Impact Analysis of Hydraulic Fracturing on the SKA:

An Initial Assessment

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Report compiled for the South African Task Team on Hydraulic Fracturing

Contents

1. Preamble

This report considers the potential impact of hydraulic fracturing, and its associated activities, on the Square Kilometre Array telescope, and its precursor telescope, the MeerKAT. Its conclusions are based on generic approximations in the absence of detailed information regarding the hydraulic fracturing operational scenario. The results in this report should therefore not be taken as final conclusions, but rather illustrative of proposed methodologies.

2. About the Author

Dr. Adrian Tiplady has a PhD in radio astronomy from Rhodes University, and has been working for the South African SKA Project Office since 2005. He is responsible for site characterisation of the Square Kilometre Array (SKA), including the analysis and impact of the nature of radio frequency interference. He is currently involved in the following local and international spectrum management activities:

i. Represents South Africa (and the only African representative) on the European Science Foundation expert Committee on Radio Astronomy Frequencies (CRAF);
ii. Represents CRAF on the ITU sector member, the Scientific Committee on the Allocation of Frequencies for Space Science and Radio Astronomy;
iii. South African rapporteur for WRC-12 Agenda Item 1.6;
iv. SKA representative on the ICASA SKA Special Working Committee.
v. Responsible for the drafting of declarations and regulations, to be promulgated in terms of the Astronomy Geographic Advantage Act

3. Introduction

This report considers the potential impact of hydraulic fracturing (commonly referred to as 'fracking'), and its associated activities on the Square Kilometre Array (SKA) radio astronomy facility, as well as the precursor instrument MeerKAT. In order to address this in an appropriate manner, the following is required:

i. an exact geographic location of hydraulic fracturing activities;
ii. a detailed description of all equipment associated with 'fracking', including electromagnetic characteristics;
iii. use profile of all the equipment referred to in ii. above
iv. full operational model during the lifetime of the 'fracking' operations, including support infrastructure.

Due to the very short timescales allowed for the development of this report (approximately 2 weeks), as well as the current status of 'fracking' operations, this detailed information was not available. However, placeholders have been used where information is lacking in order to derive a reasonably appropriate impact analysis. The derived methodology should be used to assess the impact of a 'fracking' site once all the items list in i. to iv. above are known.

'Fracking' activities may result in a wide variety of detrimental impacts on the radio astronomy environment. However, radio frequency interference (RFI) poses the most significant threat. Measures to mitigate against RFI should result in the protection of the radio astronomy environment from other potential sources of interference.

Section 4 considers the nature of RFI, and shows how it produces a potential detrimental impact on radio astronomy. Section 5 attempts to identify potential sources of RFI in 'fracking' activities, and characterises these sources in terms of potential electromagnetic emissions. Section 6 presents an impact analysis based on the potential sources of interference, providing an accurate methodology for future impact assessments.

4. The Nature of Radio Frequency Interference (RFI)

4.1. Spectrum Management

The ability of a radio telescope to conduct radio astronomy observations relies on a radio frequency environment that is as free from sources of interference as possible. Historically, radio telescopes have operated in narrow parts of the radio frequency spectrum. The International Telecomunications Union (ITU) recognises the radio astronomy service, and allocates approximately 1% of the spectrum to radio astronomy on a primary basis, split into a number of small channels. This primary allocation gives protection rights to the radio astronomy service internationally. One of the most important of the allocated channels is situated between 1,400 MHz and 1,427 MHz, and is aimed at protecting the critically important neutral hydrogen spectral line (HI) for radio astronomy.

Modern and next-generation radio astronomy facilities operate across very wide frequency ranges, due to the red-shift of HI that allows it to be measured at any frequency below 1,421 MHz. The SKA will operate from 70 MHz to 10 GHz, later to increase to an upper frequency limit of 25.5 GHz.

The protection threshold limits for the radio astronomy service are prescribed in the ITU Recommendation ITU-R RA.769-2. Received artificial, or man-made, radio signals that exceed the prescribed limits are considered to be detrimental to radio astronomy observations. As a guide to the reader, these threshold limits are in general 15 orders of magnitude more sensitive than a conventional cellular phone, making a radio telescope an extremely sensitive radio frequency receiver. It is therefore particularly sensitive to radio frequency signals that may either interfere radio astronomy observations, or even damage radio astronomy receiver equipment.

