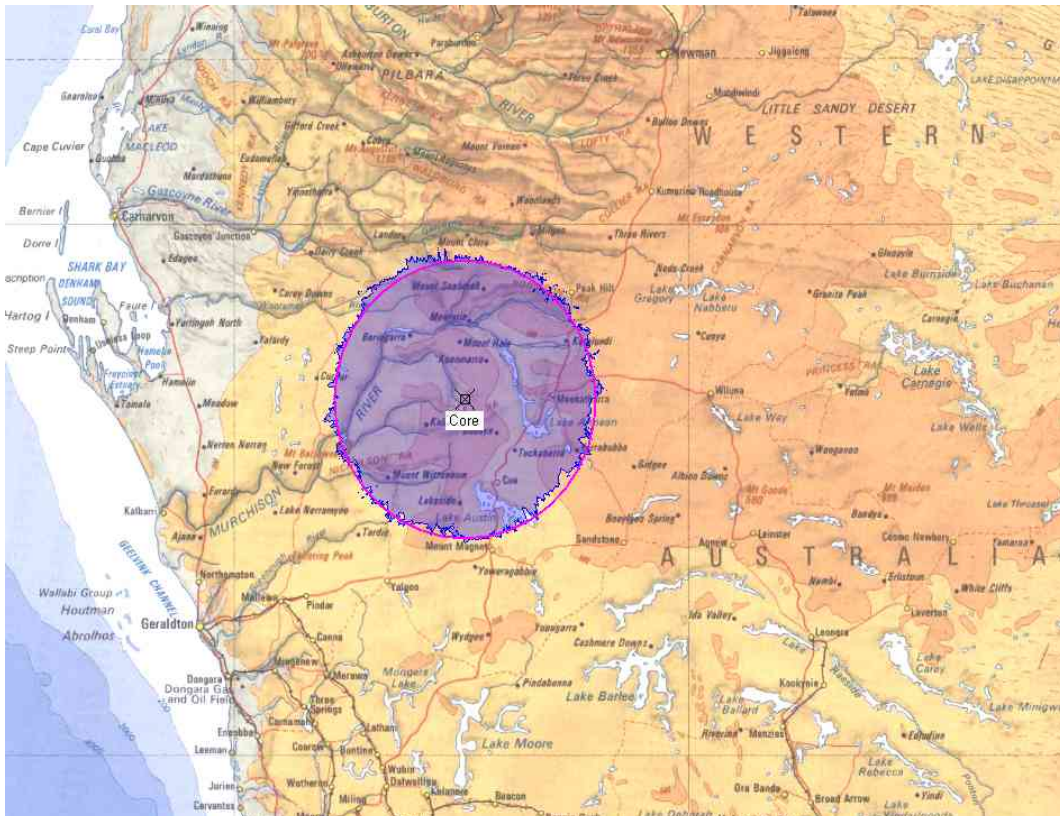


FIGURE 51

Zone for 1 000-2 300 MHz (circle radius: 140 km)

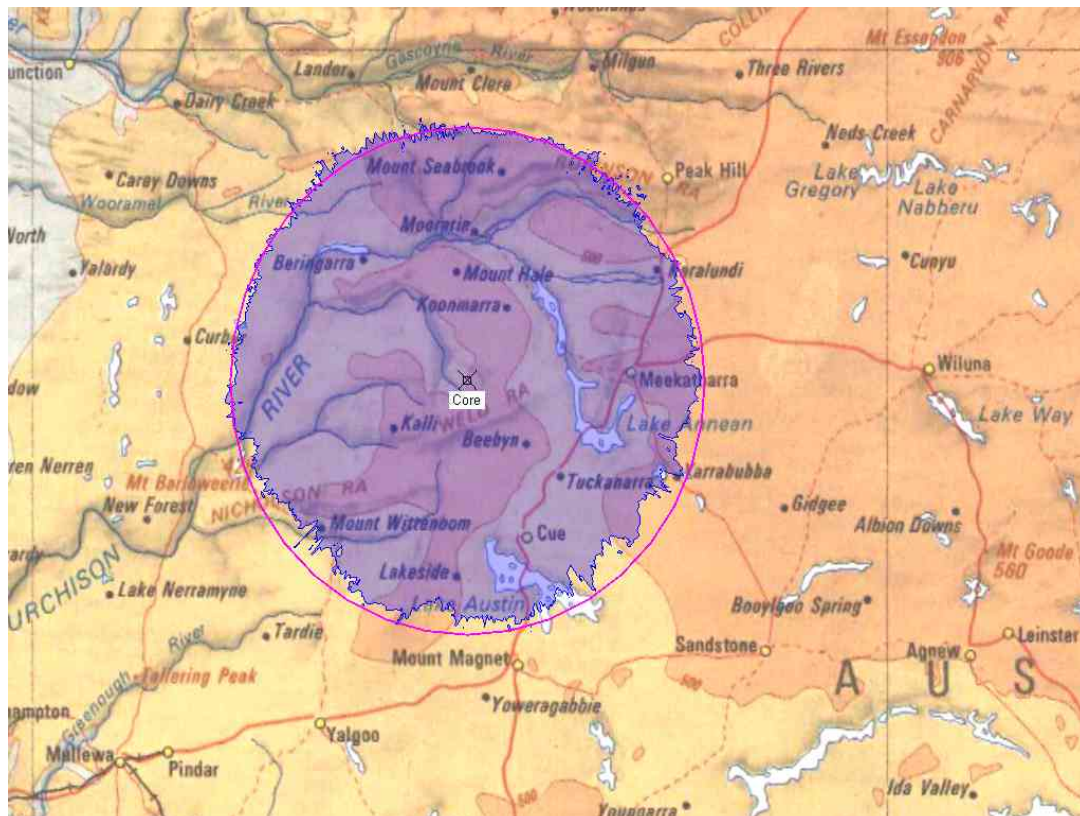




FIGURE 52

Zone for 2 300-6 000 MHz (circle radius: 120 km)

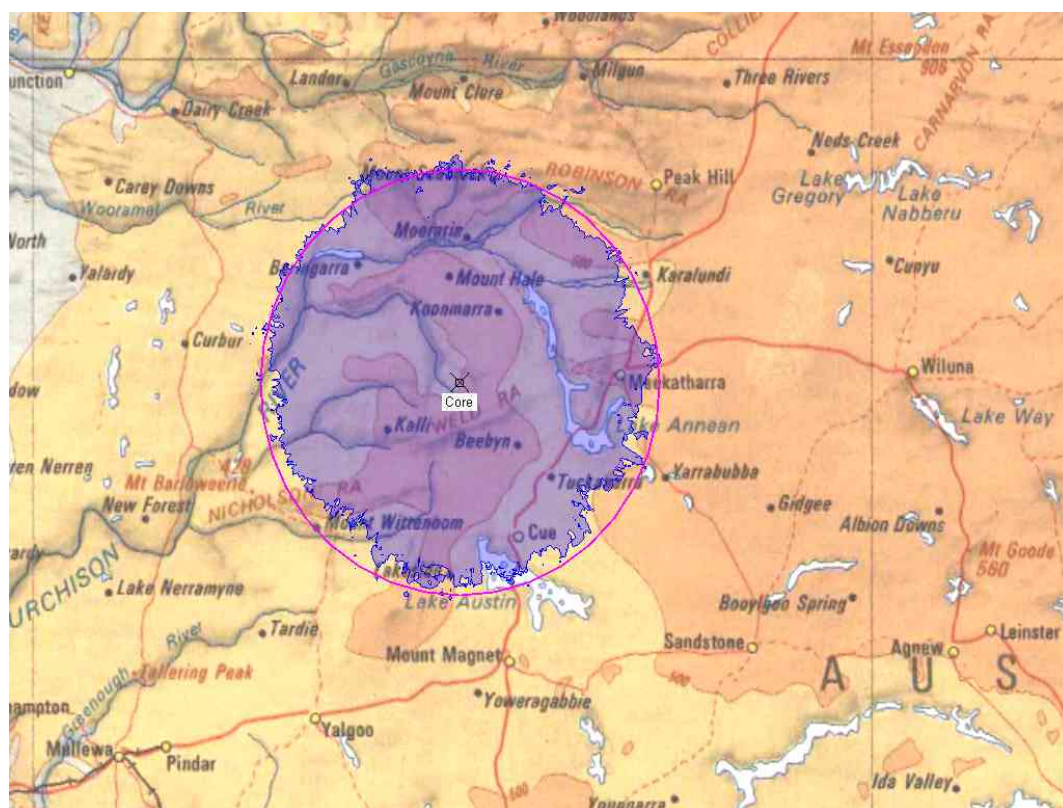


FIGURE 53

Zone for 6-10 GHz (circle radius: 90 km)

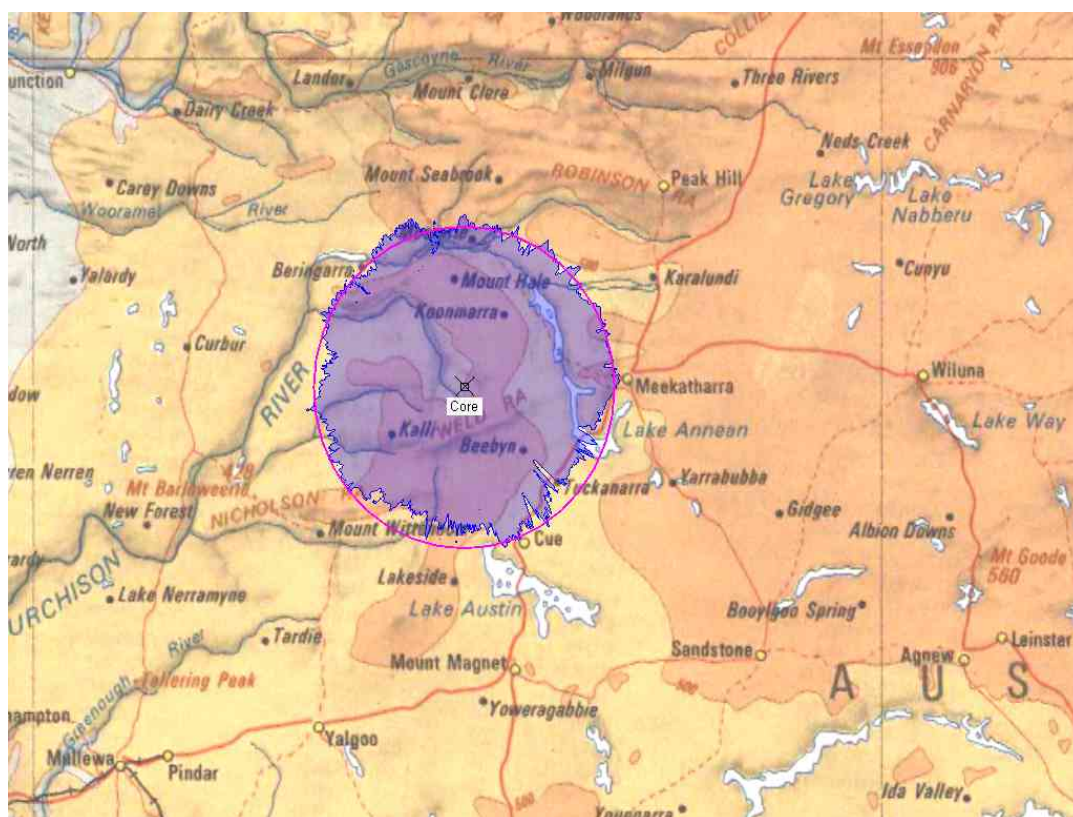
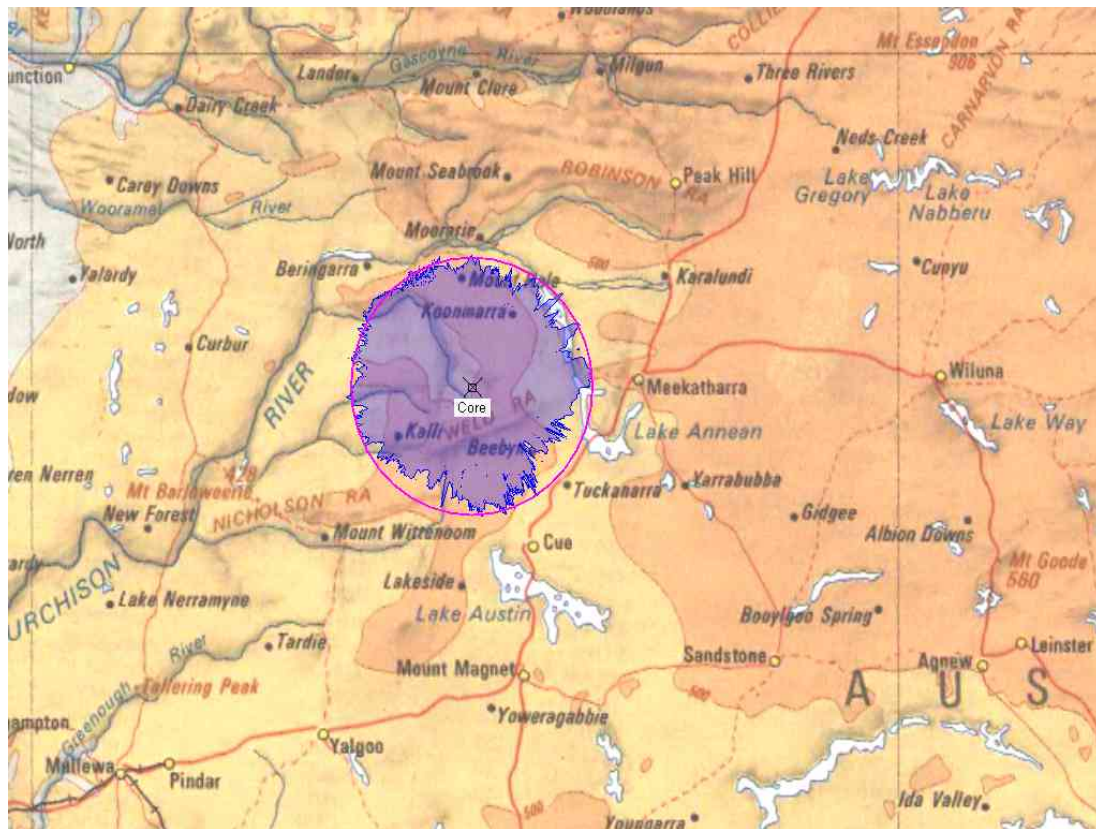


FIGURE 54

Zone for 10-25 GHz (circle radius: 80 km)



## Appendix 4 to Annex 6

### Frequency assignments within the RQZ

- 100 MHz to 230 MHz. This band is used predominantly by the land mobile service. An average of eight new frequency assignments per annum has been made in this zone.
- 230 MHz to 400 MHz. There are no assignments registered in this zone; however this band is used Australia wide by the Department of Defence.
- 400 MHz to 520 MHz. In the 400 to 520 MHz band, the most common assignment type within this zone is to “point-to-point” links. P-P links typically use directional antennas, and the small number of new services may be able to be co-ordinated within this zone.
- 520 MHz to 820 MHz. This band is used for television broadcasting. During the last 6 years 9 analogue television channels have been assigned within 190 km of the central site.
- 820 MHz to 890 MHz. This band is used for primarily for mobile phones. There have been few new assignments in this band in the last six years, and with the low population of the area this is expected to be the case in the future.

- 890 MHz to 1 000 MHz. This band is used primarily for mobile phones. There have been few new assignments in this band in the last six years, and with the low population of the area this is expected to be the case in the future.
- 1 000 MHz to 2 300 MHz. The assignments in this zone are predominantly to “point-to-point” and “point-to-multipoint” licences. P-P services use directional antennas, and the small number of new services may be able to be coordinated within this zone. Only two point-to-multipoint services have been licensed in the last six years. An average of two new frequency assignments per annum has been made in this zone.
- 2 300 MHz to 6 000 MHz. There is currently one earth-to-satellite service within this zone.
- 6 000 MHz to 10 000 MHz. There are currently no assignments in this zone.
- 10 000 MHz to 25 000 MHz. There are currently two “point-to-point” services within this zone.

TABLE 40  
100 MHz to 230 MHz

Quantity	Type of service	Notes
93	P-P	
64	Land mobile system	2 surrendered, 1 expired
30	Analogue television (10 stations)	3 (1 television station) not issued
22	FM radio	
7	Aeronautical	
2	Narrowcasting service stations (HPON)	
1	Radiodetermination	
1	Ambulatory system	

TABLE 41  
230 MHz to 400 MHz

Quantity	Type of service	Notes
0		

TABLE 42  
400 MHz to 520 MHz

Quantity	Type of service	Notes
36	P-P	
17	Land mobile system	
11	Point-to-multipoint	
6	CBRS Repeater	UHF CB radio
1	Paging system – interior	

TABLE 43

**520 MHz to 820 MHz**

Quantity	Type of service	Notes
48	Broadcast service	16 stations

TABLE 44

**820 MHz to 890 MHz**

Quantity	Type of service	Notes
4	800 MHz upper band	CDMA mobile phone
2	800 MHz lower band	CDMA mobile phone
1	P-P	

TABLE 45

**890 MHz to 1 000 MHz**

Quantity	Type of service	Notes
2	PMTS Class B	GSM mobile phone
2	ACA assigned	Not issued – replaced by the PMTS assignments
1	P-P	

TABLE 46

**1 000 MHz to 2 300 MHz**

Quantity	Type of service	Notes
42	P-P	
16	Point-to-multipoint	
2	Radiodetermination	
1	Fixed receive	

TABLE 47

**2 300 MHz to 6 000 MHz**

Quantity	Type of service	Notes
1	Fixed Earth	



TABLE 48  
6 000 MHz to 10 000 MHz

Quantity	Type of service	Notes
0		

TABLE 49  
10 000 MHz to 25 000 MHz

Quantity	Type of service	Notes
2	P-P	

### Appendix 5 to Annex 6

#### Notes regarding condition to manage radio-frequency emissions around the future square kilometre array radio-telescope area

Australia is competing internationally to be the country in which the next-generation radio-telescope (the Square Kilometre Array or SKA) will be built, at a capital cost of some \$1.8 billion. Australia has selected the Murchison Radio astronomy Observatory (MRO) site located between Meekatharra, Cue and Yalgoo (See Fig. 55).

The facility will require protection from electro-magnetic interference (referred to as Radio-Frequency Astronomical Interference [RFAI]) caused by electric motors, generators, alternators, radio transmitters, welders and in fact anything that creates or conducts electricity.

In order to protect the operation of the radio telescope, the Government has decided that no mining tenement will be allowed within 30 to 40 km of the core of the facility, and the Department of Industry and Resources (DoIR) is implementing Government's intent.

To locate a suitable site in Western Australia, considerable work was undertaken in the 1990s by the Geological Survey of Western Australia in collaboration with the CSIRO. As a consequence, in order to avoid unnecessarily tying up prospective land, the present areas were selected where the mineral potential was relatively low based on the information available at the time. The core and areas surrounding it are currently (2007) exempt from applications for tenements pursuant to Section 19 of the *Mining Act 1978*. Further from the centre of the MRO out to 80 km is a "Mineral Resource Management Area" (shown in DoIR's Tengraph tenement mapping system as File Notation Area 7681), and all tenements or those parts of tenements that occur within this zone will have a condition imposed by the Minister for Resources stating:

- 1) *Prior to carrying out any on-ground activities, the licensee or lessee developing a plan of activities to ensure that electromagnetic emissions from those activities will not interfere with the radio-quiet requirements of the Murchison Radio astronomy Observatory. The plan shall be submitted to the Australian SKA Coordination Committee's 'Coordinator for Land Management Issues' at the Department of Industry and Resources (DoIR) for approval by the Director-General of DoIR.*



- 2) *The approved plan to be included with any program of works or mining proposal submitted to the DoIR for approval under the Mining Act.*

## **1 The facility and tenements**

The proposed radio telescope will be some 100 times more sensitive than any currently existing radio-telescope and will enable astronomers to look back in time towards when the universe was created in the “Big Bang”.

The design of the radio telescope is still being researched, and so its eventual design and appearance is currently evolving. It is likely to consist of a large number of small structures in groups covering perhaps a hectare at any individual site and while most of these groups will be concentrated in the proposed MRO they will ultimately be spread or arrayed across Australia and into New Zealand. The total area for radio-wave collection is planned to be one square kilometre. The receivers will be linked with a supercomputer, probably to be sited in Geraldton, that will integrate all the radio signals from all the receivers and process them into usable information for astronomers to interpret. This is leading-edge technology, and the facility will be using technology that is still to be developed.

As humankind develops, our activities create increasing amounts of more powerful RFAI emissions. This interference is making it much harder to site radio telescopes. The Murchison is amongst the last regions in the World where the interference levels are still low, and therefore it is a responsible position for the State to adopt to support international research by designating a site that it will protect from future interference. However, protection of this site will impose some restrictions on other users of the area by requiring them to limit or to not create radio emissions in accordance with management prescriptions. The Western Australian Government has accepted that these restrictions are an acceptable compromise in order to have the SKA radio telescope built in this State. Considerable studies have led to the identification of the site as being one that will impose minimum restrictions on the minimum number of people.

Ultimately legislation will be passed to protect the MRO area from activities that would interfere with the SKA.

The core of the MRO will be an area of about 30 km radius. Tenements will be prohibited within this zone while the MRO is operating. For the immediate future the Section 19 Exemption that is currently in place will prohibit any applications for tenements within that and a larger area. Surrounding the core area will be the Mineral Resource Management Area within which the Minister for Resources will impose conditions on tenements in order to minimize mineral resources activities impacting on the MRO operations.

