# Memo 73

## Spectrum Protection Criteria for the Square Kilometre Array

SKA Task Force on Regulatory Issues

November 2005

# 1. INTRODUCTION

The Square Kilometre Array 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 requirements for satellite RFI will be addressed in a separate document.

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 Section 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. Regulations 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. Recommendation ITU-R RA.769-2 does not explicitly include closely spaced arrays as a separate category. Different sets of detrimental levels need to be established for arrays depending on the spacing between stations, the number of interferometer pairs, and other parameters. 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.

The composition of the SKA Task Force on Regulatory Issues is presented in Appendix E.

# 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, dated 1 September 2004, 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. However, it is recognized that further studies may lead to a refinement of the required levels before SKA construction. Such changes would only be made in consultation with, and with the agreement of, relevant authorities. These protection levels are based on ITU-R Recommendation RA.769-2, 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. Ultimately, these requirements will depend on the detailed final configuration of the instrument. 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.

2.2 The **intermediate region** with the **near-in remote stations** up to 150km 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 ITU-R RA.769-2 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 ITU-R RA.769-2 Table 3 should be sufficient.

It should be noted that the levels specified in ITU-R RA.769-2 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).

ITU-R Recommendation RA.769-2 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 Figures 1 and 2, under the assumptions used in Recommendation ITU-R RA.769-2.

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

a) The observed continuum bandwidth, assumed in Recommendation ITU-R RA.769-2 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 2000s in Recommendation ITU-R RA.769-2 for both continuum and spectral line observations,
c) The system temperature Tsys, and
d) The antenna response pattern, assumed to be:
   G= 32-log(phi) dBi $1^{o}$<phi<$19^{o}$
   G = 0 dBi $19^{o}$<phi<$180^{o}$

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 (<1s) 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 Figure 2. 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 Rec. 769-2). 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 ITU-R RA.769-2. 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.

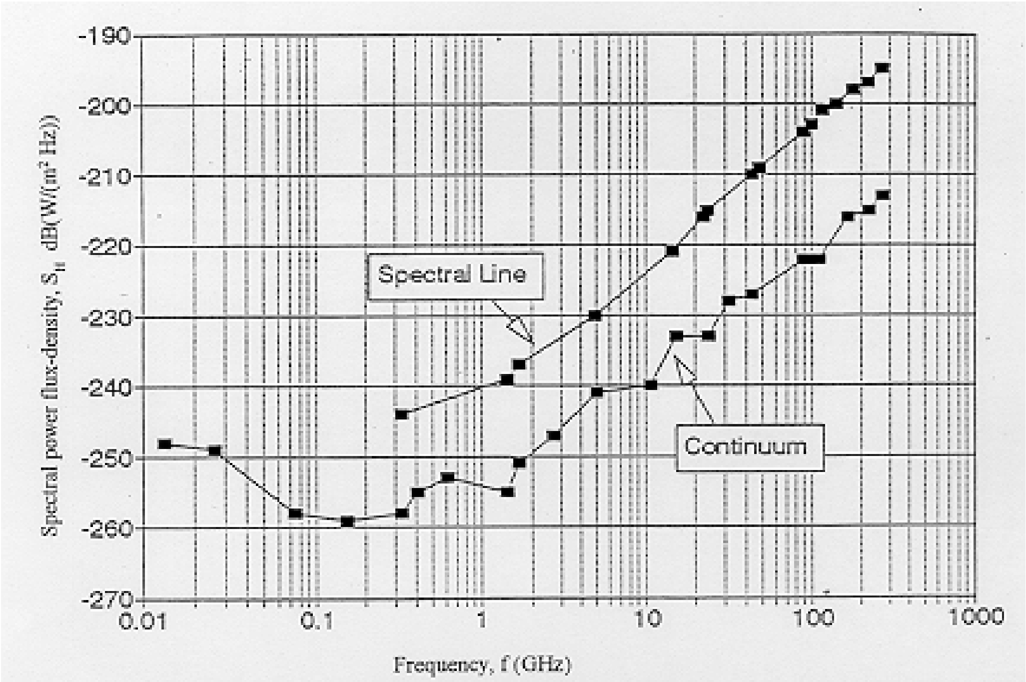


Figure 1. Harmful thresholds of interference for spectral line and continuum observations for single-dish telescopes. *The ordinate is in power flux-density*. The integration time of 2000 seconds has been used and the bandwidth is 20 kHz for spectral line and the whole allocation in the ITU Radio Regulations is used for the (broadband) continuum observations. (from ITU-R Handbook on Radio Astronomy).