The protection threshold limits for radio astronomy in units of dB(W/m^2/Hz) are provided in Figure 1, and indicated by the red dots on the graph. The blue line, which indicates an interpolated and relaxed level, is illustrative of the protection limits for a radio interferometer. Examples of such an interferometer is the SKA – a large array of individual radio telescopes that operate together to form one large radio telescope, distributed over a wide area. This technique provides greater resolution in the images produced by the telescope, and allows for an increase in available collecting area without the difficulties of constructing one very large dish aperture. A further advantage of this technique is a slight immunity to localised interference, known as interferometric attenuation. This is due to RFI at one receiver being uncommon to all other receivers, and its impact can be reduced in the data processing stage. This technique can provide approximately 15dB of relaxation in the protection threshold limits. This attenuated level is provided in units of dB(W/Hz) in Figure 2.

The Minister of Science and Technology is due to promulgate the South African Radio Astronomy Service standard, in terms of the Astronomy Geographic Advantage Act. This standard prescribes protection threshold limits across the entire operating frequency range of the SKA, and do not include a relaxation as a result of interferometric attenuation.

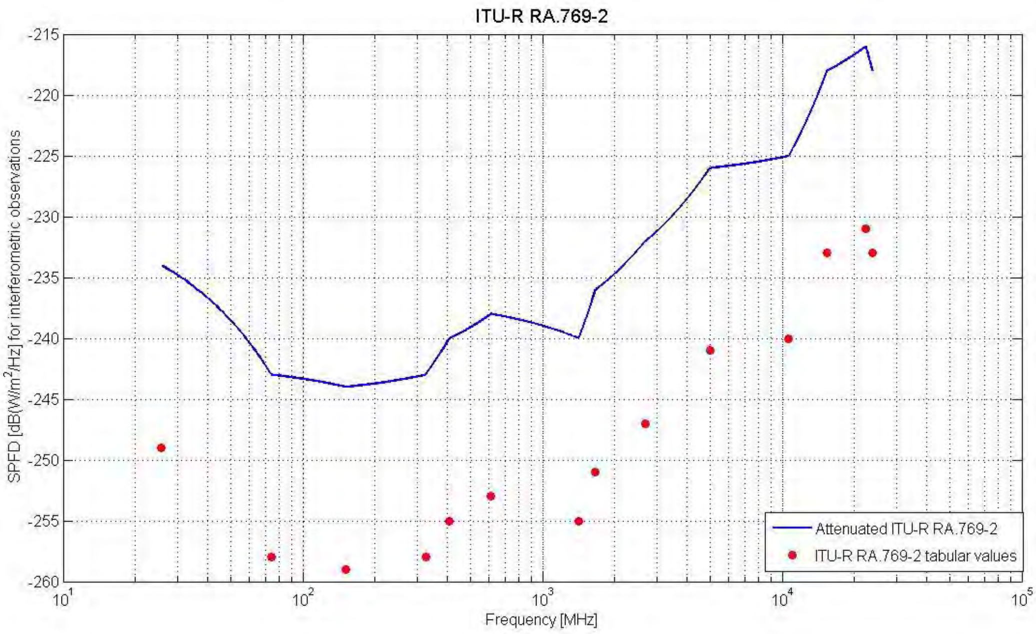

Figure 1: ITU-R RA.769-2 threshold levels. The markers indicate the tabulated levels, whilst the plotted line indicates those levels expected for interferometric observations.