Although construction of the actual SKA will not commence until after 2011, a large amount of scientific investigation, preparatory test-work, and construction and operation of precursor receivers and equipment will be required to assist in the eventual design of the MRO. These projects, including the Australian SKA Pathfinder Project, will develop radio telescopes that are major research developments in their own right. Experiments commenced in 2006 will go on into the future and the equipment will require similar protection from RFAI as the eventual SKA project will need.

## **2 Implications of mineral resource activities for the radio telescope operations**

Any stray radio waves that radiate from equipment within the vicinity of the radio telescope receivers may cause RFIA with the signals from outer space. These radio waves may be designed (such as mobile radios or phones, radio base stations or other scientific equipment) or accidental (from electric motors or generators, arc-welders, electronic equipment).

The purpose of the mining act conditions is to ensure that if any emissions are generated, they are firstly known by the operators of the radio telescope and, secondly, are minimized or restricted in time or location. The operation of the radio telescope does not necessarily require the elimination of all radio waves, but to create an area that is ‘radio quiet’.

### **Exploration activities**

These are usually of relatively short duration, though the activities could occur over a broad area. It will be a requirement that prior to accessing the area, the explorationist will contact the appropriate people within DoIR and discuss the activities and likely management required for the duration of the exploration. Exploration programs normally proceed in a series of stages. Early stages, using hand-held or small-scale equipment, are less likely to emit unacceptable levels of stray RFAI than later stages that are likely to use heavy drilling rigs and high-powered alternators for camps.

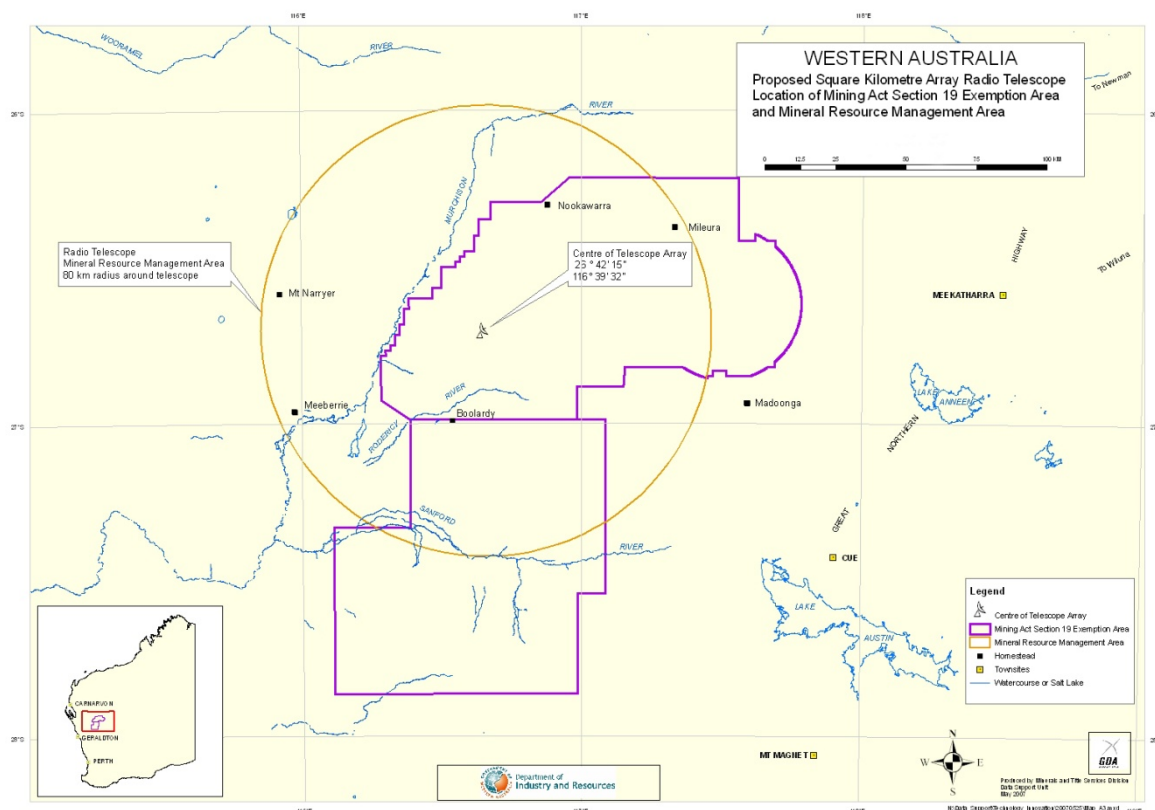
Details of abatement methods are likely to evolve with time as operations proceed and experience is gained by both the explorationists and the MRO management team. Amelioration methods could involve restricting the use of types of equipment to certain times or periods or using equipment behind shields, inside Faraday Cages (such as, in worst-case scenarios, inside steel mesh cages or steel sheds) or by other means to reduce emissions. It may effectively prohibit the use of some types of equipment that emit energetic RFAI.

An unknown factor (at least initially) will be the effect of emissions from the use of some active geophysical equipment. For example, EM equipment that is designed to generate strong fields may have to be analysed to determine if that item of equipment will create major difficulties for the MRO. It will be important for users of this equipment, whether airborne or ground-based, to work with the managers of the MRO in order to assess the likely effects and minimize impacts on the SKA project or related operations.

### **Mining activities**

Compliance with the tenement condition will require early consultation with DoIR and thence potentially with the CSIRO to ensure the design and layout of any minesite activities, especially those involving radio communications, will not interfere with the operation of the radio telescope. Design and erection of buildings and equipment at any minesite that may be located within the Mineral Resource Management Area is likely to have a fundamental effect on the emission of RFAI from the mining plant and equipment. While it may be possible to retro-actively change plant and equipment after it is installed and operating, early attention to design could reduce impacts and the costs of essential amelioration activities. Although the CSIRO can provide advice on RFAI matters, there are also consultant electronic consultants who are able to undertake designs or provide detailed advice at an early stage to meet these requirements.

FIGURE 55

**Map of Murchison radio astronomy observatory area**

## Attachment 1 (to Appendix 5 to Annex 6)

### Guidelines for assessment of proposed work within the MRO file notification area

#### Introduction

The document “*Notes regarding condition to manage radio-frequency emissions around the future Square Kilometre Array Radio-Telescope Area*” describes a procedure for protecting the Murchison Radio astronomy Observatory (MRO) from electromagnetic interference. In particular, it specifies a Mineral Resource Management Area extending 80 km from the centre of the MRO. The licensee or lessee of a tenement (or part of a tenement) within this area must submit a plan of activities to the Department of Industry and Resources (DoIR) for approval by the Director-General of DoIR. This plan must demonstrate that electromagnetic emissions from the activities will not interfere with the radio-quiet requirements of the MRO. Approval of the Activity Plan will be a necessary prerequisite to filing a program of works or mining proposal with DoIR under the Mining Act.

This document provides guidelines for the evaluation of the Activity Plan by the Australian SKA Coordination Committee “Coordinator for Land Management Issues” at DoIR. It describes and interprets requirements of radio astronomy protection as defined by national regulation and international standards. It also specifies essential elements to be included in the Activity Plan to

enable adequate assessment against the radio astronomy requirements. It also provides a consultation procedure with MRO management.

### **Radio astronomy requirements**

The limits for electromagnetic emissions at the MRO are given, for example, in Radiocommunications Assignment and Licensing Instruction (RALI) MS 32, “Coordination of Apparatus Licensed Services within the Mid West Radio Quiet Zone” issued by the Australian Communications and Media Authority (AMCA). Table 1 of RALI MS 32 provides threshold values for received power spectral density, by frequency range, at the centre of the MRO. It must be noted that some wide-band noise sources may cover more than one of the frequency ranges in Table 40 and should be evaluated accordingly.

The calculation of received power spectral density is also given in RALI MS 32. This requires information about the transmission power, frequency and bandwidth of the radio source and the gain of the antenna. In the case of purposeful radiocommunication transmitters, the power, frequency, bandwidth and antenna characteristics should be well known and described in the Activity Plan. However, for non-intentional radiators (electric motors, generators, power tools, etc.), the transmitted power must be estimated from measurements or standards. The Activity Plan should provide evidence of the emitted characteristics of the proposed equipment to enable the evaluation of potential interference.

Calculation of received power also requires an evaluation of the propagation path loss between the radio source and the MRO, either with a simple free-space equation, or by using a digital terrain map to evaluate diffraction losses. The free space equation and the relevant procedure from Recommendation ITU-R P.526-10 are given in Appendix 1 of this document. The free-space approach will provide a conservative result and should be used if there is no specific information about location or height of the radio source. It is therefore recommended that the simple free-space equation be used first; if the loss predicted is not adequate to reduce the emissions below the threshold of Table 1 in RALI MS 32, a more detailed analysis should be undertaken with the digital terrain map and the cascaded knife-edge diffraction model of Recommendation ITU-R P.526-10.

Advice on the use of the digital terrain map and diffraction calculations can be provided by CSIRO.

For multiple sources of interference within the same development, the effect of each transmitter or piece of equipment should be calculated as if they were located at the centre of the development, and the resulting power density levels should be summed within each frequency range listed in RALI MS 32.

The aggregate, over the entire development, of the calculated received power density within each frequency range must be shown to be below the appropriate threshold value(s) in RALI MS 32. If the threshold values are exceeded, the applicant will need to consult with DoIR and the management team of the MRO to modify the proposed development activities so that the thresholds can be met.

### **Requirements of the Activity Plan**

The conditions imposed by the Minister for Resources specify that the licensee or lessee must ensure that electromagnetic emissions from the proposed activities will not interfere with the radio-quiet requirements of the Murchison Radio astronomy Observatory. An Activity Plan submitted to DoIR must therefore contain enough information to confirm that the requirements described above are satisfied. Attachment 2 gives the information required to undertake the analysis.

### **Consultation procedure**

A consultation procedure between the applicants, DoIR and the MRO Management is proposed as follows. The applicant will submit an Activity Plan to the Land Management Issues Coordinator at

DoIR. This Activity Plan will include information about the equipment proposed for the tenement, as outlined in Attachment 2, an analysis of the aggregate power density within each frequency range (including details of the propagation method used), and conclusions about the power density as compared to the threshold values in RALI MS 32.

The Land Management Issues Coordinator at DoIR will consult with a qualified assessor to evaluate the information, analysis and conclusions in the Activity Plan. The cost of this initial evaluation will be covered by DoIR. Within 15 working days, the Land Management Issues Coordinator at DoIR will advise the applicants of the outcome of this evaluation.

If the Activity Plan is satisfactory and demonstrates that electromagnetic emissions from the activities on the tenement meet the requirements of RALI MS 32, DoIR will advise the applicants and the MRO Management, and the activities can proceed. Details of the Activity Plan will be kept in the CSIRO archives for future reference.

If the Activity Plan does not have sufficient information, does not contain an adequate analysis of aggregate power, or indicates that the proposed activities will exceed the limits set in RALI MS 32, DoIR will consult with the assessor and, if necessary, the MRO management about the information or actions required to bring the Activity Plan into conformity. The cost of the additional consultation and any further work by the assessor will be borne by the applicants. This process will continue until the Activity Plan demonstrates compliance with RALI MS 32 levels or until the applicants withdraw the proposal.

## **Attachment 2** **(to Appendix 5 to Annex 6)**

### **Required components of an Activity Plan**

The Activity Plan should include the following information for equipment proposed to be used within the Mineral Resource Management Area.

- 1) Radiocommunications Equipment (any purposeful transmission of radio-frequency signals, such as HF/UHF radios, mobile phones, Wireless LANs)
  - a. Manufacturer, model number(s)
  - b. Number of radio units
  - c. Frequency band and bandwidth
  - d. Power level (maximum, average)
  - e. Height of antenna when in use
  - f. Position (if fixed use), or area to be covered (if mobile use)
  - g. Hours per day and typical length of each use (or continuous use)
  - h. Any mitigation techniques used to reduce transmitted power
- 2) Other electrical equipment (such as motors, generators, alternators, power tools, welders, etc.)
  - a. Manufacturer, model number(s)
  - b. Number of units
  - c. Height of equipment when in use



- d. Position (if fixed use), or area to be covered (if mobile use)
  - e. Outdoor use or indoor (specify type of structure)
  - f. Hours per day and typical length of each use (or continuous use)
  - g. Any other information on electromagnetic emissions from device (preferably measurements from the same or similar equipment)
  - h. Any mitigation techniques used to reduce emissions from devices
- 3) Calculation of received power spectral density thresholds as defined in RALI MS 32, including method of calculation. Power spectral density should be summed within each frequency range based on the number of devices that have emissions in that frequency range. The propagation loss should then be applied using one of the methods in Attachment 3.
- 4) Summary of received power density at the MRO site for each frequency range listed in RALI MS 32 and comparison to the threshold values, and conclusions.

### Attachment 3 (to Appendix 5 to Annex 6)

#### Propagation calculations

##### Units and power density

Radio system parameters are expressed in decibels (dB) to avoid the use of very large or very small numbers and to allow common calculations to be done with addition or subtraction. Decibels represent a ratio with respect to a reference value; for example power in “dBW” stands for “decibels relative to a Watt” while power spectral density in “dBm/Hz” represents “decibels relative to one milliwatt per Hertz”. Standard calculations involving multiplication become addition when the quantities are expressed in decibels; similarly, calculations involving division become subtraction. For the purposes of this document, two quantities need to be expressed with decibels: propagation loss and power spectral density. All logarithms in the calculations are base 10.

Propagation loss is itself a ratio (power at the end of the path compared to power at the start) and so the units are simply “dB”.

Power density in (dBm/Hz) as used throughout this document is calculated from:

$$\text{Power density (dBm/Hz)} = 10 \log \left[ \frac{\text{power (mW)}}{\text{bandwidth (Hz)}} \right] \quad (1)$$

Since 1 Watt is 1 000 milliwatts, power density in (dBm/Hz) can be calculated from (dBW/Hz) by adding 30:

$$\begin{aligned} \text{Power density (dBm/Hz)} &= 10 \log \left[ \frac{\text{power (mW)}}{\text{bandwidth (Hz)}} \right] = 10 \log \left[ \frac{\text{power (W)} * 1000}{\text{bandwidth (Hz)}} \right] \\ &= 10 \log \left[ \frac{\text{power (W)}}{\text{bandwidth (Hz)}} \right] + 10 \log(1000) = \text{power density (dBW/Hz)} + 30 \end{aligned} \quad (2)$$

The power density from a number of identical devices can be calculated by adding  $10\log$  (number of devices) to the value for an individual device. For example, a single CDMA satellite phone at 1 600 MHz has a maximum emission of  $-34$  dBm/Hz. If eight such phones are expected to be used on the site, this increases the maximum emission by  $10\log(8)$  or 9 dB, bringing the total emission from these phones to  $-25$  dBm/Hz.

Other sources within the same frequency range should then be added in the same way. Unequal sources are summed as:

$$\text{Total power density} = 10\log\{10^{(A/10)} + 10^{(B/10)} + 10^{(C/10)} + \dots\} \quad (3)$$

where the power densities, in dBm/Hz, of the individual devices are  $A$ ,  $B$ ,  $C$ , etc.

### Free space loss

Free space loss represents the weakening of a signal as it spreads out, apart from any other losses due to obstacles in or near the path. It is therefore a conservative estimate of loss since in a real environment, overall path loss will be equal to or greater than the free space loss. With frequency  $f$  expressed in MHz and distance  $d$  expressed in kilometres, free space loss is simply:

$$L_{fs} = 32.4 + 20 \log(f) + 20 \log(d) \quad \text{dB} \quad (4)$$

Example: at a frequency of 420 MHz, the free space loss at 100 km is:

$$32.4 + 20 \log(420) + 20 \log(100) = 125 \text{ dB}$$

### Cascaded knife-edge diffraction loss

Additional loss due to diffraction can result when radio energy travels over irregular terrain. Recommendation ITU-R P.526-10 specifies a prediction technique using cascaded knife edges and a digital terrain data base. This section summarises the prediction method.

Refraction through layers in the atmosphere can cause the radio signal to bend towards (or sometimes away from) the earth, so that the “straight line” distance around the earth’s curvature is different than (and typically longer than) the geometric line-of-sight. This is modelled by an “effective earth radius” which is the physical radius (6 370 km) multiplied by a  $k$ -factor. The  $k$ -factor varies with time but the median value of  $4/3$  is recommended for initial diffraction calculations.

From a digital database, a terrain profile is extracted; point spacing of 250 metres is typical. At each profile point, a height  $h$  is calculated, representing the height of the terrain above a line joining the first and last point of the profile and accounting for effective earth radius. Using the same unit for all variables, where  $h_n$  is the  $n^{\text{th}}$  terrain point,  $d_{ab}$  is the distance from the first point of the profile to the last point,  $d_{an}$  and  $d_{nb}$  are the distances from the  $n^{\text{th}}$  point to the first and last point, respectively, and  $r_e$  is the effective earth radius,  $h$  is calculated as:

$$h = h_n + [d_{an} d_{nb} / 2 r_e] - [(h_a d_{nb} + h_b d_{an}) / d_{ab}] \quad (5)$$

The dimensionless diffraction parameter  $v$  is then calculated for wavelength  $\lambda$  (still in self-consistent units) at each point of the profile:

$$v_n = h \sqrt{2d_{ab} / \lambda d_{an} d_{nb}} \quad (6)$$

The point with the highest value of  $v$  is termed the principal edge,  $p$ , and the  $v$  value is labelled  $v_p$ . If  $v$  is greater than  $-0.78$ , the process is repeated twice, once between the beginning of the path and  $p$ , and then between  $p$  and the end of the path. If  $v_p$  is less than  $-0.78$ , diffraction loss is negligible and the calculation can be abandoned.

The terrain points with the largest value of  $v$  on either side of the principal edge are termed “auxiliary edges” with values  $v_t$  and  $v_r$ . Again,  $v$  values less than  $-0.78$  indicate negligible loss and the contribution of that edge is ignored. Diffraction is then calculated for the path of length  $D$  (km) by:

$$L = J(v_p) + \{1.0 - \exp(-J(v_p)/6)\} [J(v_t) + J(v_r) + 10.0 + 0.04D] \quad (7)$$

where  $J(v)$  is approximated (for  $v$  greater than  $-0.78$ ) by:

$$J(v) = 6.9 + 20 \log \left( \sqrt{(v - 0.1)^2 + 1} + v - 0.1 \right) \quad \text{dB} \quad (8)$$

The total predicted loss on the path is the sum of  $J(v)$  and free space loss from equation (4).

### Calculation of received power

The relationship between received power and emitted power is:

$$\text{received power density (dBm/Hz)} = \text{emitted power density (dBm/Hz)} - \text{path loss (dB)}$$

## Appendix 6 to Annex 6

### RFI Standards for equipment to be deployed on the MRO

Any electrical or electronic equipment in the vicinity of the Murchison Radio astronomy Observatory (MRO) has the potential to create harmful Radio Frequency Interference (RFI) which could contaminate the radio astronomy observations. This applies to equipment used by the observatory operations as well as that used by external parties.

RFI from other users (telecommunications carrier, mining operations, tourists) is addressed in other documentation. This document sets limits on the equipment to be deployed on the MRO site itself. Measurement of very low levels which are nevertheless harmful to radio astronomy is difficult. The Military Standard MIL-STD-461F is used as the basis of assessment, as shown in the Table 50 below. For equipment within 10 km of the MRO facilities, control of RFI requires the use of additional screening.

TABLE 50

#### Fundamental thresholds for emissions as a function of frequency

Distance (km)	Threshold emissions allowable for equipment to be deployed	Comments
$d > 10$	$\leq$ levels defined in Military standard MIL-STD-461F category RE102, Navy Mobile and Army (Figure RE102-4)	
$10 > d > 1$	$\leq$ Military standard MIL-STD-461F as above, plus a screened box at $>20$ dB	Need to take great care with equipment connections to maintain RFI screening between tested components
$d < 1$	$\leq$ Military standard MIL-STD-461F as above, plus a screened box at $> 80$ dB	Only permitted on a case-by-case basis with careful testing

The Distance (km) refers to the minimum separation between co-located facilities at the MRO. A facility may include a single antenna system, multi-element array or any other electrical/electronic equipment(s).

### **Acceptance protocol for equipment on the site**

Proponents will be required to have entire systems or subsystems tested in a qualified EMC lab and results assessed by the CSIRO as MRO Management to ensure that equipment meets the standards in Table 1, appropriate to the equipment site on the MRO.

A subsystem shall, as practically as possible, replicate the situation that will be deployed in the field. The subsystem should be connected with typical input or output signal lines and typical terminations on those lines. The subsystem should be as large a functional block as practically possible, operating in an active mode and with typical power consumption and loads. Where several functional modes are possible, a representative set of measurements for each operational mode should be made and assessed individually, and the equipment will be required to pass the criteria in each mode.

### **Procedure for approval**

Before formal testing is undertaken, consultation with the MRO Management will be required to reach agreement on the level of subsystem to be tested and the specific test requirements for any particular instrument, thus minimising the need for retesting.

The MRO Management require that EMC laboratory reports, certificates obtained, and plots of equipment test results be prepared and presented to the MRO management to enable characterisation and assessment of the proposed equipment to be deployed on the MRO.

CSIRO is investigating options to develop test laboratories in Australia to enable equipment to be tested and characterised prior to deployment. In the meantime, other test facilities which are certified to test to MIL-STD-461F must be used.

Test certificates must be supplied before installation of equipment commences, and all parties are advised to wait for MRO approval before further equipment acquisition. MRO Management will advise within 15 working days if the equipment has been satisfactorily tested and meets the requirements shown in Table 50.

CSIRO reserves the right to require equipment to be checked for compliance to MIL-STD-461F and additional screening after commissioning on the MRO site.