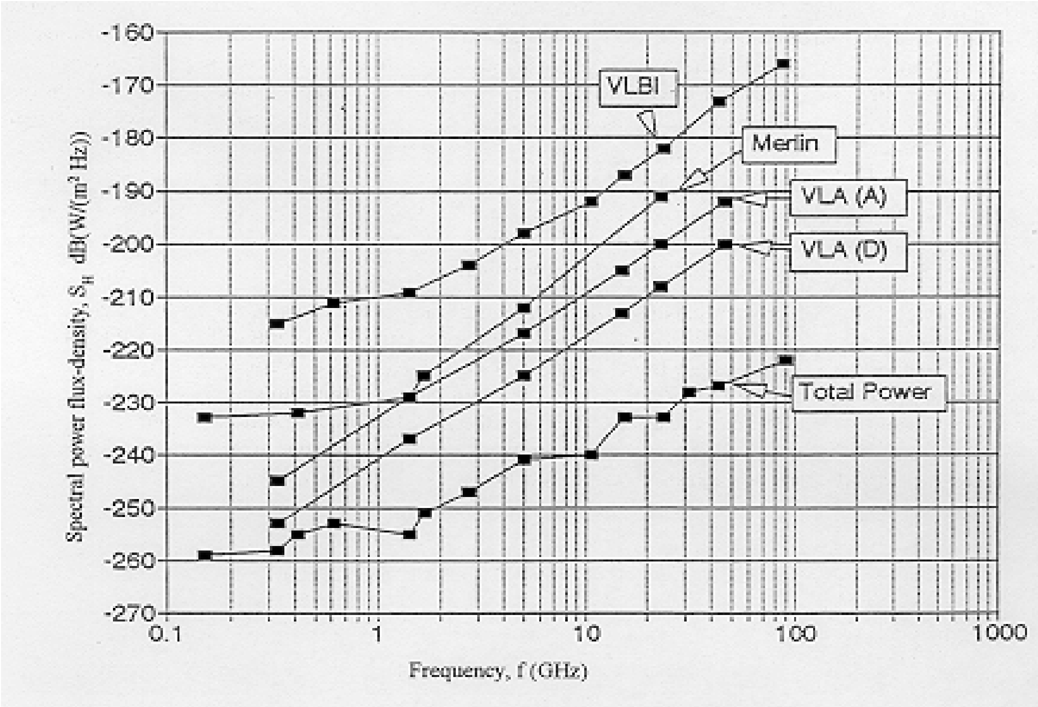


Figure 2. Harmful thresholds of interference for (broadband) continuum observations with several types of radio telescope systems. The curve marked as Total Power is for single dish telescopes *The ordinate is given as power flux-density*. (from ITU-R Handbook on Radio Astronomy).

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.

## 4 POLICY AND REGULATORY CONTROL

Policy and regulatory control of the environment with regard to the SKA not only involves the establishment of radio quiet zones, but also other measures.

The SKA will have a national and international impact wherever it is to be located. As far as the national impact is concerned, it is likely to require contacts with the various state agencies that may have to deal with the requirements of the SKA. Typical sectors that may be affected would be communications (both regulation and communications infrastructure),land affairs, environmental affairs, civil aviation and mineral affairs. There may be further impact at the state or provincial level in terms of roads, distribution networks of electrical power and other public services.

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.
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## 5 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.

The establishment and the definition of RQZs need to form part of an overall approach to regulation of the radio environment required for the SKA, as expressed in the Request for Proposals and the associated documents and needs to fit in with national policy of the bidding countries to host the SKA.

Interference from transmitters outside the host country's jurisdiction, such as satellites or stations in neighbouring countries, need to be addressed through bi-lateral agreements or through the procedures of the ITU.

## *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)

## Appendix A SOURCES OF RFI

It is appropriate to provide a listing and definition of potential RFI sources when the requirements for the SKA are dealt with. The different RFI source types need to be recognized as their impact differs and as they require different treatment in providing protection for the SKA.

In order to develop the requirements for protecting the SKA, it is necessary to have an understanding of the potential RFI involved. The description and examples quoted below are not necessarily exhaustive but are meant to demonstrate the circumstances involved in order that an effective approach can be adopted to minimize the RFI impact. Countermeasures are referred to in each category. Mitigation is not mentioned as that is left as a last resort to combat RFI. Regulatory measures required for the protection of the SKA will be dealt with elsewhere in the document.

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. ITU-R regulations are not very stringent in limiting unwanted out-of-band emissions and further regulation at national and international level may be required in the context of RQZs in order to limit the effects of these unwanted emissions of active services on the SKA operations. These issues are relevant for terrestrial services but especially for space-to-Earth applications in the Aeronautical and Satellite Services.

### A.1 Electromagnetic Compatibility (EMC)

RFI sources in this category usually cover unintentional and consequential radiation of signals as a result of electrical or electronic processes taking place within equipment and in connections between equipment. Examples include computers and signal processors, transmission equipment and cables, lighting equipment, electrical machines, etc.

RFI in this case has to be combated by not allowing any such sources within the area to be protected or keeping them sufficiently far away or to provide adequate screening of the sources, if possible.

