THE RADIO FREQUENCY INTERFERENCE ENVIRONMENT
AT CANDIDATE SKA SITES

Document number ................................................. WP3-010.020.000-R-001
Revision ........................................................................................................ 1.2
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Date ................................................................................................. 2010-02-05
Status .................................................................................................... Approved for release

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DOCUMENT HISTORY

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<th>Revision</th>
<th>Date Of Issue</th>
<th>Engineering Change Number</th>
<th>Comments</th>
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<tr>
<td>1</td>
<td>2010-02-04</td>
<td>-</td>
<td>First release after internal review</td>
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<tr>
<td>1.1</td>
<td>2010-02-04</td>
<td>-</td>
<td>Transferred to template</td>
</tr>
<tr>
<td>1.2</td>
<td>2010-02-05</td>
<td>-</td>
<td>Added paragraph to section 1.</td>
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DOCUMENT SOFTWARE

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<tr>
<td>Wordprocessor</td>
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<td>Word 2003            WP3-010.020.000-R-001-1.2_SitesRFIEnv</td>
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ORGANISATION DETAILS

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LIST OF ABBREVIATIONS

AFSATCOM .................. Air Force Satellite Communications
DME ............................. Distance Measuring Equipment
EMI .............................. Electromagnetic Interference
EMC .............................. Electromagnetic Compatibility
FLTSATCOM .................. Fleet Satellite Communications System
GSM .............................. Global System for Mobile Communications (originally from Groupe Spécial Mobile)
GPS .............................. Global Positioning System
HSS .............................. High Speed Sampling
K ................................. Kelvin
NOAA ............................ National Oceanic and Atmospheric Administration
RAS .............................. Radio Astronomy Service
RFI .............................. Radio Frequency Interference
RQZ .............................. Radio Quiet Zone
SKA .............................. Square Kilometre Array
SPDO ............................ SKA Program Development Office
SSSM ............................ SKA Site Spectrum Monitoring
1 Introduction

For the design of parts of the Square Kilometre Array it is of importance to define the conditions under which it will have to perform. For radio telescopes one of the important factors of the environment is the radio interference that it will have to deal with. For present radio telescopes operating in the lower regions of the electromagnetic spectrum an increasing amount of effort is put into mitigating the effects of radio interference. Newly designed facilities should take considerations for dealing with the interference environment into the design process from the start and at all relevant levels of the system: from receiver to correlator, and from infrastructure to spectrum management.

This document aims to provide an overview of the radio frequency interference (RFI), which can be expected to be present at various areas in the array. Some of the considerations can be triggered from practical measurement results, such as the RFI survey that was done for the site selection process in 2005. Others will have their origin from organisational or theoretical aspects, such as protection measures incorporated from the start, for example the Radio Quiet Zones (RQZs), and the suppression of interference by interferometric attenuation. The main purpose of this document is to present data from the RFI measurement campaign of 2005, carried out at the proposed cores of the two shortlisted candidate sites: the Karoo in South Africa and Western Australia. A future edition will present updated information resulting from the RFI measurement campaign that will be carried out in 2010, which will also include measurements taken at a selection of remote station locations.

This new measurement campaign will be carried out to further characterise the RFI environment of the two shortlisted sites. In particular the measurements will be done with much greater sensitivity, close to the RA769-2 levels. These high sensitivity measurements will be carried out at the two candidate core sites. In addition, a representative number of remote sites will be visited as well, in order to collect RFI information outside of the RQZs.

2 The Radio Quiet Zone

The central part of the SKA will be situated within the Radio Quiet Zone, which will be established at the candidate sites. The protection criteria were established in [1]. The RQZ extends to at least 150 km from the centre of the array and maximum levels of interference in various zones are listed in [1]:

- the core and central area, up to 2.5 km radius, the maximum level of protection according to RA769-2 tables 1 and 2;
- the intermediate region, up to 150 km from the centre of the array, 15 dB less stringent than the levels in RA769-2;
- the outer region, beyond 150 km from the centre of the array, where the VLBI levels from Table 3 in RA769-2 apply.

The levels of R769-2 that are referred to can be summarised as follows, see [2]:

- Table 1 of RA769, for single dish continuum observations;
The Recommendation provides maximum levels of interference only for the recognised frequency bands reserved for passive use by the Radio Astronomy Service (RAS). In the current document, as in Memo 73 [1], interpolated figures are assumed as a continuous range of levels. In Figure 1 the values for the three RA769 categories of specified maximum levels of RFI are plotted. In addition, the level of ‘continuum single dish’ relaxed by 15 dB, which applies to the protection level in the intermediate region, has been plotted.