### **Ongoing compliance**

If, in the future, any equipment is found to exceed the threshold limits in Table 1, then the owners and users of the equipment may be required to immediately switch off the equipment so that it ceases to emit RFI. The equipment may need to be either modified so that its levels of emission are within the thresholds defined, or removed from the site.

Furthermore, if, in the future, any equipment is found to compromise research activities at higher sensitivities than that specified in the table, over the same receiving bands or in different receiving bands, it will be the responsibility of the owner of the equipment to further minimise or mitigate emission levels affecting other research programs.

### **References**

MIL-STD-461F Requirements for the control of electromagnetic interference characteristics of subsystems and equipment.  
[http://assist.daps.dla.mil/quicksearch/basic\\_profile.cfm?ident\\_number=35789](http://assist.daps.dla.mil/quicksearch/basic_profile.cfm?ident_number=35789).

## Annex 7

### Characteristics of radio quiet zones: protection of the IRAM 30 m radio telescope in Spain

#### 1 Actions taken by the administration of Spain to protect the IRAM 30 m telescope operating in the Sierra Nevada near Granada

##### a) Introduction and description

The Instituto de Radioastronomía Milimétrica (IRAM), in collaboration with the (Spanish) National Geographic Institute (NGI), operates a radio astronomy observatory station at Pico Veleta (Veleta Peak-Loma del Dilar), Sierra Nevada, Granada, at WGS coordinates: N 37° 03' 58", W 03° 23' 34", 2904.0 m. The radio astronomy instrument there is a 30 m telescope (The IRAM 30 m telescope) with surface accuracy of 70 microns, operating in the frequency range 70-275 GHz. Further information about the telescope is available at <http://www.iram.es/>.

The observatory is in the midst of a large ski resort, above the resort buildings, hotels, *etc.* but somewhat below the ski trail peaks. When the ground is bare it is possible to drive directly to the telescope on paved roads (but only by authorized vehicles) and the area sees occasional hikers and sightseers. When the ground is snow-covered, access is by a specialized snow vehicle. The telescope is visible both from the city of Granada (a 50 minute drive; see Fig. 56) and the nearby ski resort base camp.

##### b) Specific protections

As stated by the Spanish administration, "In order to ensure the efficient reception of signals from outer space and to provide protection of the instrument from radio interference," Resolution 5998 of March 10, 2006 of the Spanish National State Secretariat for Telecommunications and the Information Society, established various limitations on nearby property rights and electromagnetic emissions. The limitations created by Resolution 5998 may be summarized as follows.

##### i) *Geographic reference point for establishing the limitations*

This are defined by WGS coordinates: N 37° 03' 58"; W 03° 23' 34"; 2904.0 m

##### ii) *Limitations on property rights*

The proprietors or occupants under any title of any of the lots adjacent to the observatory shall be inhibited from building or modifying buildings not in accordance with the limitations and bounds established in the present resolution.

Within a radius of 1000 m from the radio astronomy station, no construction should appear above an elevation of 3 degrees as viewed by the telescope.

The minimum separation between an industrial facility, high voltage power line or railway, and any of the receiving antennas of the observatory will be 1000 m.



To determine the minimum distance from the observatory at which radio transmitters may be located, taking into account that the station operates at frequencies above 3 000 MHz, the limitations set out in the following table shall apply:

Range of frequencies ( $f$ ) (MHz)	Interfering service	Apparent radiated power of the transmitter in the direction of the station to be protected (kW)	Maximum distance limitation that may be applied between the transmitting antenna and the station to be protected (km)	Maximum distance limitation and radio electric conditions (CRE)* that may be demanded (km)
$f > 3\,000$	Radiolocation Space Research (Earth-to-space)	$0.001 < P \leq 1$	1	
		$1 < P \leq 10$	2	
		$P > 10$	5	
	Other services	$0.001 < P \leq 0.01$	0.6	02, and CRE
		$0.01 < P$	1	

\* The radio electric conditions that may be demanded (CRE) will be understood, in accordance with those established in Royal Decree 1066/2001, of 28 September.

iii) *Limitations on the intensity of the electric field*

To protect the frequency bands used by the observatory which are allocated to the Radio Astronomy Service on a primary basis in the National Table of Allocations in force, the intensity of the electric field in the above referenced bands will be limited to the following values, when measured at the observatory, independently of where the transmitter is located:

Frequency band	Pfd (dB(W/m <sup>2</sup> ))	Equivalent intensity of the electric field (dB(μV/m))
86-92 GHz	-125	20.8

For all other frequencies, the intensity of the electric field shall be limited to +88 dB(μV/m) (-57 dB(W/m<sup>2</sup>)), also measured at the site of the Radio Astronomy Station.

iv) *Radio coordination zone*

Prior to assigning frequencies to radiocommunication stations with an apparent radiated power that exceeds 25 Watts in the direction of the observatory, within a 10 km radius of the same, studies will be carried out to determine that the intensity of the electric field at the reference point of the Observatory shall not exceed the appropriate values given in iii). A theoretical model will be employed to calculate the electric field intensity, and the radiation pattern of the station and the terrain attenuation will also be taken into account.

Should the theoretical calculations result in an electric field intensity in excess of the limits stipulated in section b, electric field intensity measurements may be carried out at observatory using trial signals, and in collaboration with observatory and State Secretariat for Telecommunications and the Information Society staff. Under no event will the outcome of such measurements exempt the definitive transmitter of the obligation to comply with the limits given in iii) above.

v) *Supervision and control*

The State Secretariat for Telecommunications and the Information Society will exercise the functions attributed to it in order to conduct inspections on compliance with the limitations and bounds established.

vi) *Appeals*

A brief period (one-two months), was granted after publication of the decree, during which appeals or lawsuits against the decree could be filed.

FIGURE 56  
Location of the IRAM 30 m telescope in the Sierra Nevada near Granada,  
Spain, shown on a relief map



## Annex 8

### Spectrum protection criteria for the square kilometre array (SKA)

#### 1 Introduction

The square kilometre array (SKA) is the next generation radio telescope, planned as a multinational project. There are two sites under consideration for the location of the central core of the SKA: one in Western Australia and another in South Africa, a decision on the final site will not be expected to be made before 2011. When built, the SKA will operate over large parts of the radio spectrum. The criteria and planning considerations for spectrum protection of the SKA are described in an SKA planning document<sup>27</sup>. SKA will bring up to a hundred-fold increase in sensitivity for radio astronomy in the frequency range of 100 MHz to 25 GHz. This increase results from a hundred-fold increase of collecting area at centimetre wavelengths combined with an increase of the operating bandwidth for continuum observations, as compared with existing telescopes. While such wide receiver bandwidths of 1 GHz and larger are technically feasible, they also overlap numerous spectral bands of active spectrum users. The transmissions of stations of other radiocommunication services constitute radio frequency interference (RFI) for the SKA user. In the years leading up to SKA initial operation, the active use of the spectrum is expected to increase due to technological advances, increased demand for wireless services and increased affluence among the customers. A growing concern in the radio astronomy community is the increase of RFI due to these signals within the projected operational bands of the SKA.

The SKA can deal with RFI by the combination of:

- 1) seeking a remote location with low population density;
- 2) building RFI mitigation technology into the SKA system; and
- 3) by establishing protection and coordination zones around the SKA.

This paper provides the levels needed to protect the SKA to the level that is required to secure the envisioned scientific output of the instrument.

The SKA will be built as a multi-station synthesis interferometer in order to take advantage of the technique of interferometry, which provides a higher resolution on the sky than a single-dish telescope for a given physical collecting area. An interferometer has a more natural robustness to RFI than a single-dish telescope (see § 3).

The determination of the level of protection needed for the SKA is based on ITU-R documents as well as technical documentation of existing array telescopes such as the Very Large Array (USA) and MERLIN (UK), and Very Long Baseline Interferometry (VLBI) instruments. Documentation describing detrimental RFI levels in the literature of the International Telecommunication Union (ITU) distinguish only between levels for single-dish and VLBI levels, and for continuum and spectral line observations and do not explicitly include closely spaced arrays as a separate category. For arrays, the detrimental levels are determined by the frequency of the fringe oscillations in the output of each correlated antenna pair and by the process of de-correlation due to integration of these signals over frequency band and time. Interference at the longest VLBI baselines becomes completely de-correlated. The ITU-R *Handbook of Radio Astronomy* (1995; Section 4.4), and *Interferometry and Synthesis in Radio Astronomy* (Thompson, Moran & Swenson 1986; Ch. 15) give details about the approach towards determining the appropriate protection levels for synthesis arrays.

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<sup>27</sup> [http://www.skatelescope.org/PDF/memos/73\\_RITaskForce.pdf](http://www.skatelescope.org/PDF/memos/73_RITaskForce.pdf).

## 2 SKA RQZ requirements

The nominal frequency range that the SKA is expected to cover is 100 MHz-25 GHz. The SKA Request for Proposals states that the Radio-Quiet Zone (or Reserve) (RQZ) should be a protected area established under regulation and/or legislation and should be at least 150 km in diameter at the Central Site. Current radio-quietness characteristics should be improved and maintained over the life time of the SKA Facility.

The actual protection within the RQZ from external interference may be achieved by two complementary mechanisms. The prohibition of all emissions within a certain area may define an *exclusion zone*, which would address EMC interference and non-licensed transmitters. The determination of coordination distances for a certain transmission power using appropriate propagation studies may define a *coordination zone*, which would achieve certain pfd levels for the stations in the central region and for the remote stations.

Protection levels are being proposed for the purpose of proceeding with SKA site determination. These protection levels are based on Recommendation ITU-R RA.769, which defines the protection criteria for radio astronomy observations in the bands allocated for the Radio Astronomy Service. The levels of detrimental interference for radio astronomy operations in other not allocated bands are determined by interpolation.

In the following, the broad term Radio-Quiet Zone will refer to the area under regulatory and/or other legislative measures that ensure the spectrum protection of the SKA. Based on the protection requirements of existing instruments and the currently proposed configurations for the SKA, one can distinguish three distinct components of the SKA, with different protection requirements.

**2.1 The core and the central SKA area (the Central Site)** where 50% of the collecting area will be located in a densely packed configuration that is concentrated towards the centre. For purposes of protection from RFI, this area will resemble a single-dish system and will require the highest level of protection, as given in Tables 1 and 2 of Recommendation ITU-R RA.769.

**2.2 The intermediate region with the near-in remote stations** up to 150 km from the centre of the array, which represents another 25% of the total collecting area, in some 30 stations along spiral arms with logarithmically scaled distances. These remote stations will have distances of ten(s) of km(s) from one another. One can think of this intermediate region as requiring protection similar to that of existing arrays, such as, e.g. the VLA. An approximate protection level required by such arrays is 15 dB less stringent than the continuum threshold level in Recommendation ITU-R RA.769 Table 1. This area also serves as a buffer zone to the Central Site.

**2.3 The remote SKA stations** beyond 150 km (the remaining 25% of the collecting area, in about 30 stations), which will be distributed at distances up to 3000 km from the Central Site. RFI received by these stations should be, in most cases completely uncorrelated, and therefore protection at VLBI levels given in Recommendation ITU-R RA.769 Table 3 should be sufficient.

It should be noted that the levels specified in Recommendation ITU-R RA.769 apply only in bands allocated to radio astronomy. For continuum measurements (Table 1) these levels are based on the whole bandwidth allocated to radio astronomy in each band.

## 3 Protection levels for the SKA

A synthesis telescope provides greater discrimination against interfering signals than a single-dish (total power) radio telescope. In an interferometer pair, separation of the stations causes relative changes in the phases of the signals, and this, in turn, results in *fringe rotation* associated with the sidereal motion of the cosmic source across the sky. The response of a radio telescope array can thus be seen as a weighted response of a large number of antenna pairs with different spatial orientation and separation distances.

In the case of broadband interfering signals, further rejection occurs because of inequalities in the time delays from one side of the observing band to the other, which results from *delay tracking* of the signals paths via the individual antennas and results in de-correlation of the RFI signals. The magnitude of the de-correlation depends on the position of the RFI source on the sky.

A detailed explanation of these effects can be found in Chapter 15, “Interferometry and synthesis in radio astronomy” by Thompson, A.R., Moran, J.M. and Swenson, G.W. (1986).

Recommendation ITU-R RA.769 discusses interference protection criteria for the radio astronomy service. It identifies three distinct threshold levels of emissions that cause interference detrimental to radio astronomy observations:

- 1) Protection levels for continuum observations for a single-dish telescope;
- 2) Protection levels for single-dish spectral line observations; and
- 3) Protection levels for VLBI observations (with strong fringe rotation).

These protection levels are presented in Figs. 57 and 58, under the assumptions used in Recommendation ITU-R RA.769.

For single-dish telescopes, the level of detrimental interference depends on:

- a) The observed continuum bandwidth, assumed in Recommendation ITU-R RA.769 to be the whole allocated bandwidth (Table 1), and the channel width for spectral line observations (Table 2) of:
  - 10 kHz for  $f < 1$  GHz
  - 20 kHz for  $f < 5$  GHz
  - 50 kHz for  $f < 22$  GHz.
- b) The integration time, that is assumed to be 2000 s in Recommendation ITU-R RA.769 for both continuum and spectral line observations,
- c) The system temperature  $T_{\text{sys}}$ , and
- d) The antenna response pattern, assumed to be:
  - $G = 32 \log(\phi)$  dBi                       $1^\circ < \phi < 19^\circ$
  - $G = 0$  dBi                                   $19^\circ < \phi < 180^\circ$

In practice, the far-side lobes of an antenna may be lower by about 5 dB and will also have angular structure. The threshold levels are, however, independent of the collecting area of the telescope.

The mode of operation of SKA may have influence on the impact of RFI on observations. For many modern interferometers the drive towards wide-field imaging has pushed towards spectral-line observations with many narrow (only a few kHz wide) channels to avoid bandwidth smearing, and very short integration times ( $< 1$ s) to avoid time smearing. The use of narrow channels and short integration times may provide easier RFI mitigation, even if it is simply through excision of affected data.

For synthesis arrays, the ITU-R Handbook shows the detrimental interference levels computed for the VLA-D and VLA-A configurations and MERLIN. These are compared to the single-dish continuum and the VLBI levels in Fig. 58. The lower threshold levels for these arrays, compared to those for single-dish telescopes, results from the separation of the stations of the array, and also observing bandwidths and integration times.

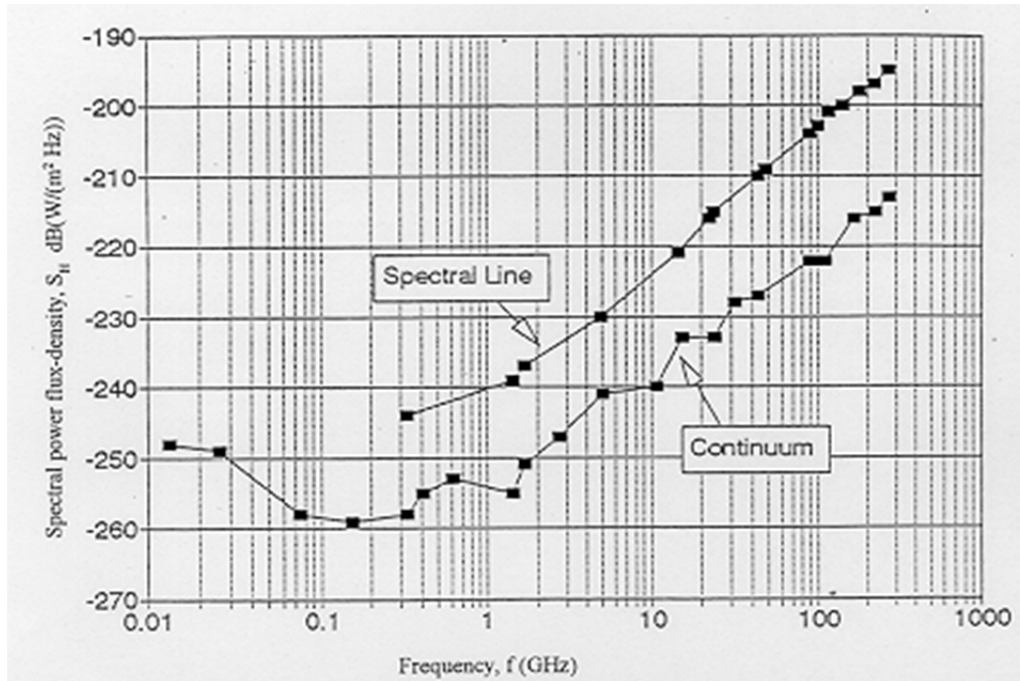
The VLA-D configuration has the densest core of all current arrays. Its RFI protection requirements are approximately 15 dB less stringent than those of single-dish (total power) telescopes (Table 1 of Recommendation ITU-R RA.769). The anticipated (random) distribution of the collecting area in the core of the SKA would suggest that the closest spacing of the stations would be even less than



the closest VLA-D spacing. Therefore, the protection of the SKA core should be closer to that of the single-dish values given in Recommendation ITU-R RA.769. The protection requirements for the stations beyond the core will start with the most stringent single-dish values and decreases to the threshold levels for VLBI observations at the outermost stations.

FIGURE 57

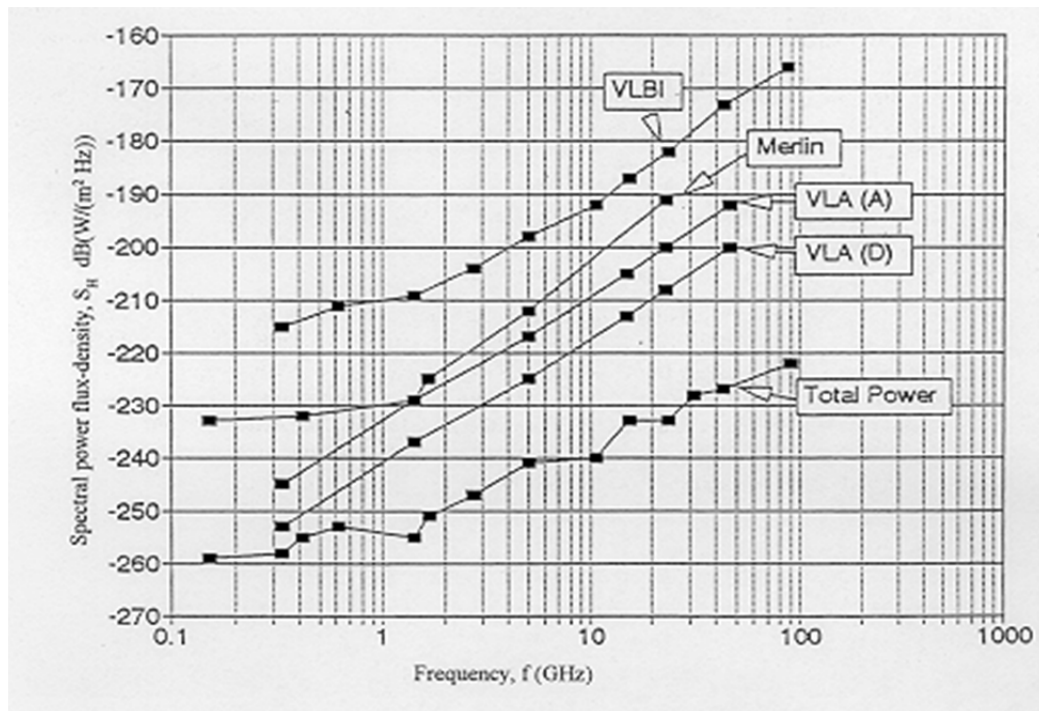
**Harmful thresholds of interference for spectral line and continuum observations for single-dish telescopes**



The ordinate is given as pfd. The integration time of 2000 seconds has been used and the bandwidth is 20 kHz for spectral line and the whole allocation in the ITU Radio Regulations is used for the (broadband) continuum observations (from ITU-R Handbook on Radio Astronomy).

FIGURE 58

**Harmful thresholds of interference for (broadband) continuum observations with several types of radio telescope systems**



The curve marked as Total Power is for single dish telescopes. The ordinate is given as *pfd* (from ITU-R Handbook on Radio Astronomy).

Consideration of the requirements for the SKA, as expressed in the Request for Proposals, makes it clear that a radio-quiet zone (RQZ) is necessary to address the issue of RFI from a wide range of active services. An inventory of these services and the nature of the RFI are presented in Appendix A. Because the impact of these various RFI sources varies strongly, it is not feasible to provide an RQZ that will protect the SKA at the desired level against all types of RFI. The RQZ is therefore only one, although a critical one, of the measures to be taken to protect the SKA. Implementation of the RQZ would depend strongly on local conditions and the local regulatory environment. It needs to take into account not only issues related to communications, but also other relevant issues, such as land usage, civil aviation, etc.

A general implementation of the RQZ for SKA may be based on the establishment of exclusion zones and coordination zones to achieve the necessary protection levels for the stations in the central region, the intermediate region and the remote stations of SKA. An example of such a spatial structure is presented in Appendix B.

The translation of the threshold levels for the spatial components of the SKA into actual separation distances needs to be established using appropriate propagation studies. ITU-R Recommendations that relate to propagation studies and propagation losses under various environments are listed in Appendix C. As an example, illustrations of propagation studies showing the necessary protection zone extents (coordination distances) are presented in Appendix D for the stations in the central region of the SKA at the Australian SKA candidate site at Mileura, WA.

The RQZ is often thought of and is described as a “Science Reserve”. The proposed RQZ for the central site of the SKA may offer great advantages to other scientific instruments. This creates the danger that any co-located instrument may produce significant RFI for the SKA. Co-located instruments will have to abide by the RQZ rules and respect interference threshold levels. Data transport and communication within the SKA system will employ optical fibre technology and will not use radio communication.