### A.2 High power fixed RFI sources

RFI sources in this category include licensed transmissions with radiated power in the kilowatt or megawatt range, which are often located on high sites in order to maximize their coverage or operational range. Interference may be experienced from these sources that are hundreds or even more than a thousand kilometres distant. Typical examples include:

A.2.1 Broadcasting transmitters operating in the VHF/FM band from 87.5 to 108 MHz, in the VHF/TV band from 174 to 254 MHz and UHF/TV from

470 to 854 MHz. Actual bands used vary somewhat for the different ITU regions.

A.2.2 Broadcasting transmitters in the medium wave (500 to 1625 kHz) and short wave transmitters operating in various small allocated bands in the frequency range from 3 to 30 MHz may be troublesome if very high level signals causing saturation of receiver front ends or out-of-band signals are received.

A.2.3 Primary surveillance radar systems for air traffic operating in the frequency bands 1240 to 1350 MHz and 2700 to 2900 MHz with transmitter powers up to 2 MW and antenna gains up to 37 dB. Fortunately these services are being phased out as they are outdated and expensive to operate.

A.2.4 Secondary surveillance radar systems for air traffic operating on an international standard frequency on 1030 MHz at lower power (1 to 2 kW transmitters) with 37 dB gain antennas.

A.2.5 Distance measuring equipment (DME) transmissions for air traffic operating in the frequency band 960 to 1215 MHz with 1 to 2 kW transmitters and low gain antennas.

A.2.6 Weather radar transmissions operating in the frequency band 5255 to 5350 MHz with transmitter powers up to 250 kW with 27 dB gain antennas.

High-level RFI may be experienced from these sources that would saturate the astronomical receiver front ends and cause them to completely malfunction. Filtering out such signals could be applied but would also blank out a portion of the frequency spectrum.

RFI in this case has to be combated by distance, topographical shielding and regulatory coordination and protection. Alternative broadcasting transmission options, such as satellite coverage and low power digital terrestrial transmission may be considered in the vicinity of a radio telescope to lessen the impact on radio astronomy. Obviously, no transmitting installations should be located inside the RQZ.

### A.3 Low power fixed RFI sources

RFI sources in this category include licensed transmissions with radiated power up to hundreds of watts and may sometimes, depending on the application, be located on high sites in order to maximize their coverage or operational range. Interference may be experienced from sources that are hundreds of kilometres distant. Typical examples include:

A.3.1 Two-way mobile radio communication system base or repeater stations, including trunking systems and paging systems, which are often on high sites and operate in the 146 to 174 MHz (parts excluded) and in parts of the band from 254 to 470 MHz.

A.3.2 Mobile cellular telecommunication system base stations which do not use high sites in high density traffic areas but do so in rural areas with low density traffic, which operate in the frequency bands 890 to 960 MHz (parts excluded) and parts of the band 1710 to 2170 MHz. (higher end for 3G).

A.3.3 Wireless local loop systems operating in a point-to-multipoint mode, are increasingly being used in lieu of open wire systems in rural areas. They operate in the frequency bands 1710 to 1980 MHz (parts of), 2300 to 2500 MHz, 2670 to 2690 MHz and 3400 to 3600 MHz.

A.3.4 Point-to-point links operating in the frequency bands 406 to 470 MHz (parts of), 790 to 960 MHz (parts of), 1350 to 1525 MHz (parts of), 1710 to 2690 MHz (parts of), 3400 to 5000 MHz, 5850 to 8500 MHz, 10.0 to 13.25 GHz, 14.50 to 15.35 GHz, 17.70 to 19.70 GHz, 21.20 to 23.60 GHz and 24.25 to 27.0 GHz.

The point-to-point links are usually highly directional and may only be troublesome if a transmitting beam happens to be directed at the radio telescope.

RFI in this case has to be combated by distance, topographical shielding and regulatory coordination and protection. None of these applications should have base stations within the RQZ unless there is a specific requirement.

### A.4 Mobile and portable RFI sources

These RFI sources are associated with the RFI sources in items A3.1, A3.2 and A3.3, and represent the other side (user side) of the two-way radio communication systems. Their licensing is coupled to the associated networks and services. They involve handheld units, cell phones, walkie-talkies and mobile units in vehicles. Fixed user installations with roof-top antennas may also be used. The transmitters are placed at low heights and employ low power with low gain transmitting antennas. The impact is therefore less and can be combated by keeping them outside the RQZ.

### A.5 Short Range Devices (SRDs)

Short Range Devices must not be allowed inside the RQZ. These devices are low power units with simple built in antennas. They are not related to licensed telecommunication services but do require equipment type approval. Typical examples and frequency bands for devices operating on frequencies above 100 MHz are:

A.5.1 Tele-command units and wireless microphones operating from 173 to 175 MHz.