**Figure 1**: RA769 protection levels and RQZ regions.

Much of the analysis in assessing detrimental levels of RFI for radio astronomy is based on [3]. For single dish continuum the central argument is that the interference-to-noise ratio must be less than 0.1 where the interference enters the system through 0 dBi side lobes of the antenna. For connected element interferometers with short to intermediate baselines, like the VLA and Merlin, interferometric suppression relaxes this by a factor depending on the baselines and uv coverage. In fact, the determination of the detrimental RFI is done by computing ratio of the rms interference level to the noise in the map, again for a maximum of 0.1. In [1] the suppression factor that applies for the short to intermediate baseline interferometers, with respect to the single dish continuum
level has been taken to be 15 dB. For baselines in the range of VLBI it is argued in [3] that there will be no correlated RFI to account with and that the instantaneous interference-to-noise ratio should be less than 0.01, which in practice implies that the detrimental levels of RFI are some 40 dB less than the single dish continuum levels, see Figure 1.

It must be stressed that while the RQZ low interference conditions are there to protect the receptors in that area, at the same time these pristine conditions must be preserved by the SKA installations and additional facilities. These systems include precursor telescopes and their installations, that are being constructed or are already in place. This implies that the highest of EMC standards, and more, should be applied to ensure that anywhere within the RQZ the specifications for the RFI environment are met.

For the planned locations of antenna systems for the SKA in both countries, at the time of writing of this document, efforts are underway to define specifications for masks that define separation distances from existing or planned EMI sources within the Radio Quiet Zones, see [4]. This concerns vehicles on roads, farmsteads, towns, rail, etc. At the same time a specification for the maximum level of intentional RFI, transmitters, is being investigated for the whole of the SKA. The driving purpose for these specifications is the design of configurations, applicable to both candidate hosts. Future useful documents will be referenced here.

3 The RFI environment at the core, 2005

Site characterisation measurements were carried out in 2005 for the site selection process, which was concluded in 2006 with the selection the two remaining candidates. The name of the campaign was: SKA Site Spectrum Monitoring, SSSM.

The measurements were done at the locations of the proposed cores at the time:

- the K3 location at Losberg in the Karoo, South Africa (30.71°S, 21.32°W),
- near Mileura station in Western Australia (26.62°S, 117.51°W).

The measurement locations are indicated in the illustration below, at about the same scale (the width of the image is ~125km). Note that for the Australian case the proposed core location has since changed to Boolardy (26.70°S, 116.66°W), indicated in the figure as well. The RFI at that location should differ only marginally from the conditions at Mileura.

Top level information on the measurement campaigns in the two countries can be found in [5] and [6]. Detailed information on equipment, methods and results is referenced there.
Figure 2: Karoo site (top), Boolardy site (bottom).
3.1 Measurement equipment and methods

The RFI survey was executed over a frequency range of 50 MHz to 24 GHz. The measurement protocol called two regimes for the measurements: mode 1 and 2:

**Mode 1** - Intended for a survey of strong signals received at the site; signals that will potentially drive sensitive receiver electronics into non-linear operation. In this survey only a limited sensitivity is required. The allowed receiver noise temperature was specified to be maximally 30,000 K. This mode includes a high speed sampling measurement at the lower L band, where strong brief pulses from (airborne) radar, DME and transponders would be underestimated with measurements with longer integrations. This measurement is identified as HSS (high speed sampling) in the SSSM measurement suite. Each of the Mode 1 measurements has 5 repetition cycles. Mode 1 measurements have a short integration time.

**Mode 2** - Intended for the high sensitivity survey of the spectrum. The specified receiver temperature here is less than 300 K. The list of measurements shows a set of general broad frequency range measurements with nominal integration times, and several long integration time measurements in specific narrower frequency bands to probe deep into the noise to detect relatively weak signals. Each of the Mode 2 measurements has 2 repetition cycles. Mode 2 measurements have a relatively long integration times (10ms to 10s).

Of interest for the current document is only Mode 1 as the purpose is to report on the strong RFI to be expected. The actually achieved receiver temperature for Mode 1 was much better than specified: better than 1000K for much of the frequency range, as illustrated in Figure 3.

![Figure 3: SSSM Mode 1 receiver temperature.](image-url)

The red line indicates the receiver temperature calculated from component properties, and the blue line the actually measured receiver temperature from noise source calibration. The steps indicate where changes in equipment components occur. For Mode 2 the receiver temperature was below 200K up to 5 GHz and below 400K to 20 GHz.

The equipment used consists of a high quality spectrum analyzer connected to two masts carrying antennas and frontend electronics. For Mode 1 measurements the antennas are two logarithmic periodic antennas of medium gain, mounted on a mast with a rotator for azimuth and polarization.
The frontend contains a set of low noise amplifiers, which can be configured remotely by means of coaxial switches. A noise source can be switched in and out of the signal path. A computer system that controls the hardware and reads out the data from the spectrum analyzer was situated inside an EMI shielded environment, together with rotor control and power supplies. Part of the digital equipment was a high speed sampler board in the computer system for doing the HSS measurements of Mode 1 in L band. Software in several levels was used to plan, schedule, control, read and process the data, with reports at several levels of detail as a result.