## 4 Conclusions

The threshold levels needed to define a RQZ have been briefly outlined. Two examples of RQZ implementations have been illustrated:

- a general description of the spatial structure of the RQZ using the concepts of coordination with more distant stations and exclusion of nearby stations, and
- the structure and extent of a protection zone for the stations in the central region of SKA at the Australian candidate SKA site.

## References

- Gergely, T, 2004, in Proceedings of RFI2004 Workshop on “Mitigation of RFI in Radio Astronomy”, <http://www.ece.vt.edu/swe/RFI2004>.
- ITU-R Handbook on Radio Astronomy, 1995, International Telecommunication Union, Geneva (Section 2.3).
- Thompson, A.R. 1982, The response of a radio astronomy synthesis array to interfering signals, *IEEE Trans. Antenna Propagation*, AP-30, 450-456.
- Thompson, A.R., Moran, J.M., & Swenson, G.W., 1986, Interferometry and synthesis in radio astronomy, (John Wiley, New York, NY), reprinted by Kreiger press, Melbourne FL (Chapter 15).

In addition to in-band emissions from the RFI sources, the out-of-band and unwanted emissions of certain sources may have detrimental effects on the quality of SKA operations in radio astronomy bands or in other allocated bands where SKA operates on a non-interference basis.

## Appendix 1 to Annex 8

### General example of an RQZ implementation

The general structure of the RQZ comprises two structural components to achieve the required radio quietness at all the array stations:

- a) **Exclusion Zones (EZ)**, within which all emissions are prohibited, are directed at EMC interference and non-licensed transmitters,
- b) **Coordination Zones (CZ)**, where the pfd levels at the core and the remote stations and the transmission power determine the coordination distances using appropriate propagation studies.

The radial structure of the RQZ is based on the particular spatial properties of the interferometry system. Section 3 in the main document discusses that the rejection of broadband and narrow-band RFI increases with the distance between the stations. This dependence has been presented in Fig. 59 (left top frame) for a SKA station of 100 m in size and shows how the protection levels can be relaxed when going from the core region to the outer stations. The following sections describe the combination of Exclusion Zones and Coordination Zones in order to provide the required levels of protection for the whole SKA system. The RQZ values are presented in Fig. 59 and Table 51.

TABLE 51

**Proposed radial structure of the SKA RQZ**

	<b>Station radial distance</b>	<b>Exclusion zone (EC)</b>	<b>pfd levels for coordination zone (CZ)</b>
Central Region	Inside 5 km	75-100 km radius	Recommendation ITU-R RA.769-levels
Intermediate Region	Annulus 5-200 km	~10 km radius* beyond 100 km radial distance	Recommendation ITU-R RA.769 Continuum levels + 15 dB
Remote Region	Beyond 200 km	~10 km radius*	Recommendation ITU-R RA.769 VLBI thresholds Continuum + 40 dB

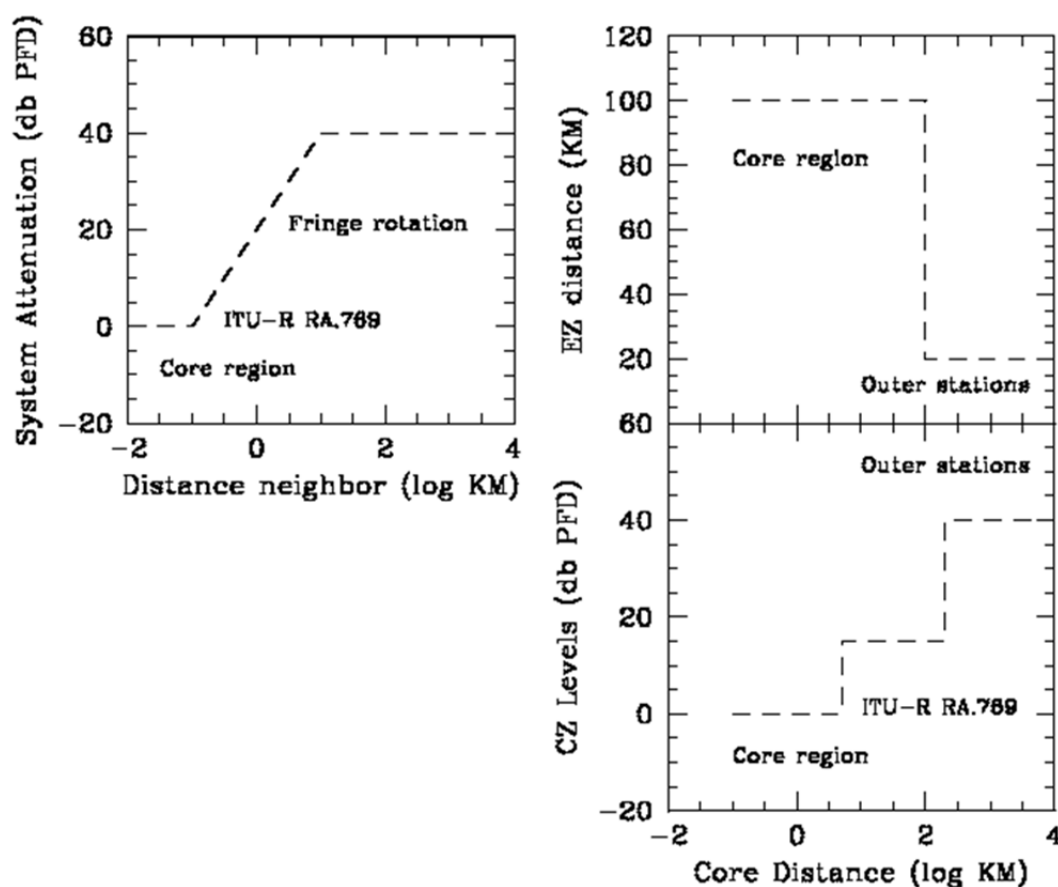
\* NOTE – The size of the exclusion zones is around remote stations will be determined by local conditions and are expected to be around 10-20 km.

## 1 Central Region

*a) Establish an appropriate Exclusion Zone* around the SKA centre with a radius of 75 to 100 km. This zone will include the core area (1 km diameter), the central area (an annulus with 1 km inner diameter and 5 km outer diameter) and some of remote stations that are still relatively close to one another so that if individual exclusion zones would be established, they would be touching or near enough touching.

FIGURE 59

A possible radial structure of the RQZ for SKA



*Top left frame:* The separation of two SKA stations results in a rejection of narrow-band and broadband RFI signals that depends on the square of the distance between the station and its neighbours. The Recommendation ITU-R RA.769 levels are used as a reference value. This Figure assumes a size for an individual station of 100 m. The rejection resulting from the separation of stations varies from 0 dB for touching stations and 40 dB for separations where the VLBI is applicable.

*Top right frame:* The radius of Exclusion Zones (in km) for stations as a function of distance (in km) to the central region. Stations beyond 100 km radius will have individual EZ of 20 km.

*Bottom right frame:* The PFD levels to be used for the Coordination Zone and the determination of the coordination distances presented as a function of distance to the central region.

The ordinate is the pfd in dB relative to the values of Recommendation ITU-R RA.769.

**b) Establish appropriate Coordination Zones with procedures to determine coordination distances** with the objective to provide the stations in the Central Core and the outer stations with a radio quiet environment with the following levels:

**1.1** For the core and central areas, up to 5 km radius within the RQZ, *coordination* must ensure that the requirements are met for the *Continuum Threshold* as set out in Recommendation ITU-R RA.769.

**1.2** For the remaining part of the inner structure, an annulus with an inner diameter of 10 km and an outer diameter of 150 to 200 km, *coordination* must ensure that the requirements are met for the *Continuum Threshold plus 15 dB*, equivalent to requirements for *Spectral Line Thresholds*, as set out in Recommendation ITU-R RA.769.



**1.3** The *central exclusion zone* should provide the stated protection against short range, portable and mobile transmissions and fixed low power transmissions which are not on high sites or high masts. No transmission facilities should be allowed within the RQZ unless they have been specifically cleared.

## **2 Remote stations**

***Establish appropriate exclusion zones*** around each of the remote SKA stations with a radius of approximately 10-20 km. The objective of the remote exclusion zones would be to provide radio quiet levels to meet the requirements for the *VLBI Threshold*, as set out in Recommendation ITU-R RA.769, and also protect against local EMC interference and LoS interference.

The remote station exclusion zones should provide protection against short-range, portable and mobile transmissions and fixed low-power transmissions, which are local to the station environment. No transmission facilities may be allowed within the EZ zone unless they have been specifically cleared.

The Coordination Zone for the outer stations will be determined by the coordination distances calculated with appropriate propagation models.

## **3 RFI originating beyond the RQZs**

Many transmissions from outside the RQZs will also have an adverse impact on the SKA. Existing transmissions that have a significantly adverse impact, as determined according to agreed standards, could be identified in the National Regulatory Database and could be subjected to an improvement scheme in conjunction with National Policy for the SKA and in collaboration with the National Regulatory Authority. From the National Regulatory Database it would become apparent what the geographical area is, beyond the RQZ, in which regulatory scrutiny and coordination is generally required, and also, which specific RFI sources beyond that must remain under scrutiny. Any changes to these RFI sources that may increase RFI need to be coordinated with the SKA.

Any new transmission facilities that are planned within the coordination range referred to above need to be approved by the Regulatory Authority in conjunction with the SKA. Any high-power and high-site transmission facility planning at a much greater distance must still be subject to scrutiny. Reference power levels and effective site heights need to be determined.

## **4 Establishment of RQZs**

The RQZs need to be established in terms of the appropriate national and local legislation, not only in terms of communications statutes but also other applicable statutes, for example with respect to land surveying including demarcation on official maps, land use and rights and civil aviation.

## Appendix 2 to Annex 8

### Propagation studies, RFI characterisation and data acquisition

#### 1 Propagation Studies

The translation of the threshold levels for the spatial array components towards actual separation distances need to be established using propagation studies with various levels of complexity.

To evaluate the effect of a distant transmitter on a radio telescope the effects of radio propagation must be taken into account. This is a very complex area and has been the subject of extensive studies. In the ITU-R there are about 80 recommendations in the propagation area.

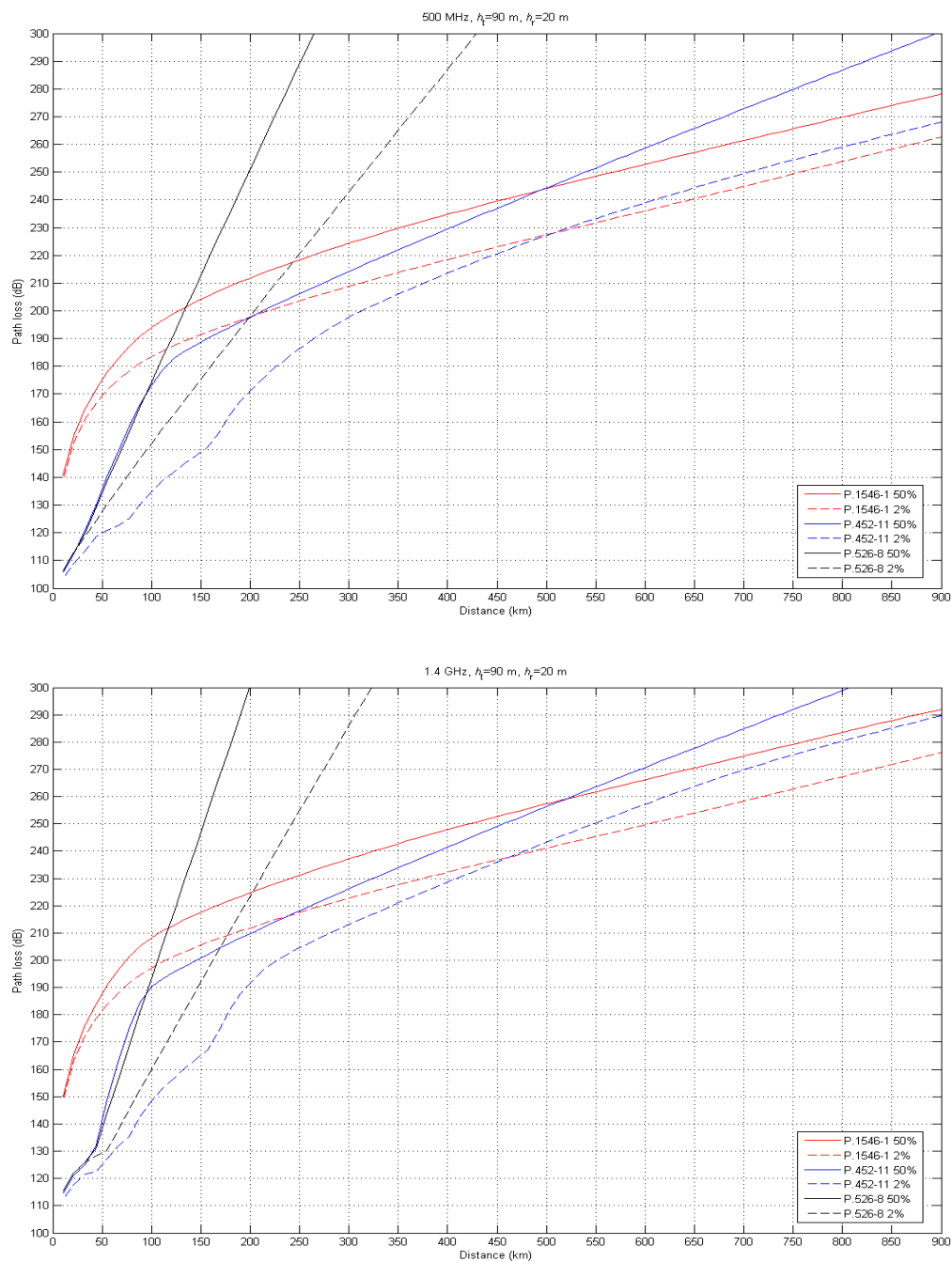
Propagation models vary from simple, accounting only for fundamental effects (free space propagation, diffraction), to very complex that account for many effects such as ionospheric and tropospheric factors, and terrain obstacles.

The results are presented in the Figures below as Path loss (dB) vs Distance (km). For all plots the following additional parameters were set:

- Flat terrain was assumed and no specific terrain information was used.
- The antenna heights were set to 20 m for the receiver (indicative for the SKA) and 90 m for the transmitter (a typical radiocommunications tower).

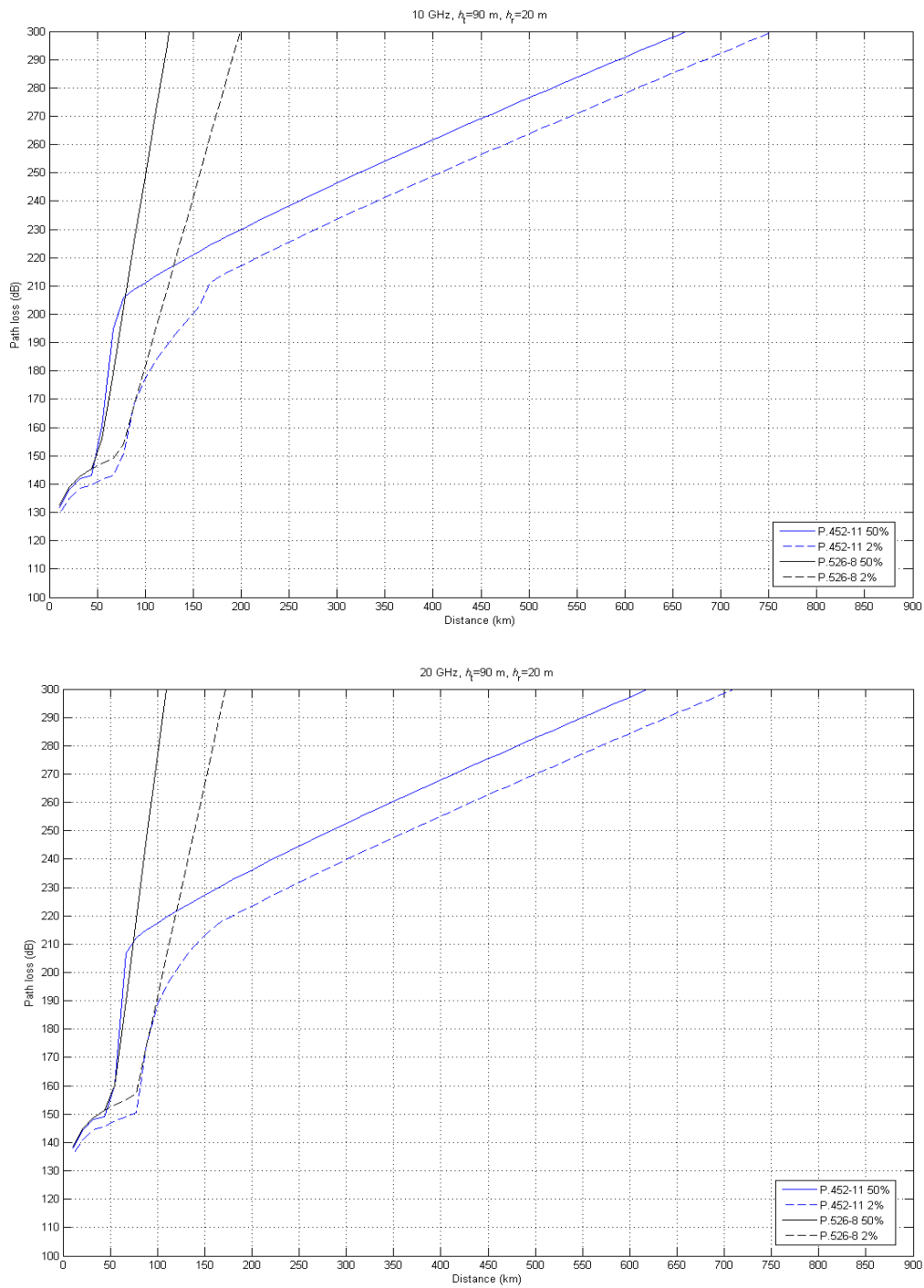
Figures 60 and 61 present 2 plots for each propagation model (each ITU-R Recommendation) labelled 2% and 50%. These percentages refer to the time percentage that field strengths are exceeded and represent a measure of the probability of interference.

FIGURE 60



Path loss (dB) at different distances (km) due to propagation models from Recommendations ITU-R P.1546-1, ITU-R P.452-11 and ITU-R P.526-8, for the low frequencies of 500 MHz (top) and 1.4 GHz (bottom). The solid lines are at 50% and the dashed lines at 2% probability of interference.

FIGURE 61



Path loss (dB) at different distances (km) due to propagation models from Recommendations ITU-R P.452-11 and ITU-R P.526-8, for the high frequencies of 10 GHz (top) and 20 GHz (bottom). The solid lines are at 50% and the dashed lines at 2% probability of interference.

## 2 Computerized predictions

The number of RFI sources across the SKA frequency spectrum, from 100 MHz to 25 GHz, will be quite large, even in a remote sparsely populated area; due to the very low threshold levels and the long distances over which such signals can be produced.

In order to produce a comprehensive characterization of the SKA sites with respect to RFI it will be necessary to use a computerized signal level prediction system. Such systems need to be based on the ITU propagation models, must be accredited and incorporate topographical models with sufficient accuracy.

### **3 Location and characterization of potential RFI sources.**

The next step is the characterization of the present and future RFI environment around candidate SKA sites.

- Creating a database of all existing transmitters that produce signals exceeding the threshold levels which will include the geographical and topographical transmitting site data and the transmission characteristics.
- The prediction of the signal levels produced by all these transmitters at the candidate SKA sites.
- Some measurements of the actual current RFI environment.
- An assessment of future radiocommunication developments in the region.

### **4 RFI database**

A database of existing licensed transmitters is usually maintained by national radiocommunication or communications regulatory authorities. From this, the density and characteristics of potential RFI sources near an SKA site can be determined. However, this information is sometimes incomplete and often does not accurately represent operating facilities.

The building of an SKA database for potential RFI sources is very important and needs to take the following into account:

- 1) The character and impact of the potential RFI sources will vary greatly due to the individual power and radiation characteristics, transmitting site characteristics, distance and the intervening topography. It includes high power sources on high sites with up to 1 MW effective radiated power and low power sources on average sites with less than a 100 W effective radiated power. The directionality of the radiation pattern needs to be taken into account. High power RFI sources may be up 1000 km (even more) distant.
- 2) Data should be obtained from the Communications Regulatory Authorities and although it is unlikely to be complete or the most accurate, it will be useful for crosschecks. The telecommunication network operators will have the most accurate data which they need for their network planning and operations. For certain applications, usually service networks, frequency spectrum blocks are allocated with different blocks to different operators. The frequency assignment to particular transmitters is then done by the operators to optimize network operations and frequency use. Direct interaction with operators can be established and their cooperation obtained.
- 3) Signal predictions (calculations) need to be carried out with computerized systems to obtain a complete picture of the radio environment and to determine the spectrum availability (conversely, the spectrum occupancy) at the various threshold levels. Although measurements need to be carried out, it cannot produce a complete picture due to the high cost of measurements and the difficulties of measuring at these very low levels without actually having the SKA.

If the data acquisition process and the prediction process are combined, then only the data for those RFI sources that exceed the threshold levels can be selected to be stored in the database.



- 4) It is also useful to have the predicted RFI available when measurements are made. Transmissions have to comply with ITU recommendations with respect to out of band (channel) radiation. Under normal circumstances, there will not be out of band transmissions. If it should occur, a valid complaint can be made to the regulator. However, operators usually will respond quickly to rectify the matter if the matter is taken up directly with them.