A.5.2 Medical implants, movement detectors, motor car electronic keys and alarm systems operating from 402 to 406 MHz.

A.5.3 Wireless audio systems, cordless phones and alarms operating from 863 to 870 MHz.

A.5.4 DECT cordless phones between 1880 to 1900 MHz.

A.5.5 Wide band wireless systems and low power video surveillance from 2400 to 2483.5 MHz.

A.5.6 Hiperlan indoor from 5150 to 5350 MHz and Hiperlan outdoor from 5470 to 5725 MHz.

A.5.7 Road transport and traffic telematics (RTTT) from 5795 to 5815 MHz.

A.5.8 Field disturbance and Doppler apparatus (FDDA) from 9200 to 9975 MHz, 10.5 to 10.6 GHz, 13.4 to 14.0 GHz and 24.05 to 24.25 GHz.

A.5.9 Hiperlan systems from 17.1 to 17.3 GHz.

## A.6 Satellite systems

There are two types of systems as described below in commercial use. Military systems are also in use but are not dealt with here.

A.6.1 Geostationary satellites with downlinks operating in the frequency bands 3600 to 4200 MHz and 10.70 to 12.75 GHz. The higher-level signals that may be the most troublesome are associated with broadband services where small parabolic antennas are used on the earth stations, such as direct-to-home satellite broadcasting. VSAT telecommunication systems also fall in this category but the downlink signal levels are usually quite low due to the low data rates involved.

A.6.2 Low orbit satellite communication systems with downlinks which operate in parts of the frequency band from 1525 to 1626.5 MHz and 2500 to 2520 MHz. Due to their lower operating height and operations in conjunction with portable devices on earth, their impact is bound to be substantial.

Uplink transmissions are not referred to above as the transmitting stations are highly directional pointing upwards and it is further assumed that they will be distant from the RQZ. Portable transceivers used with low orbit systems will have to be kept outside the RQZ. Regulatory measures in connection with satellites needs to be dealt at an international level.

## A.7 Aircraft

The only way to combat RFI from aeronautical sources is to keep aircraft sufficiently away from the RQZ and to avoid fly-overs. The various onboard systems are summarized below. The relevant earth stations are not mentioned here as they have either been dealt with under fixed RFI sources in item 3.2 or it is assumed that they are located near commercial airports that would be distant from the RQZ.

A.7.1 Voice and data communication and navigation in the frequency band 117 to 137 MHz.

A.7.2 Secondary Surveillance Radar (SSR) and Airborne Collision Avoidance System (ACAS) operating on an international standard frequency on 1090 MHz.

A.7.3 Radio altimeters in the frequency band 4200 to 4400 MHz.

A.7.4 Microwave landing systems in the frequency band 5000 to 5250 MHz.

A.7.5 Airborne weather radar in the frequency band 5350 to 5470 MHz.

A.7.6 Airborne Doppler radar in the frequency band 8750 to 8850 MHz.

A.7.7 Precision approach radar in the frequency band 9000 to 9500 MHz.

A.7.8 Airborne Doppler radar in the frequency band 13.25 to 13.40 GHz.

## Appendix B 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 Figure B.1 below (left top frame) for a SKA station of 100m 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 Figure B.1 and Table B.1

**Table B.1 Proposed Radial Structure of the SKA RQZ**

| | **Station Radial Distance** | **Exclusion Zone (EC)** | **PFD Levels for Coordination Zone (CZ)** |
|---|---|---|---|
| Central Region | Inside 5km | 75-100 km radius | ITU-R RA.769-2 Levels |
| Intermediate Region | Annulus 5 - 200km | ~10 km radius* beyond 100 km radial distance | ITU-R RA.769-2 Continuum Levels + 15dB |
| Remote Region | Beyond 200km | ~10 km radius* | ITU-R RA.769-2 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.