The calibration of the system was carried out by regular calibration sequences involving switching the noise source on and off. The resulting gain and receiver temperature plots were used in calibrating the data, and for testing the integrity of the receiver throughout the campaign.

### 3.2 Measured spectra

The spectra shown in this section are snapshots of the RFI environment at the two candidate core locations at that time, as described in section 3. The plots show data from both sites combined in the following manner:

1. for each site, the maximum level for Mode 1, over all antenna pointings and polarisations is calculated;

2. next for these two datasets the maximum is plotted in the red trace and the minimum in the blue trace;

3. self-generated RFI is identified in the data and plotted in black. This serves to isolate this from the true RFI environment. As can be seen in the graphs the levels of self-generated very narrow RFI peaks are such that the assessment of true RFI is not compromised in any way. The self-generated RFI was discovered at one of the sites (mainly originating from external equipment) and identified in time so that it became possible to flag these responses in the data.

It should be noted that the RFI environment may have changed since 2005. A future update of this report will reflect the situation in 2010, and also include the RFI at a selection of remote sites.

The spectrum shown in Figure 4 should serve as an indication of the amount of RFI that can be expected at the cores of the sites, as based on the situation in 2005. It shows the entire frequency range, originally specified for the Mode 1 measurements. Despite the forest of lines, comparisons with spectra taken at the majority of current radio astronomy sites will show that these sites are very clean as far as electromagnetic pollution goes.

It should be understood that the discrete steps in the spectra stem from physical changes to the receiver equipment in several frequency ranges in addition to changes in integration time and bandwidth. The way to look at these plots is to read the flux for the RFI responses, while using the baseline as an indication of the detection limit at the frequency of interest. It is apparent that common knowledge is confirmed, namely that the strongest RFI is found below 3 GHz, and in particular below 300 MHz.
Figure 4: Mode 1 overall spectrum, 70-22000MHz.

Attention is drawn to the part of the spectrum from 960 to 1400 MHz, which is measured with much less sensitivity. Plotted here is the part that is measured with the High Speed Sampling facility (HSS), which uses large analog bandwidth (1 MHz) and high time resolution (2 μs). This has allowed capturing the strong peaks in that part of the spectrum. These would never have been detected using the standard spectrum analyzer modes. The peaks seen here are strong, but have very low duty cycle. The statistics of these signals have been reported in [7] and [8].

In the following figures the full spectrum has been split into several smaller frequency ranges to be able to discern interesting spectral features.

Figure 5: Mode 1, 70-150 MHz.

Note the FM and the aeronautical communication bands and the NOAA satellite carriers in Figure 5.
Figure 6: Mode 1, 150-300 MHz.

The two broadband features in Figure 6 have not been identified, but are possibly self-generated interference. The swarm of responses around 260 MHz that bear the signatures of multi channel digital communications are associated with the US military FLTSATCOM and AFSATCOM services. These are geostationary satellite systems and were easily detected at all four sites visited during the site selection survey. In addition numerous analog television signals are seen in the spectrum, albeit at rather low levels.

In Figure 7, more television responses are seen apart from a single broadband feature.

In Figure 8 mobile GSM can be seen around 950 MHz.

Figure 9 shows the HSS results in more detail. The block-like steps are artefacts of data processing.

Figure 10 shows several satellite signals, including Afristar and GPS. Mode 2 measurements obviously show these with much more sensitivity.

Figure 7: Mode 1, 300-600 MHz.
Figure 8: Mode 1, 600-1000 MHz.

Figure 9: Mode 1, 950-1450 MHz.
Figure 10: Mode 1, 1400-1600 MHz.

Figure 11: Mode 1, 1400-3000 MHz.
4 Summary remarks

As has been mentioned, an updated edition of this document will be prepared when new information will become available.

It should be noted that the measured spectra represent the RFI environment at the prospective core sites only, for the year 2005. Spectra measured at remote sites, together with an update of the environment at the cores for 2010 will be added later.

The data presented in the report therefore are not intended to drive EMI robustness specifications for receivers outside the RQZ.

Inspection of the graphs in this document of the levels of RFI deemed to be required for the RQZ and the levels of RFI that have been measured at the core locations points to a rather substantial difference between what is desired and what is encountered in the field. This is a situation, which needs to be addressed in the proper forums. Some of the RFI encountered in the field originates from satellite services, which are hard to shut down. The same may be true for airborne communication and navigation. Some of the other sources can perhaps be mitigated by legislation.

Proper design of hardware and software should at least provide the possibility of mitigating the RFI through methods of excision. It should be clear that at the worst-case levels of RFI that in practice will be encountered in the field all components are well within their range of linear operation.

5 References