Many transmitters produce strong “out-of-band” unintended emissions. Although such emissions may fall within the limits set within the ITU Radio Regulations, they can still strongly affect sensitive radio telescopes like the SKA. Thus radiocommunication services in bands even hundreds of MHz away from the telescope operating frequency should often be considered in RFI evaluations.

## **5 Field measurements**

Field measurements and identification of RFI sources is extremely important in characterizing the present “radio quietness” of a potential SKA site. The RFI measurement program defined for SKA siting is addressing this issue. However, achieving sensitivity levels equivalent to those described in Recommendation ITU-R RA.769 is very difficult. Thus the measurement program may not adequately describe the RFI environment at the required level.

## **6 Potential future RFI**

Likely future radio transmitters are much harder to determine. Obvious areas of population and development are probably the best indicators of future activities. Thus SKA sites will need to be as remote as possible.

Telecommunications operators do not do long term network planning anymore. They rather respond to market demand which is often coupled to technological developments.

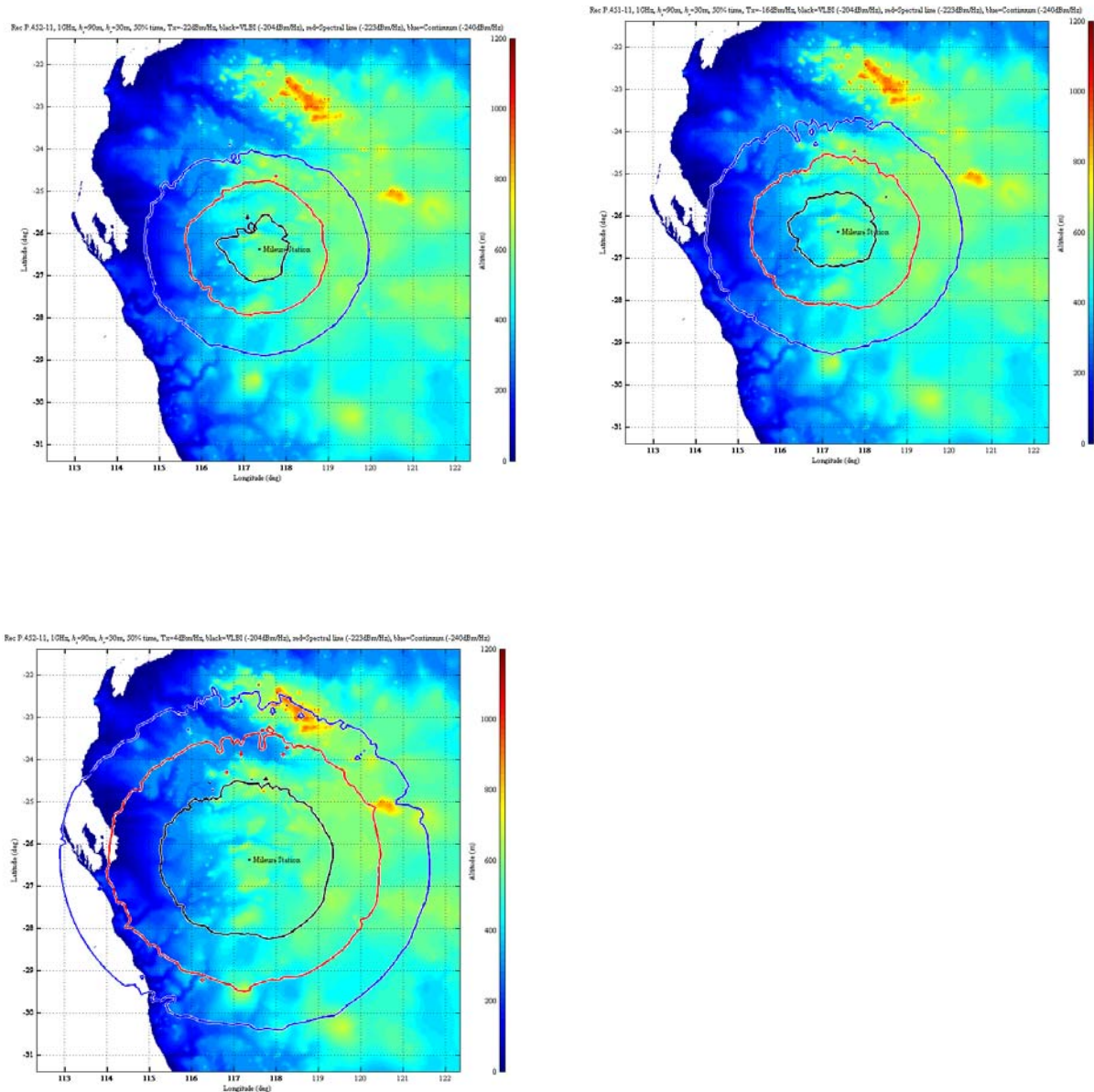
Potential future RFI should rather be controlled through regulatory processes coupled to the SKA.

## **7 Illustration of RQZ for the Australia SKA candidate site**

To illustrate the requirements with respect to RQZs, CSIRO studied the extent of potential RQZs around the Australian SKA candidate site at Mileura, WA. The results are shown in Fig. 62 (a, b, c) below.

FIGURE 62

**Protection zone sizes needed at Mileura for Recommendation ITU-R RA.769 levels (black=VLBI, red=spectral-line, blue=continuum) for three types of transmitters provided by CSIRO (Commonwealth Scientific and Industrial Research Organisation of Australia)**



The propagation model from Recommendation ITU-R P.452-11 includes local terrain characteristics and an interference probability of 50%. The three service examples are:

- Frame a (top left): GSM base station transmitters (–22 dBm/Hz);
- Frame b (top right): from fixed link transmitters (–16 dBm/Hz);
- Frame c (bottom left): DME transmitters (4 dBm/Hz).

The following parameters were used in this study: 1) Frequency: 1 GHz; 2) Interference probability: 50% of time; 3) Limits defined via Recommendation ITU-R RA.769: a) Single-dish Continuum: –270 dBW/Hz; b) Spectral line: –253 dBW/Hz (approximately Continuum + 15 dB); and c) VLBI: –234 dBW/Hz; 4) Propagation model: Recommendation ITU-R P.452-11; 5) Terrain for Mileura region included; 6) Receiver antenna: Height 30 m in 0 dBi; 7) Transmitter antenna: Height 90 m, Gain 0 dBi.

**Note by the Secretariat:** Recommendation ITU-R P.452-11 was superseded by the latest version – Recommendation ITU-R P.452-13.

## Annex 9

### Characteristics of the radio coordination zone around the Itapetinga radio telescope

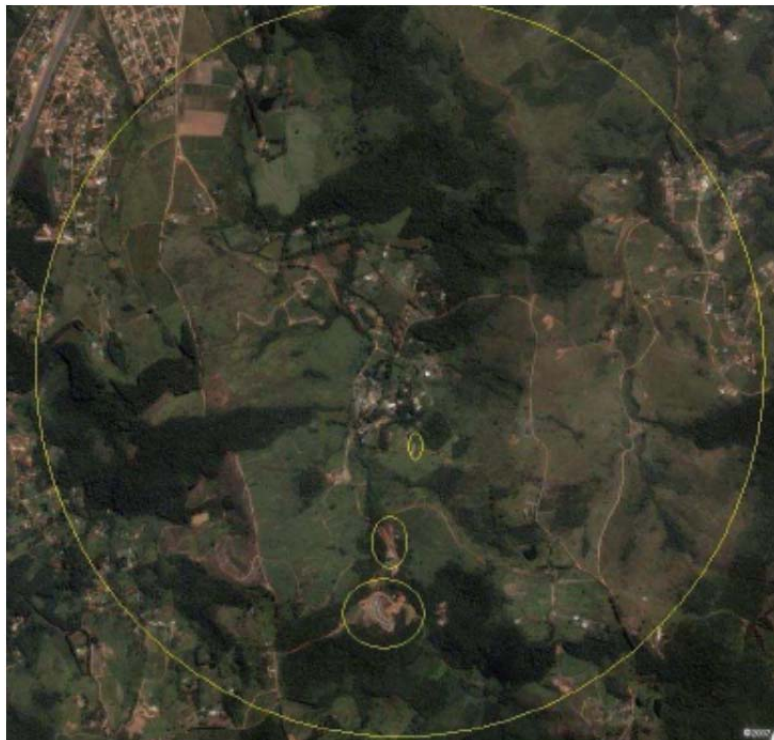
#### 1 The coordination zone around Itapetinga radio telescope

##### a) Introduction and description

The Itapetinga radio telescope is located at, latitude 23°11' 05.77"S, longitude 46°33' 28.429" W with 805 m elevation, in Itapetinga, city of Atibaia, São Paulo state, Brazil. It was built in 1973 in what was then a remote site. It is protected from the neighbourhood by hills having average elevation of 960 m. The population of Atibaia is around 96,000 inhabitants and population density is about 271 persons/ km<sup>2</sup>. Its main economical resources come from agriculture and tourism having very small industrial activity. During the last ten years, the urban area of the city increased getting close to boundary of the Electric Silence Zone created around the radio observatory.

FIGURE 63

The large yellow circle shows the electric silence zone around the Itapetinga radio telescope



Itapetinga was the first radio telescope built by ESCO in 1972. It is a 13,7 m single dish telescope optimized to operate in 18 GHz to 50 GHz band and to operate with smaller aperture efficiency in the band of 70 to 100 GHz. Due to the weather conditions at the observatory site, it has been used mainly in the lower frequency band. The diameter of the large yellow circle shown in Fig. 63 is about 4 km and the radome of the radio telescope is seen in centre as a white dot. Top left shows an urban area on the border of the Silence Zone. The small circles show areas of illegal deforestation.

Radio-frequency spectrum between 80 MHz to 3 GHz and from 3 GHz to 8 GHz has been measured using discone and horn antennas, respectively, in the radio telescope site and on the top of the hills.

Figures 64 and 65 shows the average of one-day measurements. It shows uncalibrated amplitude (dBm) versus frequency.

FIGURE 64  
Average daily spectra observed on the top of the hill

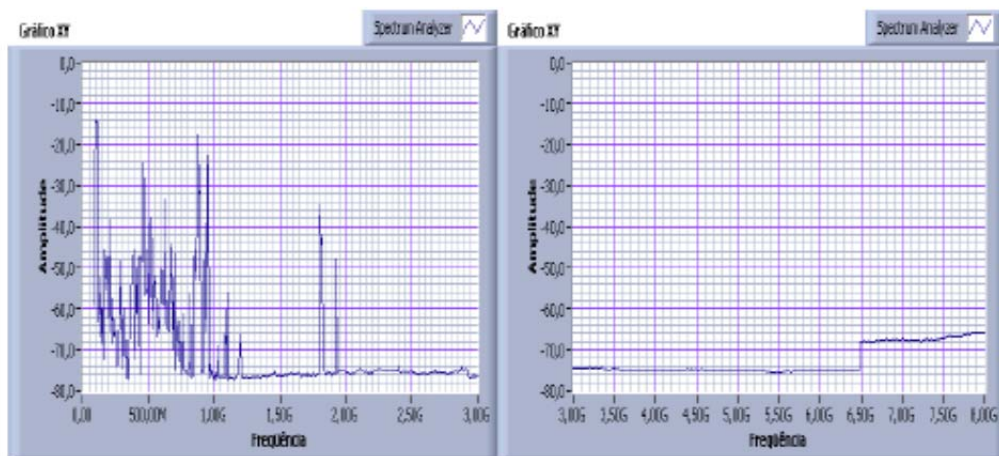
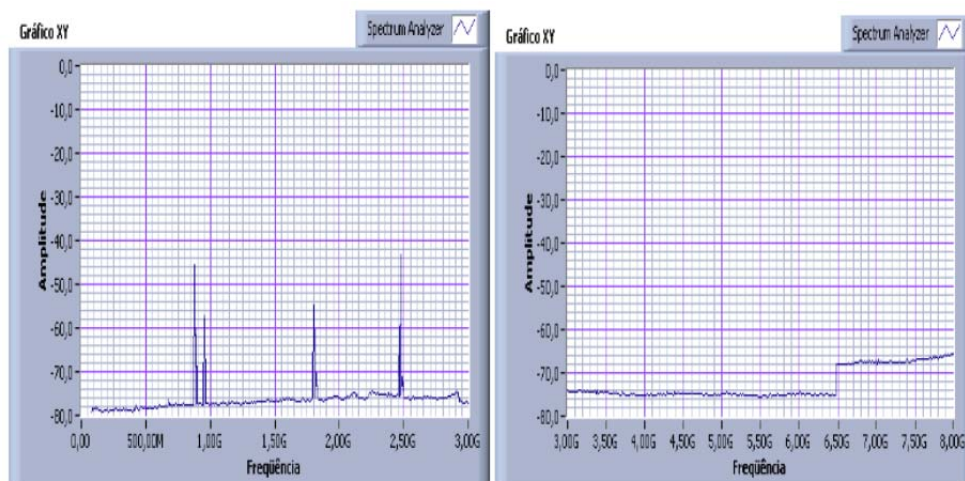


FIGURE 65  
Average daily spectra observed on the site of the observatory



## b) Local legislation

In order to protect the operation of the radio telescope and passive experiments operating in radio observatory from local radio interference, in 1972 the municipal law 1285/1972 was created



defining an Electrical Silence Zone adjacent to the Itapetinga observatory. In 1975 this law was modified to law 1503/1975 defining a circle of 4 km diameter, centered at the observatory, as the Electrical Silence Zone.

According to the definition of electrical silence adopted, no urban expansion is allowed in this area to avoid interferences due to power line transmission, microwave oven, radio control devices, neon signs, and all kind of devices capable of producing radio interference. The few people already living in this area receives instructions in order to avoid generate harmful interferences to the observatory.

This area is also protected from urbanization and deforestation since it is classified as a Permanent Protection Area (PPA), according to the federal laws 4771 stated in 15/09/1965 and 7803 stated in 08/08/1993.

In this particular case, the preservation of the Silence Area increased strongly the value of the land motivating the landlords to propose projects to divide their areas in small lots for sale. The laws above are impeding this kind of business. However a lot of effort is still necessary to preserve this silence zone. Besides the municipal law, the Observatory together with the National Agency of Telecommunications (ANATEL) play an important role in the maintenance of this zone.

## **Annex 10**

### **Establishment of Astronomy Geographic Advantage Areas in the Republic of South Africa for the protection of radio astronomy observations**

#### **1 Background**

The Republic of South Africa has been shortlisted to host the Square Kilometre Array (SKA), a next-generation radio astronomy facility that will operate within frequency bands outside of the traditional Radio Astronomy Service (RAS) primary allocations, as per the International Telecommunication Union (ITU) Radio Regulations. Further technical details for the project can be located at [www.skatelescope.org](http://www.skatelescope.org).

Metrics used to determine the suitability of the host site's radio frequency environment to support radio astronomy observations are:

- 1) the limitation of sources of detrimental radio frequency interference (see § 2), as measured by radio astronomy receiver equipment located at the host site;
- 2) the implementation of protection measures to ensure that the radio frequency environment does not deteriorate. That is, no new sources of detrimental radio frequency interference within a specified operating frequency range may appear during the lifetime of the radio astronomy facility, unless by approval from the operating radio astronomy institute.

The mechanisms and procedures developed to protect the radio frequency environment at the proposed South African SKA Core Site, with reference WGS co-ordinates S 30.714800, E 21.388000, may be generalised for the radio astronomy service.



## 2 Protection threshold levels

### 2.1 Introduction

The establishment of a protected area<sup>28</sup> includes, but is not limited to, the enforcement of threshold levels of protection on sources of interference within the operating frequency range of the RAS requiring protection. This section outlines current threshold levels of protection against interference, its limitations, and the establishment of South African RAS threshold levels of protection.

### 2.2 Existing protection mechanisms

According to ITU Radio Regulations, the RAS has primary allocations in 21 frequency bands. The bands are afforded threshold levels of protection against sources of detrimental in-band radio frequency interference. These protection levels are located in Table 1 of Recommendation ITU-R RA.769-2 (hereon referred to as RA.769-2), and reproduced in Fig. 66 for ease of reference.

FIGURE 66  
Threshold levels of protection against interference detrimental to  
radio astronomy continuum observations

Centre frequency <sup>(1)</sup> $f_c$ (MHz)	Assumed bandwidth $\Delta f$ (MHz)	Minimum antenna noise temperature $T_A$ (K)	Receiver noise temperature $T_R$ (K)	System sensitivity <sup>(2)</sup> (noise fluctuations)		Threshold interference levels <sup>(2) (3)</sup>		
				Temperature $\Delta T$ (mK)	Power spectral density $\Delta P$ (dB(W/Hz))	Input power $\Delta P_H$ (dBW)	pfd $S_H \Delta f$ (dB(W/m <sup>2</sup> ))	Spectral pfd $S_H$ (dB(W/(m <sup>2</sup> · Hz)))
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
13 385	0.05	50 000	60	5 000	-222	-185	-201	-248
25 610	0.12	15 000	60	972	-229	-188	-199	-249
73.8	1.6	750	60	14.3	-247	-195	-196	-258
151.525	2.95	150	60	2.73	-254	-199	-194	-259
325.3	6.6	40	60	0.87	-259	-201	-189	-258
408.05	3.9	25	60	0.96	-259	-203	-189	-255
611	6.0	20	60	0.73	-260	-202	-185	-253
1 413.5	27	12	10	0.095	-269	-205	-180	-255
1 665	10	12	10	0.16	-267	-207	-181	-251
2 695	10	12	10	0.16	-267	-207	-177	-247
4 995	10	12	10	0.16	-267	-207	-171	-241
10 650	100	12	10	0.049	-272	-202	-160	-240
15 375	50	15	15	0.095	-269	-202	-156	-233
22 355	290	35	30	0.085	-269	-195	-146	-231
23 800	400	15	30	0.050	-271	-195	-147	-233
31 550	500	18	65	0.083	-269	-192	-141	-228
43 000	1 000	25	65	0.064	-271	-191	-137	-227
89 000	8 000	12	30	0.011	-278	-189	-129	-228
150 000	8 000	14	30	0.011	-278	-189	-124	-223
224 000	8 000	20	43	0.016	-277	-188	-119	-218
270 000	8 000	25	50	0.019	-276	-187	-117	-216

Use of the threshold levels in Fig. 66 as a basis for protection of the RAS is limited as:

- 1) modern radio astronomy facilities operate across wide frequency ranges, which include spectral bands that do not have primary allocations for the RAS and so are currently not afforded any protection through the ITU;
- 2) modern radio astronomy receivers have noise performances that are superior to current specifications in Recommendation ITU-R RA.769-2;
- 3) modern radio astronomy receivers have bandwidths that approach 20% of the observing frequency using traditional feedhorn design, and can approach operating frequency ranges of 10:1.

<sup>28</sup> A protected area is an area in which all sources of radio frequency interference within the operating frequency range of the astronomical facility in question are under strict control. This control may include, but is not limited to, the enforcement of threshold levels on radiated emission anywhere within the protected area.

The requirement for protection in frequency bands that lie outside of the RAS primary allocations results in the need for development of threshold levels of protection against interference that are contiguous across a broad frequency range.

### 2.3 South African Radio Astronomy Service protection levels

South Africa has defined the South African Radio Astronomy Service (SARAS) protection level, which is contiguous across a broad frequency range. These threshold levels of protection against interference have been defined for:

- 1) bands in which the RAS has a primary allocation, in terms of ITU Radio Regulations;
- 2) bands in which the RAS has a secondary, or shared, allocation, in terms of ITU Radio Regulations;
- 3) bands for which the RAS has no allocation, in terms of ITU Radio Regulations.

The methodology used to calculate the SARAS protection levels follows Recommendation ITU-R RA.769-2 in principle. The following assumptions are required:

- 1) receiver and sky temperatures were linearly interpolated from values provided in Table 1 of Recommendation ITU-R RA.769-2;
- 2) bandwidth of the receivers are assumed to be 10% of the observing frequency;
- 3) radio frequency interference fills the observing band in question.

Assumption 2 above is based on the technical specifications of modern day radio astronomy receivers. Many receivers in development for next generation radio astronomy facilities claim bandwidths of 10:1 or more. Assumption 3 is made due to the nature of self generated<sup>29</sup> radio frequency interference, which is by its nature broadband.

The SARAS protection level, in units of spectral pfd, is calculated as:

$$SPFD[\text{dB(W/m}^2\text{/Hz)}] = 10\log_{10}(Power_{in}) + 20\log_{10}(f) - 10\log_{10}(\Delta f) - 158.5$$

where  $Power_{in}$  is 10% of the smallest detectable change in input power to the radio astronomy receiver for a 2000 second integration,  $f$  is the observing frequency in Hz and  $\Delta f$  is the bandwidth of the receiver in Hz. Due to the variety of units used within the telecommunications and regulatory sector, the SARAS protection levels are published in units of (dBm/Hz). The unit conversion is as follows:

$$\text{dB(W/m}^2\text{/Hz)} \rightarrow \text{dBm/Hz} : SPFD - 20\log_{10}(f) + 188.5$$

The result of this calculation of the interpolated Recommendation ITU-R RA.769-2 continuum threshold levels is shown as the dashed line in Fig. 67. In order to simplify reference to the protection levels and to facilitate the use computerised calculation and assessment systems, a linearly piecewise function is fitted to the data. This function is described by the following set of equations, and is referred to as the SARAS protection levels.