## B.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.

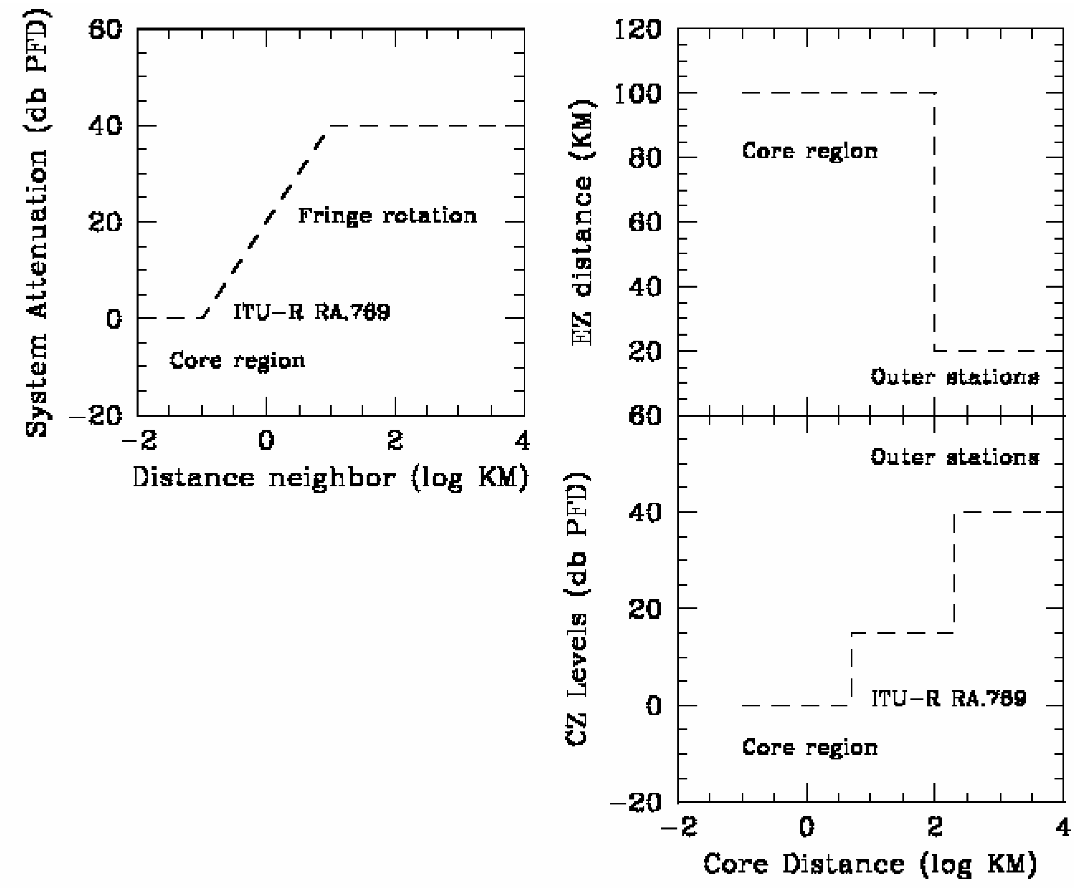



Figure B.1. A possible radial structure of the RQZ for SKA
*Top left frame:* The separation of two SKA stations results in a rejection of narrow band and broadband RFI signals that depends on the square of the distance between the station and its neighbours. The ITU-R RA.769 levels are used as a reference value. This figure assumes a size for an individual station of 100m. The rejection resulting from the separation of stations varies from 0 dB for touching stations and 40 dB for separations where the VLBI 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 power flux-density in dB relative to the values of 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:

B.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.769-2

B.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.769-2.

B.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.

## B.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 line-of-sight 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.

## B.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.

## B.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 C RELEVANT ITU RECOMMENDATIONS

The ITU-R Recommendations on propagation can serve as a guide to practical models that can be readily used in numerical studies. CSIRO conducted such a study, which evaluated 3 different models:

- Recommendation ITU-R P.526 “Propagation by diffraction”

-- Recommendation ITU-R P.1546 “Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3000 MHz”

-- Recommendation ITU-R P.452 “Prediction procedure for the evaluation of microwave interference between stations on the surface on the Earth at frequencies above about 0.7 GHz”

Rec P.526 presents the simplest propagation model, whereas Rec P.1546 and P.452 use complex propagation models accounting for all known effects including anomalous short-term modes of propagation (e.g. hydrometeor scatter).

The following ITU recommendations are also useful in the determination of propagation losses:

-- Recommendation ITU-R P.1144 – Guide to the application of the propagation methods of Radiocommunication Study Group 3.

-- Recommendation ITU-R P.341 – The concept of transmission loss for radio links.

-- Recommendation ITU-R RA1513 – This recommendation relates to the issue of data loss and percentage of time loss for radio astronomy telescopes.

## Appendix D PROPAGATION STUDIES, RFI CHARACTERISATION AND DATA ACQUISITION

### D.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. ITU-R Recommendations that relate to propagation studies and propagation losses under various environments have been listed in Appendix C.

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. For a general introduction to the field see http://www.iucaf.org/sschool/procs/propag.pdf.