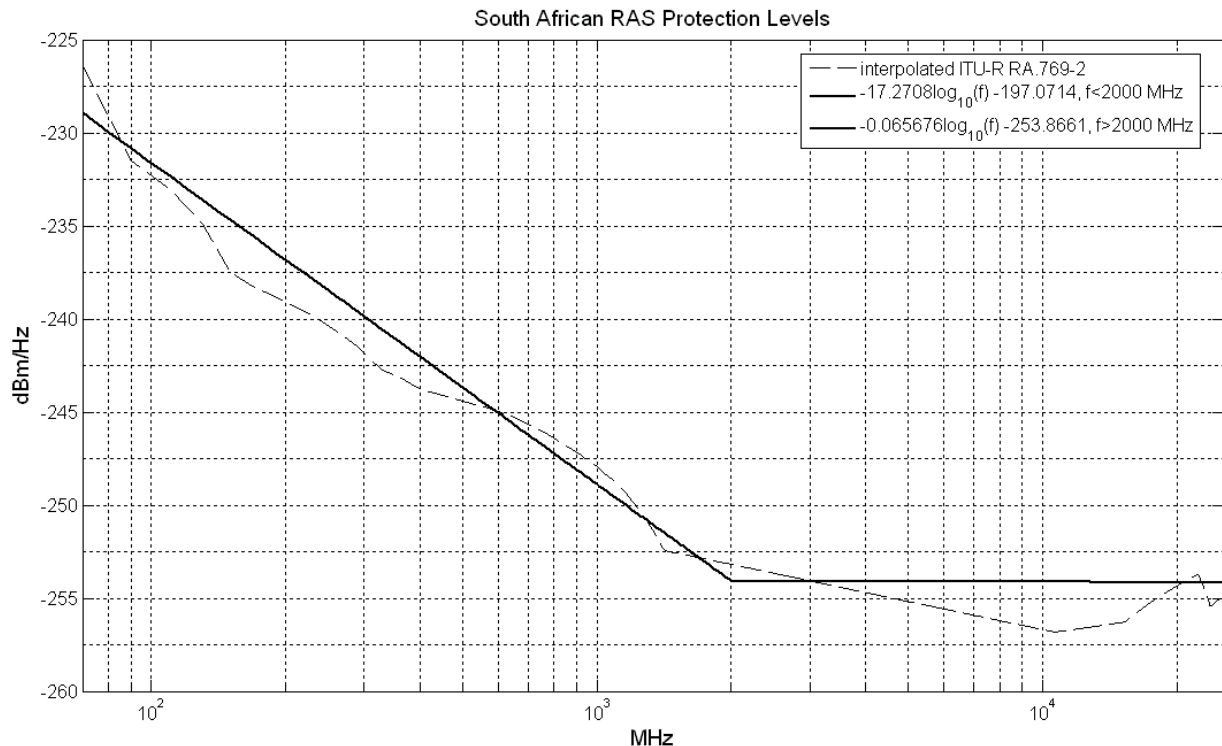
$$SARAS(\text{dBm/Hz}) = -17.2708\log_{10}(f) - 197.0714, \quad f < 2 \text{ GHz}$$

$$SARAS(\text{dBm/Hz}) = -0.065676\log_{10}(f) - 253.8661, \quad 2 \text{ GHz} \leq f \leq 25.5 \text{ GHz}$$

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<sup>29</sup> Self-generated radio-frequency interference is caused by electrical and electronic equipment required at the radio astronomy facility even though precautions are taken to minimize the emission of this interference.

FIGURE 67  
South African RAS protection levels



### 3 Establishment of protection mechanisms

#### 3.1 Introduction

Regulatory environments in some countries may hinder the establishment of protected areas that meet exact user requirements for the operation radio astronomy facilities. Many countries around the world that invest in radio astronomy infrastructure do not have the necessary regulatory support that enables efficient radio astronomy observations. Some countries may consider the development of legislation that will allow the relevant ministries or departments responsible for radio astronomy infrastructure to protect these facilities accordingly.

South Africa has established the Astronomy Geographic Advantage Act (Act no. 21 of 2007, hereon referred to as the Act) to provide sufficient mechanisms to establish protected areas for the advancement of astronomical activities. The Act takes precedence over all conflicting pieces of South African legislation.

#### 3.2 Protected areas

Three types of protected areas, known as Astronomy Advantage Areas (AAAs) are defined.

- 1) Core Astronomy Advantage Area
  - a) The area including and immediately surrounding an existing, or potential, astronomy facility. The area concerned would in most instances be private land, owned by the operating institution.

- b) The area will have a natural astronomical advantage. That is, the inherent environmental conditions of the location are suitable<sup>30</sup> for hosting astronomical facilities.
- c) Any activity within the Core AAA deemed to be detrimental<sup>31</sup> to astronomical observations is prohibited to maximum extent scientifically and practically possible, but may be authorised due to operational requirements for short periods of time.
- d) The extent area includes the airspace above the Core AAA, up to a height of 18,500 m.

2) Central Astronomy Advantage Area

- a) The immediate area surrounding any Core AAA. The size and shape of this area is determined by inverse reciprocal coverage predictions<sup>32</sup> of standard radio frequency transmissions within the area concerned, calculated to the required threshold levels of protection against interference. The area, which should be large enough to encompass these predictions, is therefore determined by:
  - i. the existing profile of radio frequency infrastructure within and surrounding the Core AAA;
  - ii. topographical features, which impact radio frequency propagation path losses.
- b) More than one frequency dependent Central AAA may be declared for any single Core AAA.
- c) Declared activities, that are activities deemed to be detrimental to astronomical observations, that are located within this area may be prohibited, unless authorized.
- d) The size and shape of the Central AAA may be manually amended, resulting in compromised protection of the radio frequency environment, to avoid high density areas of radio frequency infrastructure.
- e) The extent of this area includes the airspace above the Core AAA, up to a height of 18,500 m.

3) Co-ordinated Astronomy Advantage Area

- a) The immediate area surrounding any Central AAA. The size and shape of this area is determined by inverse reciprocal coverage predictions of high powered radio frequency transmissions (typically greater than 60 dBm e.i.r.p.<sup>33</sup>) within the area concerned, calculated to the required threshold levels for protection against saturation of astronomy receiver equipment. The size and shape of this area are therefore determined by:
  - i. the existing profile of radio frequency infrastructure within and surrounding the area of the Core and Central AAAs;

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<sup>30</sup> The suitability of an environment is highly dependent on the type of astronomical observations to be performed, in particular the operating frequency range. For the RAS it means a remote area with the lowest existing level of radio communication and acceptable weather and geophysical conditions.

<sup>31</sup> A detrimental activity is one that produces radiated emission at levels that exceed the SARAS protection levels, as calculated at a reference point. This reference point is usually co-located with the astronomy facility. In the case of an array facility, this reference point may be located at the virtual centre of the array.

<sup>32</sup> Radio frequency predictions should be performed using any appropriate method described in Recommendation ITU-R P.526.

<sup>33</sup> Effective isotropic radiated power.

- ii. topographical features, which impact radio frequency propagation losses;
  - iii. technical specifications for the radio frequency equipment used in the radio astronomy receivers being protected.
- b) Declared activities within this area must ensure coordination with the managing authority.
  - c) More than one Co-ordinated AAA may be declared for any single Core AAA.

Any activity within a Core, Central or Co-ordinated AAA that is detrimental to radio astronomy observations is required to undergo a review process. This results in authorization or prohibition of the activity, or a published set of conditions that must be met in order to obtain authorization. These conditions would usually result in reduction of the impact of an activity on radio astronomy observations at the common reference point.

Assessment of transmissions is carried out as follows:

- 1) The signal level of each transmission is calculated at a common reference point using modern radio propagation prediction techniques<sup>34</sup>. This level is compared with the prescribed threshold levels of protection against interference.
- 2) Transmissions that exceed the required protection level should be investigated further by the relevant operator in order to reduce signal levels, as calculated at the common reference point. Measures that can be taken into consideration include reduction in transmitted power, spectral shaping and beam shaping, reassignment of the radio-frequency spectrum used or even the closing down of a transmission facility.
- 3) If the transmission is an essential service<sup>35</sup>, and all measures to reduce the impact of the transmission have been investigated and implemented, a concessionary protection level may be authorised. This level cannot exceed the saturation level<sup>36</sup> of the radio astronomy receiver equipment.

### 3.2.1 Case Study – South Africa

Table 52 summarizes the relevant details following the draft implementation of astronomy advantage areas in the Northern Cape Province of South Africa. The SARAS threshold levels were used as reference for required threshold levels of protection against interference at the common reference point, located within the Core AAA.

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<sup>34</sup> Radio-frequency predictions should be performed using any appropriate method described in Recommendation ITU-R P.526.

<sup>35</sup> An essential service is a service that is required, and for which the transmission facility is located, within a Central AAA, and can include all safety of life services, radiocommunication services operated by the safety and security cluster, health services and emergency services, and broadcasting terrestrial services. A service that can be provided through alternate technologies and signal transmission strategies is not an essential service.

<sup>36</sup> The saturation level is defined to be that input power level that causes radio astronomy receiver equipment to behave non-linearly.



TABLE 52

**Implementation of protected astronomy advantage areas in the  
Northern Cape province of South Africa**

<b>Type of AAA</b>	<b>Frequency low</b>	<b>Frequency high</b>	<b>Size (km<sup>2</sup>)</b>	<b>Authorizations</b>
Core	70 MHz	25,500 MHz	140	No transmissions authorized
Central	70 MHz	1,710 MHz	123,408	Existing essential services that meet conditions to reduce impact on common reference point
Central	1,710 MHz	6,000 MHz	80,264	Existing essential services that meet conditions to reduce impact on common reference point
Central	6,000 MHz	25,500 MHz	44,607	Existing essential services that meet conditions to reduce impact on common reference point
Co-ordinated	70 MHz	1,710 MHz	238,422	Existing services
Co-ordinated	1,710 MHz	6,000 MHz	43,145	Existing services

## Annex 11

### **Radio quiet zone – Pushchino Radio Astronomy Observatory of the Astro Space Centre in the Physics Institute of the Russian Academy of Sciences**

The Pushchino Radio Astronomy Observatory is one of two largest observatories on the territory of the Russian Federation according to the quantity of the radio-telescopes and to the value of their common wave range. Three radio telescopes now in operation occupy an area of about 150 hectares. The size of a DKR-1000 telescope (a cruciform band radio-telescope) is 1000 by 40 m. The bandwidth of the telescope is 30-120 MHz. A LPA telescope (a large phased array) consists of 16,384 dipoles with the central frequency of 111.5 MHz and the bandwidth of 4 MHz. A RT-22 telescope represents a parabolical reflector of diameter 22 m. The working frequency range of the telescope is 327 MHz-37 GHz. Thereby the telescopes of the observatory may conduct observations using the wavelength from 10 m up to 8 mm.

The observatory uses superheterodyne receivers and a new generation of digital receivers as well. Observations using DKR-1000 and RT- 22 radio-telescopes are carried out in the bandwidths which are allocated to the RAS. They also are carried out in a number of frequency bands that are not allocated to the RAS but allow conducting radio observations with high sensibility and solving certain astrophysical problems.

Interferences from the systems of mobile communication, radio navigation systems, satellite communication, television, and noises from the natural sources (thunderstorm discharges, hoar-frost on the dipoles, etc.) which are observed at the Pushchino radio telescopes allow using the telescopes for observations in different bandwidths during 20-80% of the whole time. Well-known methods of interference reduction are applied depending on the type and power of interferences, these are tuning-out (a shift of the frequency of observations), a digital and analog signal filters (for superheterodyne receivers), cutting-out of narrow-band noises, and the digital signal filtration (for digital receivers). Work is underway on monitoring of interferences from the means of radiocommunication stations. In the long-wave part of the radio astronomy waveband the interference situation is improved by the fact that the nearest buildings are situated not nearer than 500 m from the telescopes.

When observations are conducted in the bands not allocated for to the RAS protection from emission of the radio communication stations insured by Administration of the Russian Federation. Due to this fact it is possible to carry out the observation in the frequency band 109.5-113.5 MHz by the LPA radio telescope.

Thereby the territory of the Pushchino Radio Astronomy Observatory could be considered as an RQZ.

## Annex 12

### **Studies of the emission management zone around the Dominion Radio Astrophysical Observatory, Penticton, Canada**

#### **1 Introduction**

Radio astronomy essentially involves making observations close to or at the sensitivity limits attainable with currently available technologies. In addition, the more spectrum available at a radio astronomy station, the more productive that observatory can be. In the case of new, major international facilities, such as the Square Kilometre Array or the Atacama Large Millimetre Array, sites have been chosen that are almost unpopulated. However, there are many major scientifically valuable radio astronomy stations in the world that are located in environments of increasing population and spectrum use. Maintaining the effectiveness of these facilities is a complicated issue in spectrum management, but is nevertheless essential. Moreover, there is no guarantee in the medium to long term that the currently isolated locations of the new instruments will remain as electromagnetically isolated as they are now. It is therefore useful to look at the task of evaluating the environments of radio observatories and the tools needed for managing the areas around them. In these cases, perhaps the use of the term “Radio Quiet Zone”, is not really accurate, and using the term “Emission Management Zone” (EMZ) would be more appropriate.

Maintaining an EMZ involves efforts at the international, national, regional and local level, and of course the radio astronomy station in question. The collaboration between these bodies comprises the development of relationships and lines of communication, measurement programmes and development of propagation modelling tools. In addition, it is necessary to understand the interference problems particularly relevant for that particular EMZ. These fall into three broad categories:

- a) unwanted emissions from transmitters operating in designated radio services in bands allocated to those services;
- b) signals and unwanted emissions from unlicensed devices operating in domestic environments (e.g. wireless networks and other wireless devices, garage door openers, ultra-wideband devices and BPL systems);
- c) emissions from computers and other domestic devices using digital systems or radio-frequency oscillators.

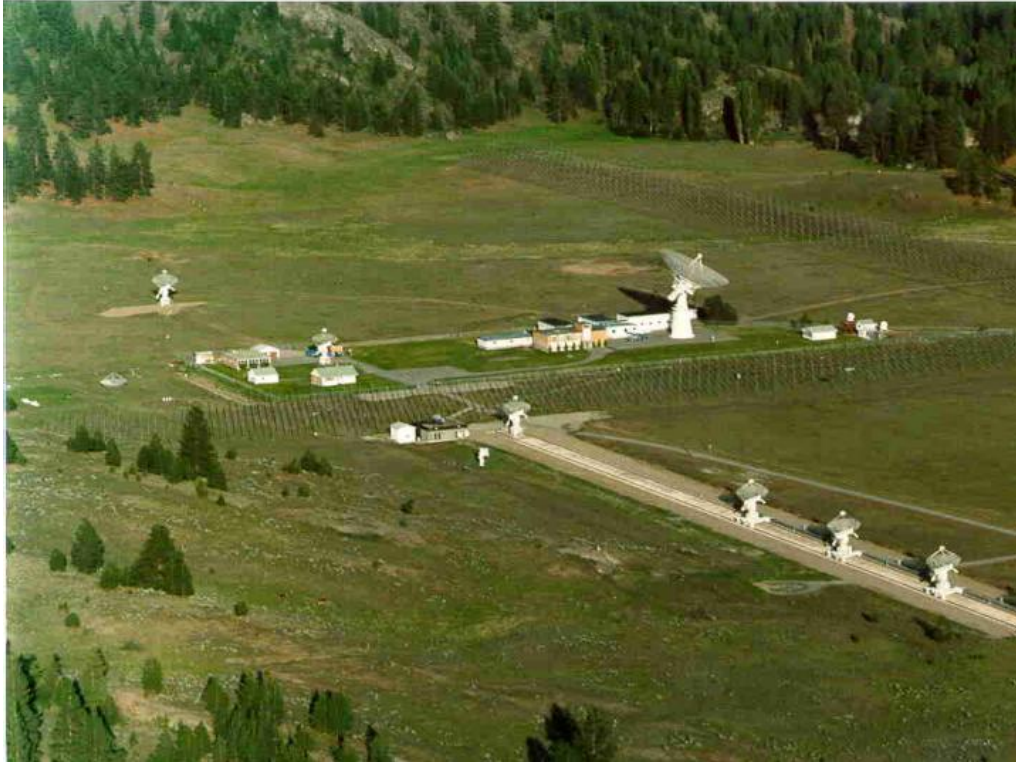
Category (a) falls in the domain of conventional spectrum management processes. However, categories (b) and (c) fall outside these processes, and the only practical approach found so far is to manage population growth in the EMZ. Finally, the protection measures used to ensure the continuing viability of the observatory must not burden other spectrum users unduly.

This report is essentially a case study, describing work in progress to review and tighten the definition of the EMZ surrounding the Dominion Radio Astrophysical Observatory (DRAO), located near Penticton, British Columbia, Canada. The study comprises measurements and modelling of path attenuation around the observatory, measurements and modelling of background noise and estimating interference levels from potential housing developments.

## 2 The Dominion Radio Astrophysical Observatory

FIGURE 68

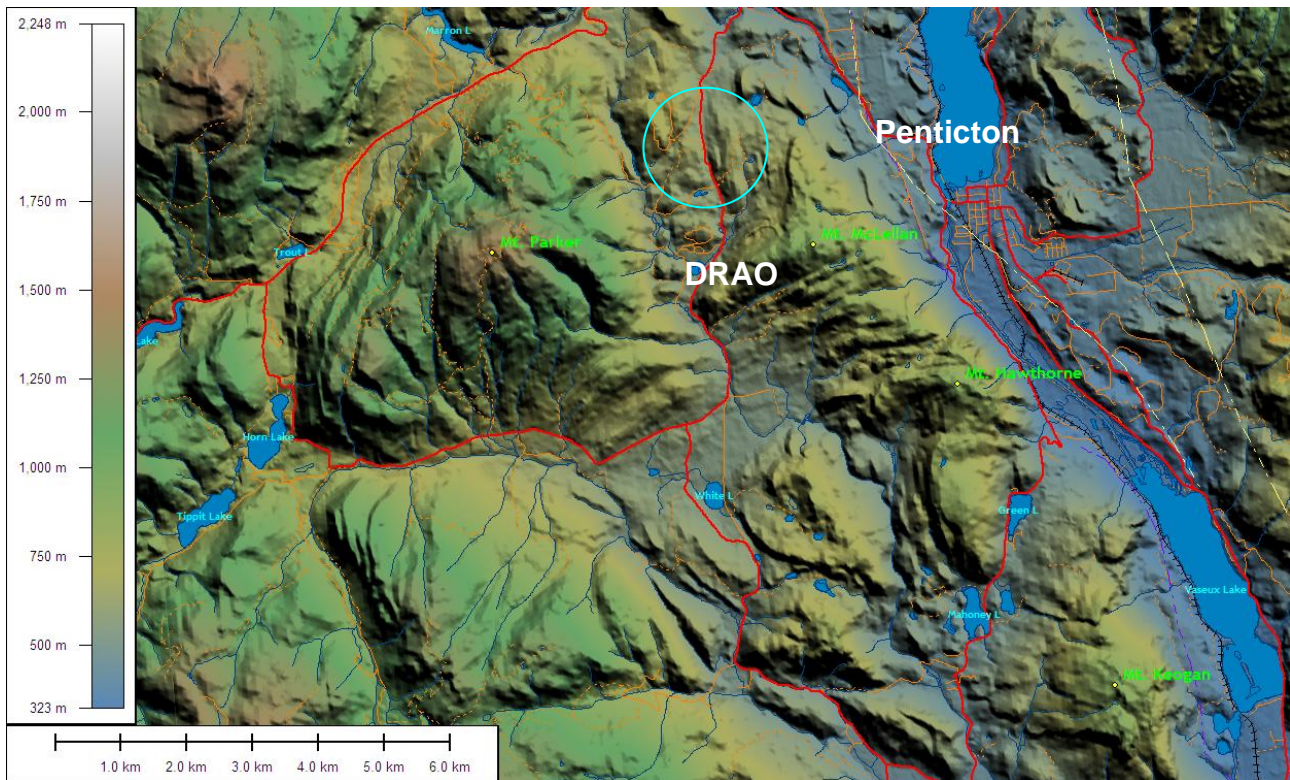
The Dominion Radio Astrophysical Observatory viewed from the North-West



There are five instruments in more or less continuous observational operation at the site: the 7 element, linear array synthesis radio telescope (one of the 9 m diameter antennas is out of shot to the right), a 26 m radio telescope, two 1.8 m solar flux monitors, producing the 10.7 cm solar radio flux index of solar activity, and a riometer (relative ionospheric opacity meter). The small antenna close to the synthesis telescope antenna at the centre of the frame is the 4 m Next Generation Solar Flux Monitor, now under construction. The land to the right of the picture is used for the development of new radio telescope technology. The observatory is located in a natural bowl, screened from most terrestrial interference by the surrounding mountains.