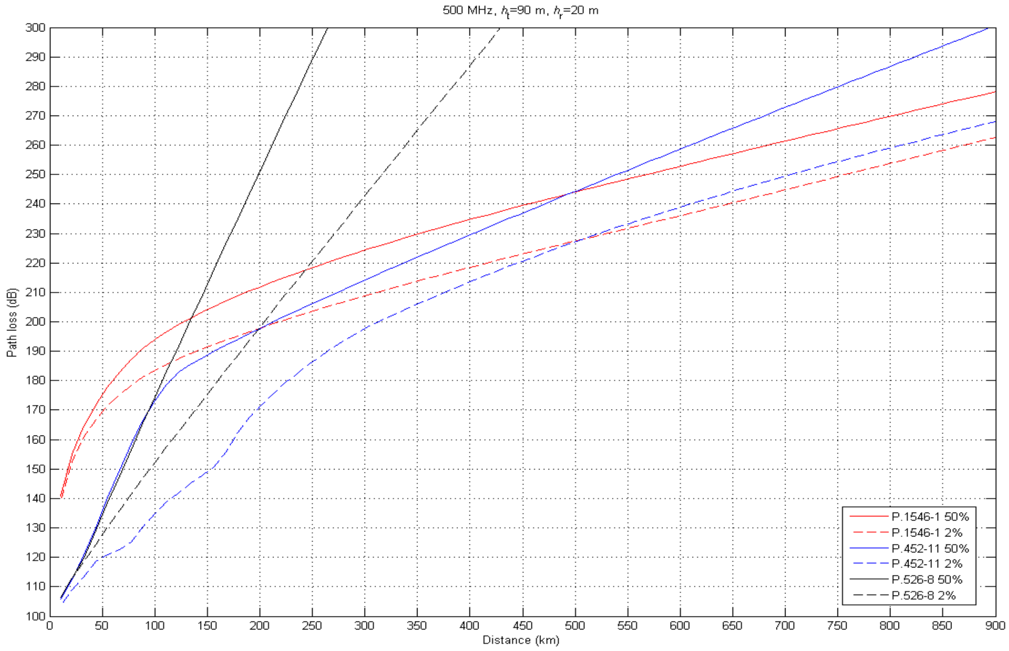
Propagation models vary from simple, accounting only for fundamental effects (free space propagation, diffraction), to very complex that account for many effects such as ionospheric and tropopheric factors, and terrain obstacles.

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 20m for the receiver (indicative for the SKA) and 90m for the transmitter (a typical radiocommunications tower).

The Figures D.1 and D.2 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.



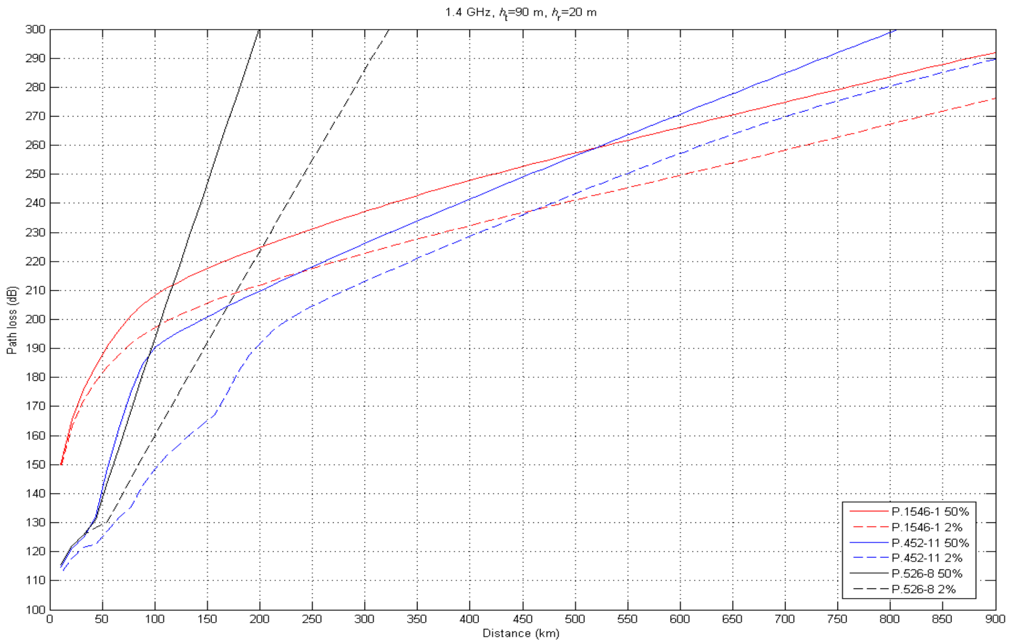
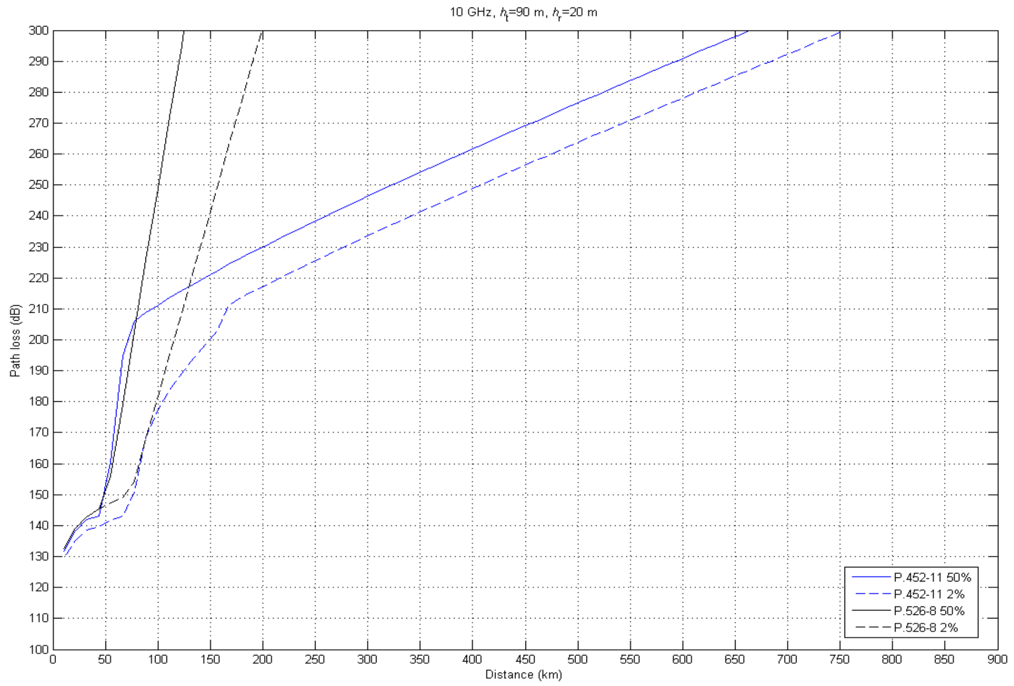