FIGURE 69

**DRAO environs.** DRAO lies about 8 km from the Okanagan Valley, and is screened from it by a range of hills. The circle marks a neighbouring housing development



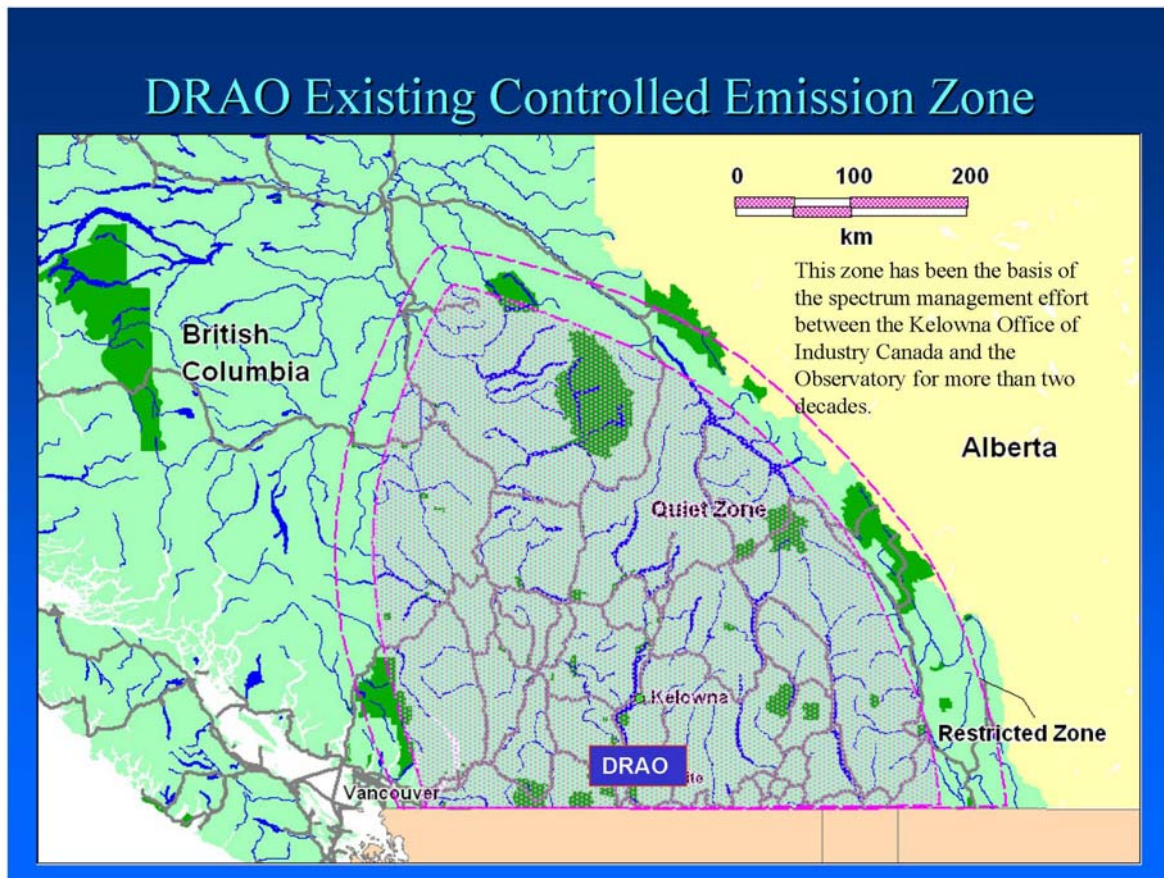
### 3 The need for a study

Within Canada, the guideline for managing the radio spectrum to protect the observatory is an EMZ, which has been in effect for more than two decades. The zone is shown in Fig. 70. Although satisfactorily large, it contains many communities. On the plus side, the interior of British Columbia comprises a series of mountain ranges running mainly North-South. Most of the populated areas lie in the valleys between these ranges, which provides significant topographic protection for the observatory from unwanted emissions from these communities, along with intended transmissions in shared bands.

The need to review this EMZ arose from the increasing pressure to provide additional spectrum to communities that are located within the boundary of the EMZ. The need for additional spectrum is driven by the constantly evolving and increasingly sophisticated radio applications as well as by the emergence of new radio applications, including consumer devices. Another contributing factor was that the EMZ was established based on radio technologies and spectrum usage dating back to more than 20 years ago which does not reflect today's reality. This shortcoming turned every licensing request addressed by the Administration and Observatory working together into a case study, which led to a lot of efforts and time being invested by all parties.



FIGURE 70  
The existing emission management zone



What was needed was a map of path loss between points on the map and the observatory, and for providing community planning information, estimates of domestic emissions and their potential impact upon observatory operations.

#### 4 The study

The study comprises two separate projects:

- theoretical calculations of path loss between points in the EMZ and a test antenna at the observatory, using the Predict and Longley-Rice propagation models and a digitized terrain map, and measurements made using a test transmitter at as many modelled points as possible;
- estimates of the emissions produced by an average house.

The project is a joint one between the national, regional and local offices of Industry Canada, and staff at DRAO.

##### 4.1 Path loss measurement and calculations

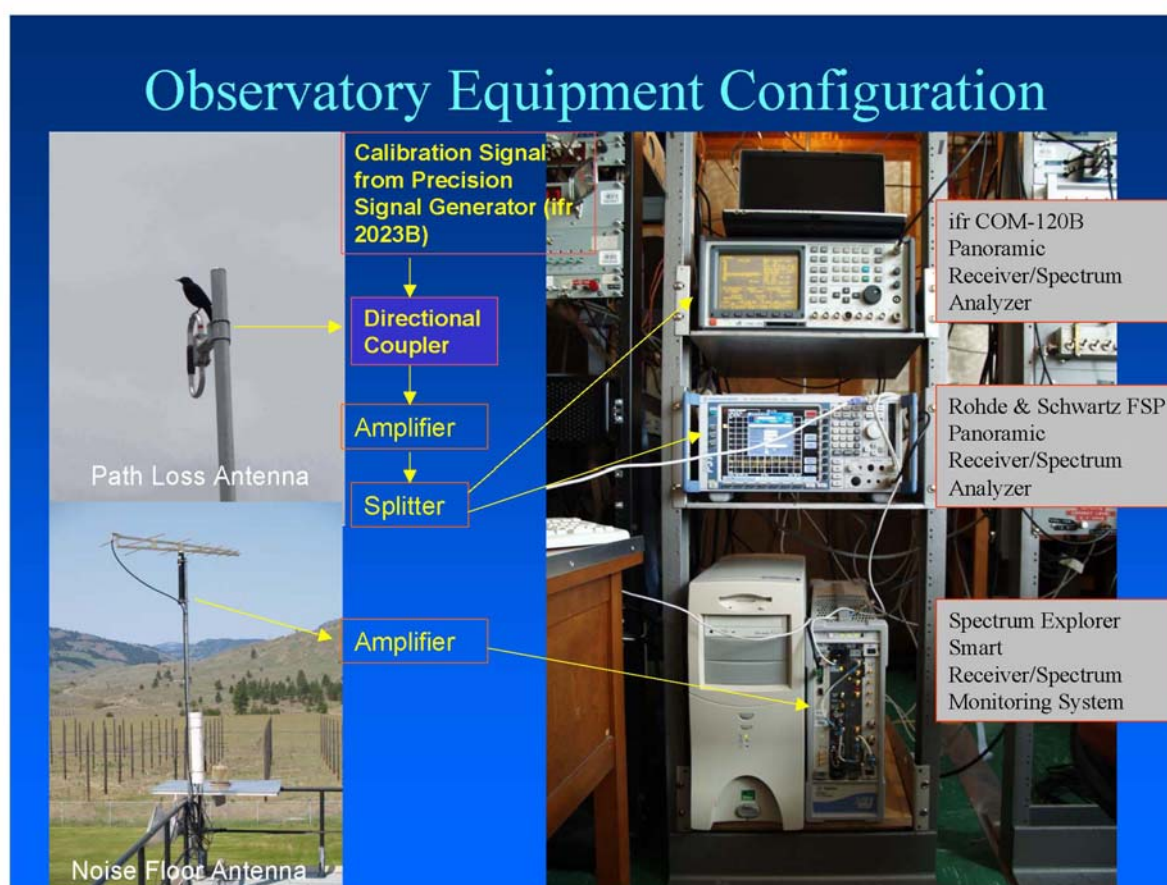
Because of unpredictable access problems in highly mountainous terrain, the experiment was done in the reverse order. Test transmissions were made from points around the observatory in the EMZ, the path losses estimated, and then the path losses between those points and the observatory estimated using both the Predict and Longley-Rice propagation models.

### 4.1.1 The hardware

The hardware at the observatory is shown in Fig. 71. The test transmissions in the 406.1-410 MHz band were received using a calibrated dipole and measured and recorded using two spectrum analysers. The log periodic antenna was used for an ongoing programme of noise floor measurements. The outputs from the lower spectrum analyser and the Spectrum Explorer system were directly accessible over the DRAO computer network, and in the Vancouver and Ottawa offices over the internet.

FIGURE 71

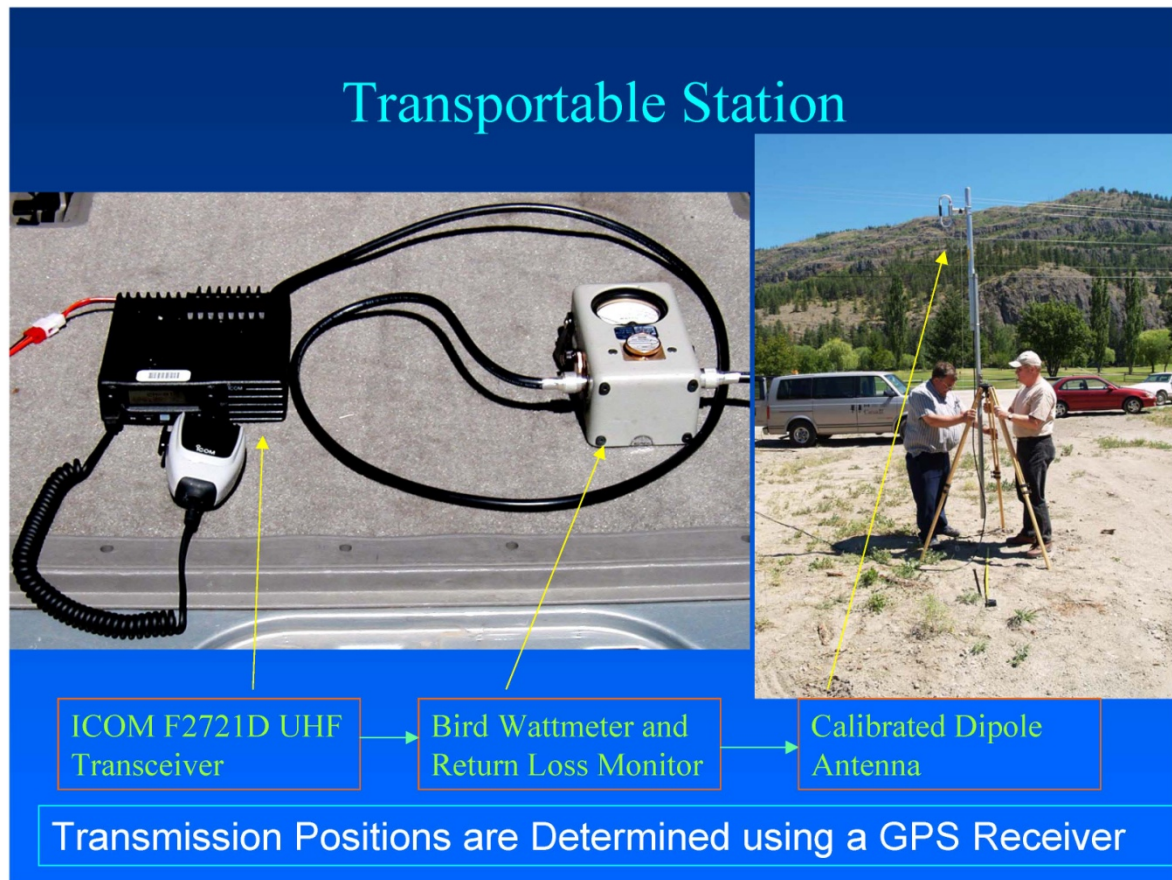
**Observatory hardware. The dipole was used for the path loss transmissions and the log-periodic antenna for noise floor measurements**



The mobile transmitter arrangement, as shown in Fig. 72, consists of an identical calibrated dipole, mounted on a tripod. A commercial transmitter provided the signals and a power meter and calibrated length of coaxial cable ensured it was possible to estimate the power radiated.

FIGURE 72

The mobile transmitter system, comprising a commercial transmitter, a power meter and an identical dipole to that used at the receiver, together with a calibrated length of coaxial cable

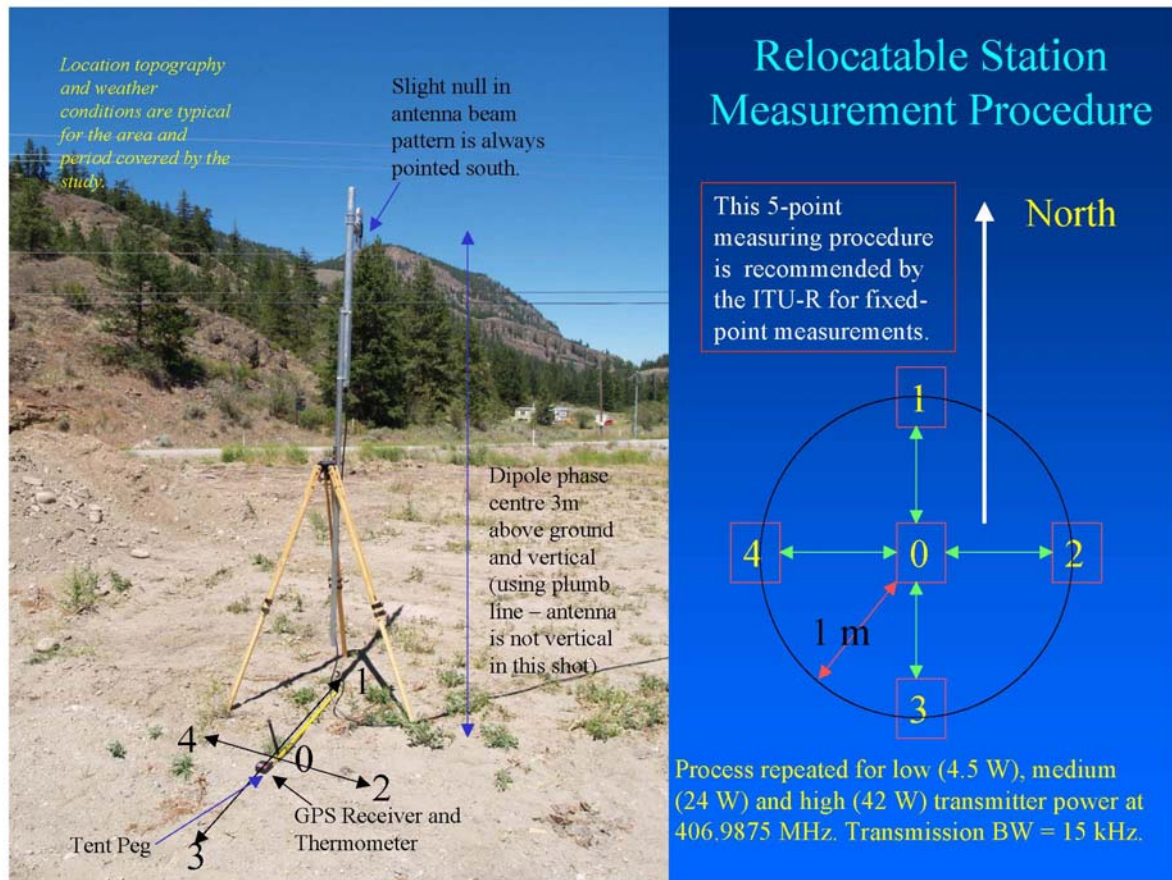


The measurement method used here reduces somewhat the errors induced in path loss measurements by local reflections. Transmissions are made from five points: the main point, and then at points North, East, South and West of this point at a distance of 1 metre from the main point. The path loss is measured for each point and the average of all five points used in the study. In order to accommodate the need for high power in some cases, and lower powers in other cases in order to avoid overloading the receiver, for each point, transmissions were made at three power levels: low (4.5 W), medium (24 W) and high (42 W). The process is shown in Fig. 73.



FIGURE 73

## Transmission procedure used for path loss measurements



#### 4.1.2 Measurements

Path loss measurements were made from a variety of locations: at the tops of hills and in valley bottoms. However, more measurements were made around valley bottoms because of (a) accessibility, and (b) that is where housing developments and other concentrations of human activity usually occur. A GPS receiver was used to determine the coordinates of the locations where measurements were taken. Of course, hilltops are the chosen places for transmitters, so hilltops either already used for transmitters, or where more might be deployed, and hilltops that might be considered suitable sites for future transmitters were tested.

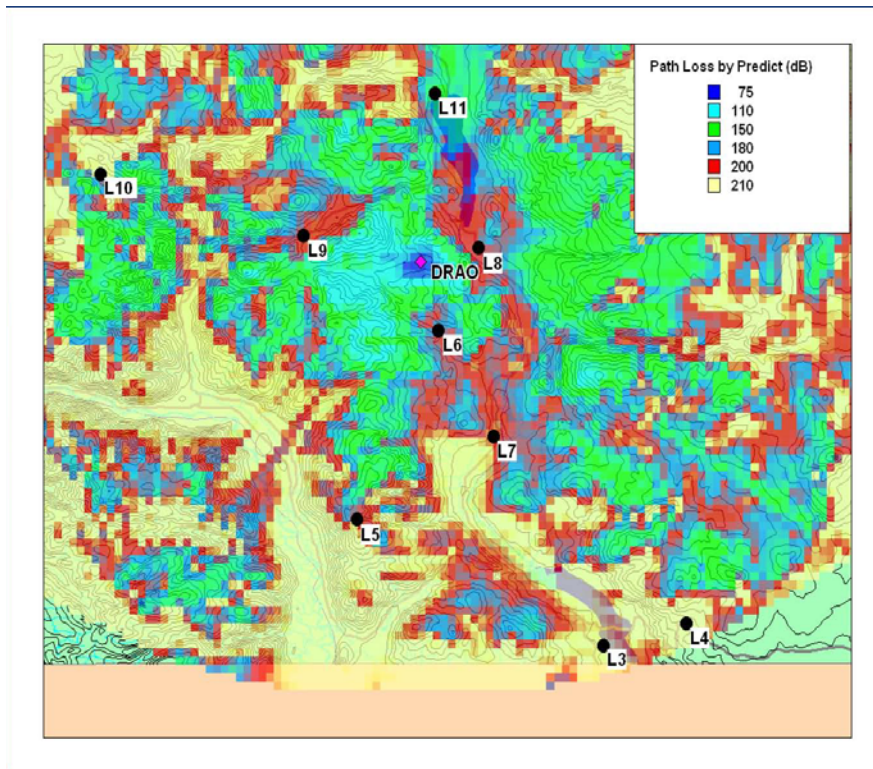
#### 4.1.3 Modelling propagation path losses

Using a digitized terrain map (50-m resolution) and propagation modelling software, the propagation path losses between the test transmission location and the observatory test antenna were estimated. Two software packages were used: “Predict” and “Longley Rice”. *Predict* is a commercially available package developed in Canada and widely used for propagation modelling. In urban, suburban and country terrain between flat and mildly hilly, it has been found to yield estimates within 10 dB of the measured values in most cases. The *Longley-Rice* propagation model is a widely available and used public software.

Figure 74 shows the local propagation loss map as estimated using the Predict software. In addition, the test sites are marked. Test point L11 was located in the centre of the housing development shown in Fig. 69.

FIGURE 74

Propagation loss map for the DRAO environs estimated using the Predict software and a digitized terrain map. The left and right edges of the map run North-South with North at the top



The measured losses from each of the test locations, together with the estimates obtained using the Predict and Longley-Rice propagation modelling software are tabulated below.

Location	Estimated path loss (dB)		Measured path loss (dB)	
	Predict	Longley-Rice	Median	Std. deviation
L3	208	187	160	3
L4	215	190	171	2
L5	184	165	154	3
L6	200	165	129	3
L7	208	172	145	3
L8	196	170	149	4
L9	191	175	160	4
L10	191	180	168	3
L11	176	170	153	5

The measured path losses from transmission sites to the observatory were in almost all cases significantly lower than estimates made for the same path using either the Predict or Longley-Rice propagation models. Therefore unless appropriate margins are allowed (these margins might be specific to the terrain surrounding the observatory), compatibility assessments regarding prospective deployment of devices or services that could possibly interfere with operations at the observatory should not be made without some measurements. The differences between modelled and measured propagation losses are almost certainly due to the rough terrain surrounding the



observatory. However, terrain properties are used to screen radio observatories from interference, so this particular case is applicable at other observatories.

Measurements made in high summer (hot and dry), and autumn (cooler and wetter) did not differ significantly from one another. However at this point it is not known whether this conclusion would apply to winter (cold and snow). Further measurements need to be done.

#### **4.1.4 Conclusions**

- 1) In assessing compatibility with proposed deployments of transmitters or housing developments, one cannot depend exclusively on modelled propagation losses without at least enough actual measurements to assess safe protection margins for making the estimates safely usable.
- 2) In the terrain surrounding DRAO, which comprises low mountains, forest and arid terrain, there was little difference between measurements made during hot dry summer weather and moister autumn conditions. However, as yet no measurements have been made under winter conditions (snow and ice). These need to be done.
- 3) In the case of housing developments or proposed transmitter deployments, specific path loss measurements need to be made. The general results in studies like this can safely be used only as guidelines during the initial evaluation process.
- 4) The collaborative effort here between spectrum managers in the Canadian Administration and DRAO radio astronomers in all stages of the study greatly improved the understanding of each other's problems in the spectrum management process and working together at all levels in the project promoted good working relationships and an excellent atmosphere for future studies.

## **4.2 Domestic radio emissions**

### **4.2.1 The problem**

An issue of growing concern is the rapidly increasing number of devices pervading both the commercial and domestic spheres that either use radio technology or electronics liable to make interference. In general, commercial applications are located in areas allocated for commercial use, but domestic applications arise everywhere there are people.

Radio telescopes such as the Atacama Large Millimetre Array, located on the Atacama Plateau in Chile, and the Square Kilometre Array, which is likely to be built in Western Australia or South Africa, are far from population centres. However, there are many radio telescopes in the world, at sites such as Jodrell Bank (United Kingdom) and Effelsberg (Germany) that were reasonably isolated when they were built but are increasingly affected by encroaching housing and community development. In addition, the number of potentially interfering devices in common use is increasing and will continue to do so. In a world with a rapidly expanding population and pressures for resource development, there are no guarantees that currently isolated sites will remain so.

The Dominion Radio Astrophysical Observatory is a typical example of a site that was well isolated but is now faced with pressure to expand communities and build housing developments closer to the observatory. The local municipal land managers understand the observatory's concerns but need more quantitative information to help them better understand what can be permitted without causing undue risk to the observatory and what cannot.

### **4.2.2 Unwanted emissions from a single device**

Consider the case of a single electronic device, producing radio emissions with power distributed over the spectrum given by  $\xi(f)$ , located at a distance,  $r$ , from the observatory, where the path loss to the radio telescope is  $L(r)$ . The loss is shown as a function of  $r$  but in rough terrain it will be a more

complicated relationship involving additional variables. The total power at the radio telescope from all electronic devices is given by:

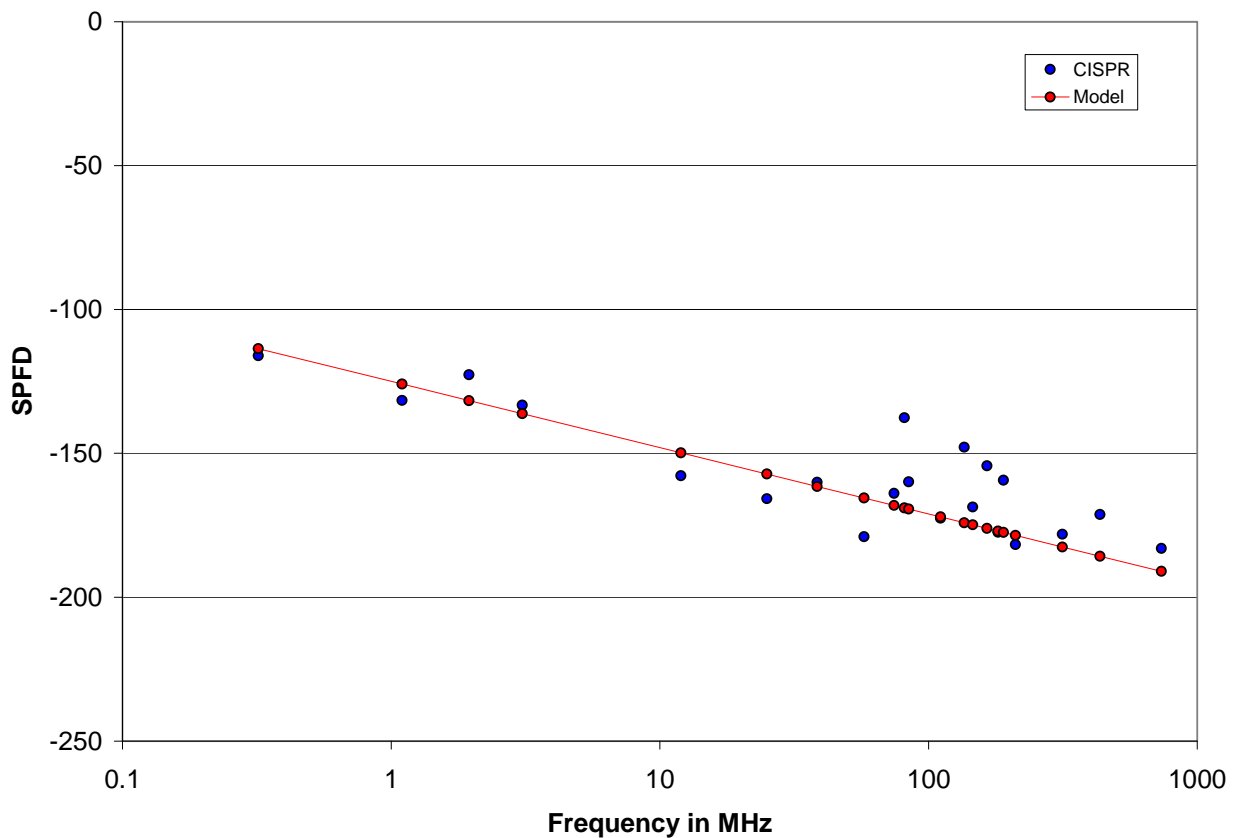
$$P = \sum_i \frac{\xi_i(f)}{L_i(r)}$$

We assume that all devices intentionally transmitting are doing so outside bands allocated to the RAS. Under these circumstances, all the emissions being considered are unwanted emissions. The upper limits for unwanted emissions from **electronic devices** are listed in documents produced by the Comité International Spécial des Perturbations Radioélectriques (CISPR) in standard documents CISPR-11 and CISPR-22.

Unfortunately the CISPR documents do not quote values for frequency bands allocated to the RAS on a primary or secondary basis. Therefore a curve was fitted to the CISPR values in order to estimate the values in bands in which radio astronomical observations are made.

FIGURE 75

The CISPR values (blue) show the maximum spfd's for devices as measured 30 m from the device. The red dots and line are a fitted equation



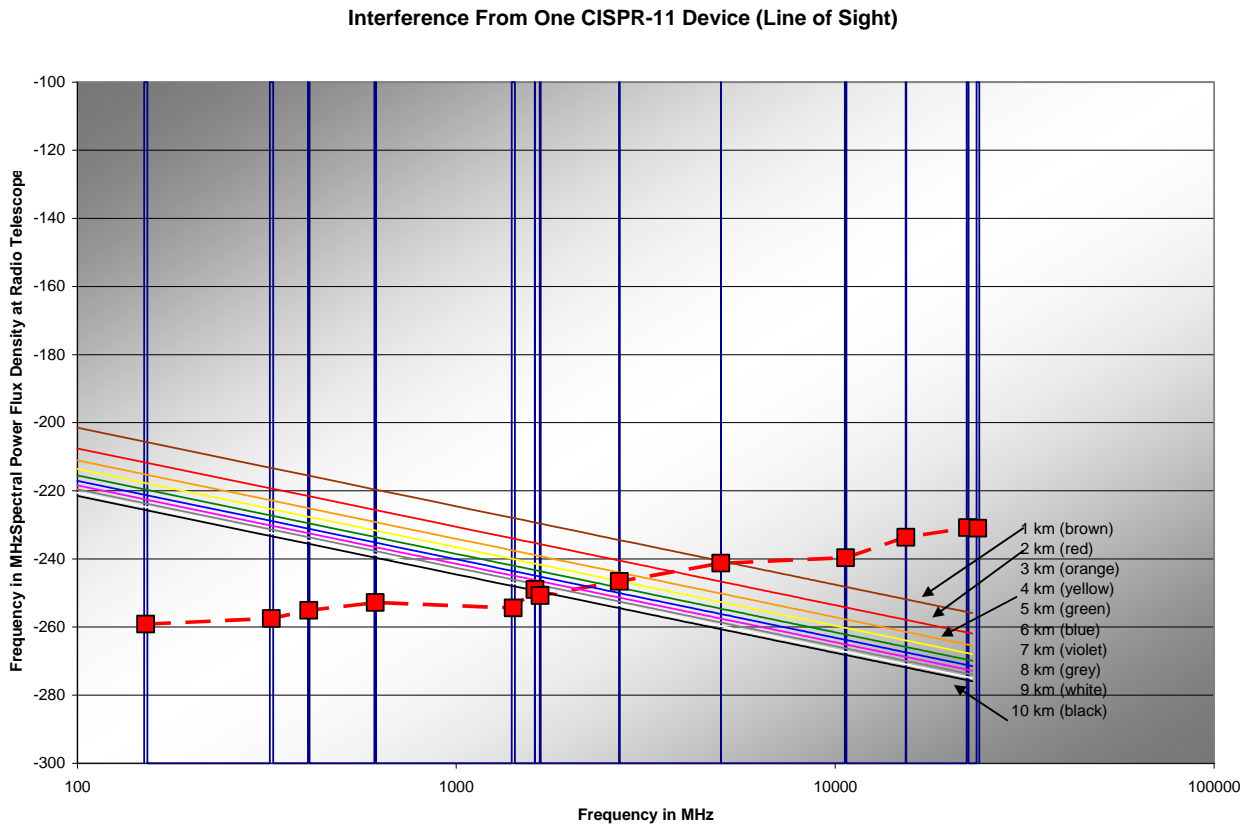
The fitted equation is:

$$spfd = -10 \ln(f) - 125$$

Where  $f$  is the frequency in MHz. The CISPR values show deviations of possibly 20 dB from the fitted line in some cases, but taking into account the deviations in real cases, plus devices actually hitting the CISPR values would be a worst case, the simplicity is justified.

Using the levels in Recommendation ITU-R RA.769 as the criterion for flagging compatibility issues, in combination with the equation above, we can estimate the problem potential for a single device emitting at the CISPR limits as a function of frequency and distance in LoS of a radio telescope. The results are shown in Fig. 76. It is clear that for radio astronomical observations at frequencies below about 2 GHz, a single device would be a problem if closer than about 10 km from the observatory, in LoS. If the device is located inside a house, it is assumed in standards calculations that this attenuates the signal by an additional 10 dB. One example of a device to which this discussion applies is the *energy saving light bulb*, some kinds of which use radiofrequency oscillators to excite the plasma. Since these are expected to be deployed in great numbers over the coming decade, they are a major issue for radio observatories located close to any significant population concentration.

FIGURE 76  
Unwanted emissions from a single CISPR device at various distances  
from a radio telescope as a function of frequency



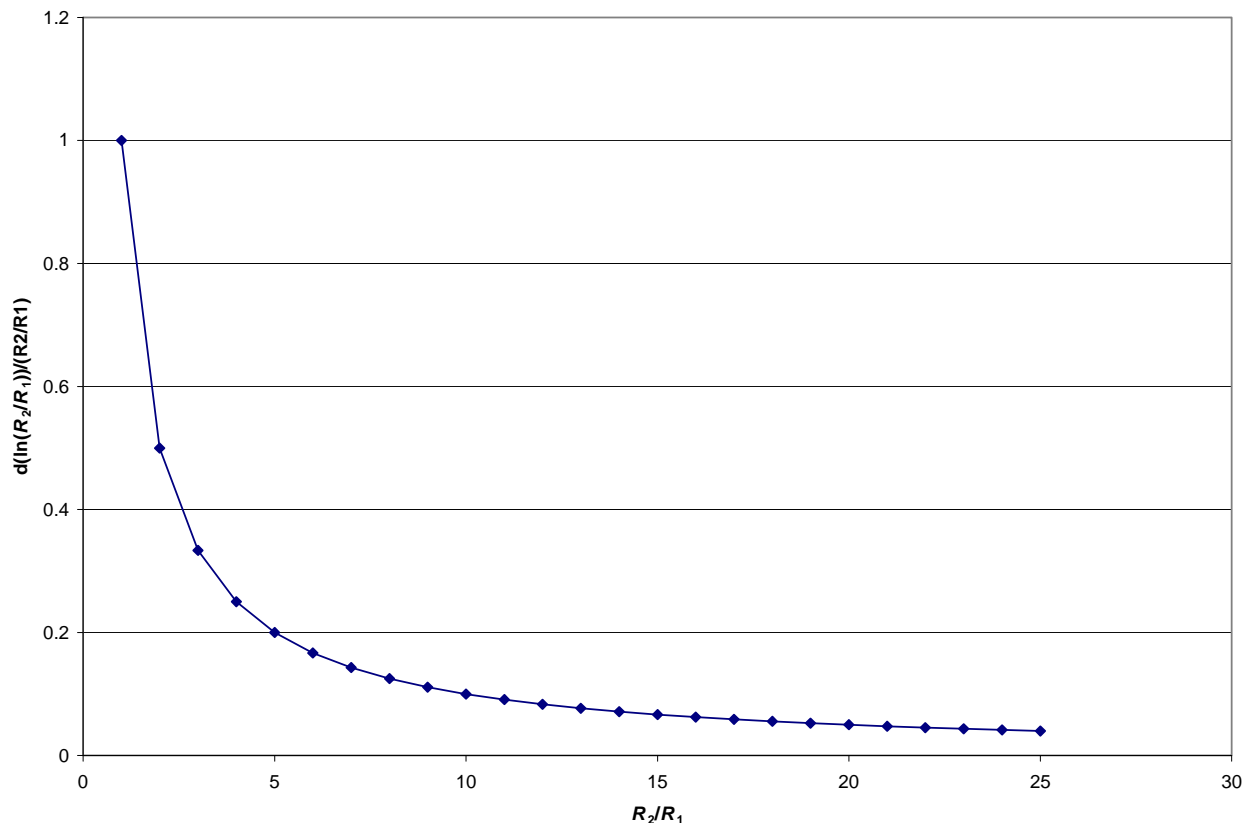
#### 4.2.3 Unwanted emissions from a community

If there is a uniformly dense housing development containing  $n$  houses per square kilometre, and each of these houses is operating  $m$  electronic devices all radiating at the CISPR specified levels  $\xi(f)$ , the total power received at the radio observatory is:

$$S(f) = nm\xi(f) \int_{R_1}^{R_2} \frac{2\pi r}{4\pi r^2} dr = \frac{1}{2} nm\xi(f) \ln\left(\frac{R_2}{R_1}\right)$$

Where the development starts at a distance  $R_1$  from the observatory and extends to  $R_2$ . The differential with respect to  $(R_2/R_1)$  of this function is shown in Fig. 77. This shows that in a uniform housing development in LoS of an observatory, extending a community outward, on the side furthest from the observatory has a far smaller effect than extending it closer to the observatory, even though fewer houses are involved in the latter case.

FIGURE 77  
The rate of change of total unwanted emission as a function  
of size of the community or development



This preliminary discussion shows that unwanted emission from communities using an increasing number of electronic devices, such as energy-saving light bulbs could be a severe problem for a radio observatory if in LoS. Measurements at DRAO show that even small hills can give additional attenuation of more than 50 dB at 408 MHz, and much more at higher frequencies.

#### 4.2.4 Conclusion

Expanding communities and encroachment of development around observatories, together with the increasing use of radio and other electronic devices in domestic use are a major issue in the management and continuing effectiveness of radio observatories. Since unwanted emissions from homes and support infrastructure is going to increase with time, but not in a predictable way, housing in LoS of an observatory should be avoided to the greatest practical extent. Terrain blocking is essential.

## Annex 13

### Proposed radio quiet zones around Five-hundred-meter aperture spherical radio telescope in China

#### 1 Background

Five-hundred-meter aperture spherical radio telescope (FAST) will be the largest single-dish radio telescope in the world. Three outstanding features of the telescope are the unique karst depressions as the sites, the active main reflector which corrects spherical aberration on the ground to achieve full polarization and a wide band without involving a complex feed system, and the light focus cabin driven by the most precise parts of the receivers. The main technical specification are shown in Table 53.

Being the most sensitive radio telescope, FAST will enable astronomers to jumpstart many of the science goals, for example, the neutral hydrogen line surveying in distant galaxies out to very large redshifts, looking for the first shining star, detecting thousands of new pulsars, etc. Extremely interesting and exotic objects may yet await discovery by FAST. As a multi-science platform, the telescope will provide treasures to astronomers, as well as bring prosperity to other researches, e.g. space weather study and deep space exploration.

Funding proposal for FAST has been approved by the National Development and Reform Commission of China in July 2007. The preliminary design was approved in Feb. 2009, and the first light of FAST is expected in 2015.

TABLE 53

FAST main technical specification

Spherical reflector: Radius ~ 300 m, Aperture ~ 500 m, Opening angle $\theta \sim 120^\circ$
Effective illuminated aperture: $D_{eff} = 300$ m
$f/D$ : 0.467
Sky coverage: zenith angle $40^\circ$ , tracking range 4 ~ 6 h
Frequency: 70 MHz-3 GHz (up to 8 GHz after future upgrading)
Sensitivity (L-Band): $A/T \sim 2000 \text{ m}^2/\text{K}$ , $T_{sys} \sim 20$ K
Multi-beam (L-Band): 19
Slewing: <10 min

#### 2 Proposed RQZ around FAST

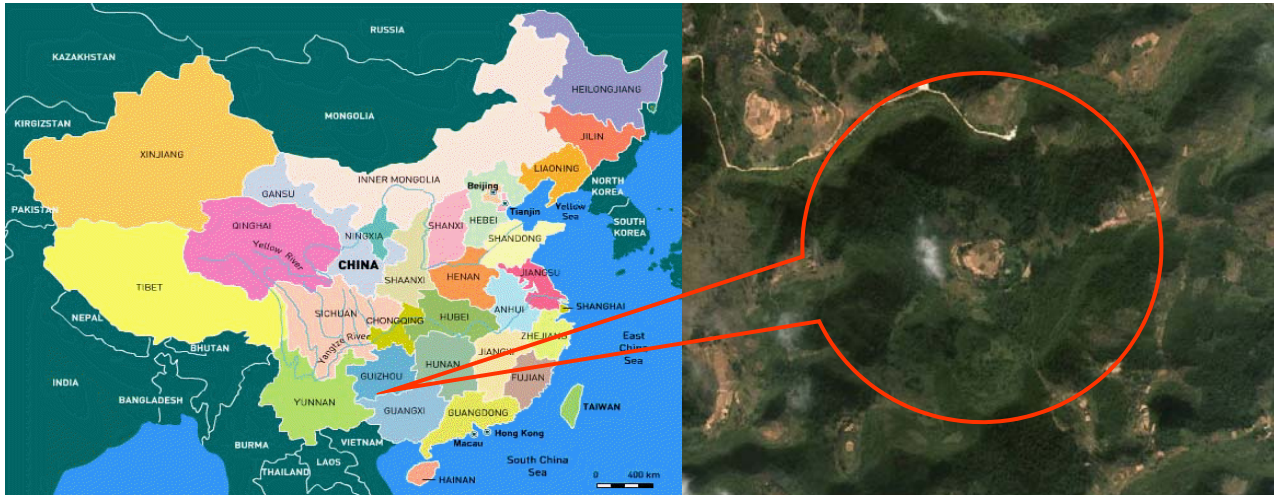
Since 1994, FAST site surveying started in Guizhou province, including geo-morphological features and the distribution of the karst depressions, climate, engineering environment, social environment, and radio interference. The site has been finally selected, a depression called as Dawodang located in south Guizhou (Fig. 78). The remoteness and sparse population density together with the futility of industrial development potentially benefit the radio environment and the safety of future FAST instruments. A series of RFI measurements were initiated with portable equipment from 1994, the results show that the radio environment of the site is extremely quiet and statistically stable. In order to protect the radio environment around FAST efficiently, an agreement



on a temporary RQZ around the site has already been signed by the Chinese Academy of Sciences (CAS) and local government.

FIGURE 78

**Depression Dawodang (East: 106°51', North: 25°38', Altitude: ~1000 m). Image by quick bird with resolution of 0.6 m, the dimension of the red circle is ~1000 m**



## 2.1 Restriction and coordination zone

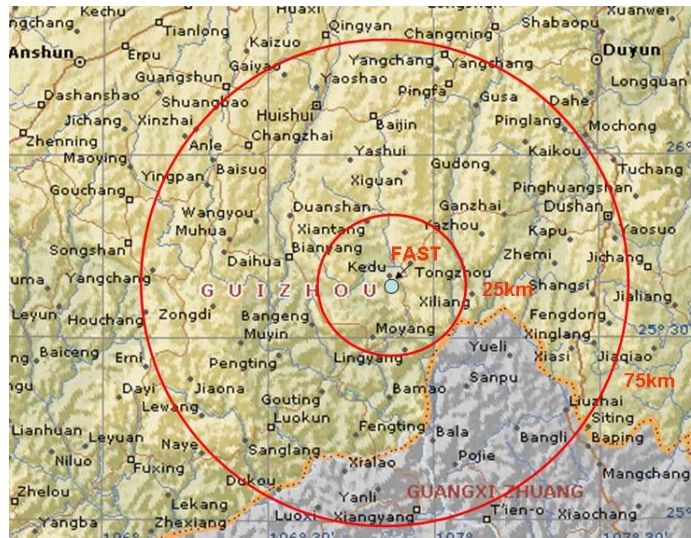
To protect the radio quiet area for FAST site, The Radio Regulatory Department of China and local government have promised to establish a RQZ, of 75 km diameter, with the Dawodang depression as the centre. The legislation of RQZ by Guizhou province is underway.

The protection area is divided into three subsections, radius  $R < 5$  km is the core area, also named as restriction zone (Fig. 79);  $5 \text{ km} < R < 25$  km is the central area and  $25 \text{ km} < R < 75$  km is the remote area, named as coordination zone (Fig. 80). Within the restriction zone, any transmitters may not be stationed. Within the coordination zone, operators wishing to station the transmitters are required to coordination with the operators of the FAST telescope, especially the transmitters operating below 1 GHz with power above 100W and the mobile service around 400 MHz band are forbidden to stationed in  $5 \text{ km} < R < 25$  km area.

FIGURE 79

**Proposed restriction zone around FAST**

FIGURE 80

**Proposed coordination zone around FAST**

## 2.2 Protection and coordination level

Since FAST operates across wide frequency ranges, which include spectral bands that do not have primary allocations for the RAS, any active services mentioned in § 3.3 in the coordination zone are required to limit its in-band and spurious emissions so as not to produce any harmful interference in the reception frequencies of FAST, according to the protection criteria presented in Recommendation ITU-R RA.769-2.

## 2.3 Transmitters which are required to coordinate

The proposed protection regulations of RQZ will apply to fixed, terrestrial transmitters which require licenses, and instruments emitting electromagnetic wave using by industry, agriculture and medicine.