Figure D.1: Path loss (dB) at different distances (km) due to propagation models from Rec P.1546-1, P.452-11, P.526-8, for the low frequencies of 500 MHz (top) and 1.4 GHz (bottom). The solid lines are at 50% and the dashed lines at 2% probability of interference.



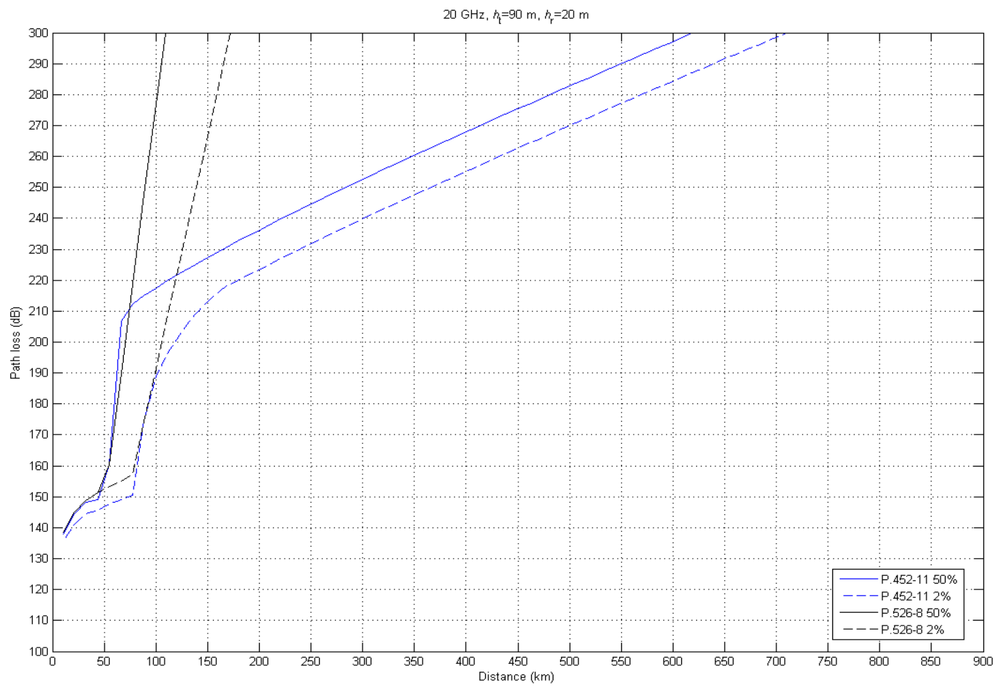




Figure D.2: Path loss (dB) at different distances (km) due to propagation models from Rec P.452-11 & P.526-8, for the high frequencies of 10 GHz (top) and 20 GHz (bottom). The solid lines are at 50% and the dashed lines at 2% probability of interference.

## D.2 Computerised 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.

## D.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

## D.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.
   It is also useful to have the predicted RFI available when measurements are made.

4. 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.

## D.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 ITU-R Rec RA.769-2 is very difficult. Thus the measurement program may not adequately describe the RFI environment at the required level.

## D.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.

## D.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 Figure D.3 (a, b, c) below.

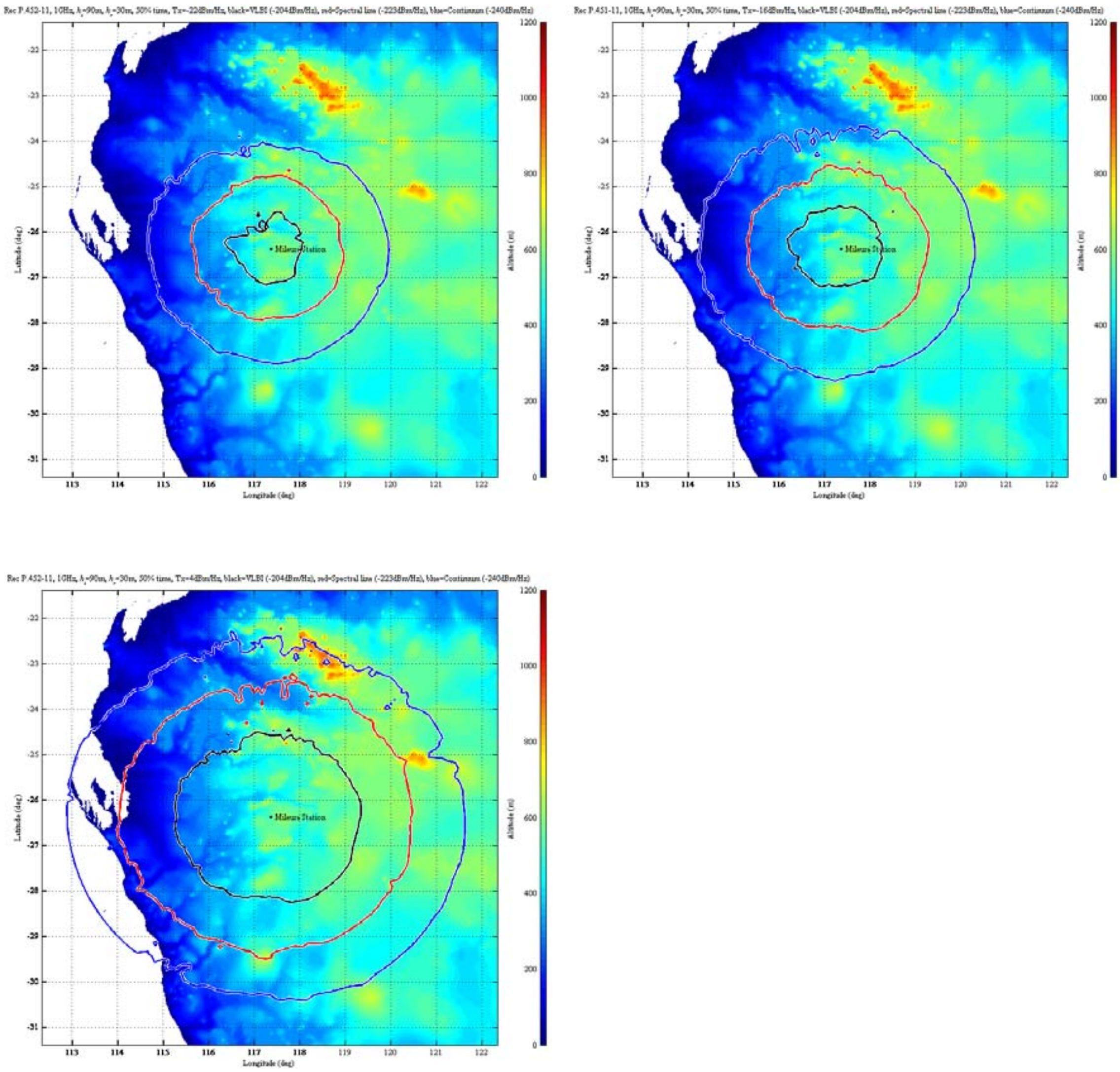


Figure D.3: Protection zone sizes needed at Mileura for Rec RA.769 levels (black=VLBI, red=spectral-line, blue=continuum) for three types of transmitters provided by CSIRO (Commonwealth Scientific and Industrial Research Organisation of Australia). The propagation model from ITU-R Rec P.452-11 includes local terrain characteristics and an interference probability of 50%. The three service examples are:

Frame a (top left): GSM base station transmitters (-22dBm/Hz),

Frame b (top right): from fixed link transmitters (-16dBm/Hz),

Frame c (bottom left): DME transmitters (4dBm/Hz).

The following parameters were used in this study: 1) Frequency: 1 GHz; 2) Interference probability: 50% of time; 3) Limits defined via ITU-R Rec 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: ITU-R Rec P.452-11; 5) Terrain for Mileura region included; 6) Receiver antenna: Height 30m in 0 dBi; 7) Transmitter antenna: Height 90m, Gain 0 dBi.

## Appendix E MEMBERSHIP OF THE SKA TASK FORCE ON REGULATORY ISSUES

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