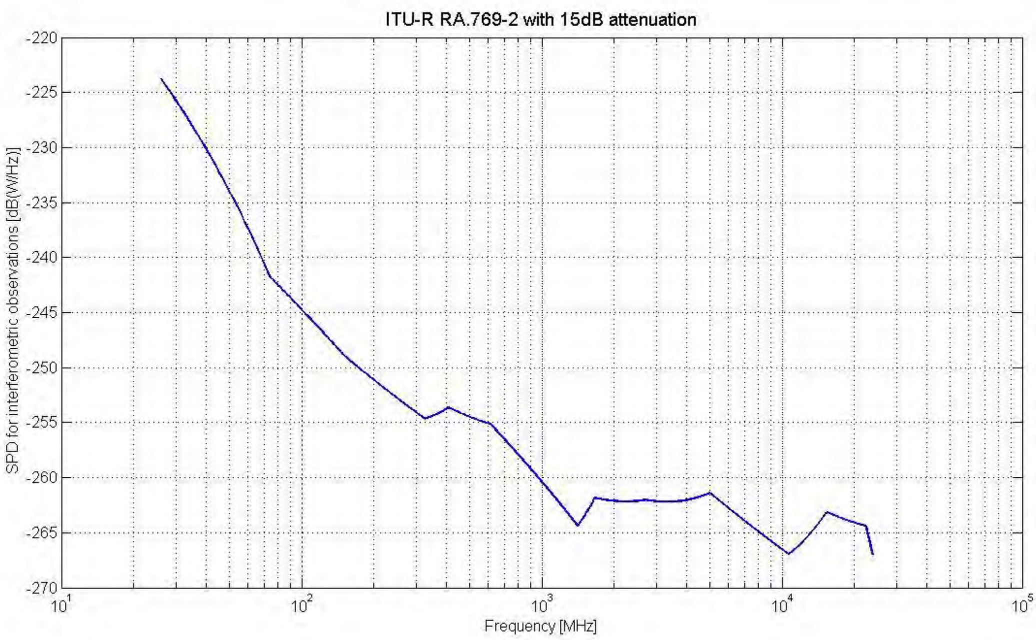

Figure 2: ITU-R RA.769-2 threshold levels in units of dB(W/Hz)

4.2. Impact of RFI

Radio astronomy facilities are sensitive to two classes of RFI. Firstly, the narrow band radio signals commonly associated with telecommunication services such as GSM, broadcasting services and Wi-Fi. These narrow band radio signals tend to be strong, and have one of three potential impacts on radio astronomy facilities (in order of increasing received signal strength):

i. The telescope would be required to filter out the narrowband interference, but may still continue to operate and perform radio astronomy observations outside of the particular frequency band. This will result in increased cost of the telescope, and decreased scientific performance;
ii. The telescope receivers would be rendered inoperational, due to the narrowband interference saturating the radio astronomy receiver equipment. Saturation produces artefacts across the entire observing band, and pushes the receiver equipment outside of its operational limits;
iii. The telescope receivers are permanently damaged. Reports have been received of radio telescopes in Germany being damaged from satellite transmission.

Any mobile radio communication equipment in use at a 'fracking' site would produce narrowband signals that could potential produce detrimental interference at one of the SKA stations.

Secondly, broadband radio emissions which are not used to provide telecommunication services, but instead are consequential electromagnetic interference (EMI) that is generated by electrical equipment. An example of this are the radio emissions generated from arc welding activities, or the sparking on power lines that may interrupt terrestrial analogue television reception. This broadband emission covers a large part of the spectrum and, although the strength of the emission does not pose a significant risk to damaging radio astronomy receivers, it fills large parts of the radio frequency spectrum and renders it unusable for radio astronomy observations, thereby reducing the scientific performance of the facility. The nature of electrical equipment is such that the bulk of EMI is produce in the critical low frequency part of the spectrum.

5. Identifying Sources of Potential Interference

This section attempts to provide a guide by addressing some of the potential sources of interference associated with ‘fracking’, and other industrial processes. The report focuses on broadband interference due to the following:

i. Any transmitters that are established to provide mobile telecommunication services would be required to comply with declarations and regulations governing use of the radio frequency spectrum, as promulgated in terms of the Astronomy Geographic Advantage Act;

ii. Broadband EMI is the area of greatest uncertainty in the analysis of potential sources of detrimental interference associated with ‘fracking’ activities.

5.1. Broadband Electromagnetic Interference (EMI)

In addressing sources of broadband interference, a variety of methodologies could be adopted. The most accurate method is to undertake a series of measurements, using accepted methodologies, to provide detailed measurement reports under all operational conditions. This would be undertaken over a wide sample of equipment to obtain a good statistical representation of the EMI characteristics associated with equipment used in ‘fracking’ activities. The very short timescales provided for the writing of this report do not allow for such a measurement activity to be undertaken. However, it is advised that this activity is undertaken in the future to provide the necessary detail required for a site-specific impact analysis.

The absence of such measurement results requires an adoption of national or international standards. In the case of this report, CISPR standards are adopted to provide EMI characteristics of general classes of equipment. The South African National Standards Authority adopts CISPR standards for use in South Africa.

Although EMI from a ‘fracking’ site is an integrated effect, in general it is the source of greatest interference that drives the strictest requirements in terms of mitigation, usually but not always resulting in a separation distance requirement between ‘fracking’ operations and the SKA. For this reason, the scope of identification has been limited. However, the analysis does provide for a generic process of identification, to be undertaken when more information becomes available.

5.1.1. CISPR Standards

The CISPR standards provided in the subsections below are the more common standards expected to be used in the EMI characterisation of 'fracking' sites and operations.

5.1.1.1. CISPR 11:2009

CISPR 11: 2009 covers the use of scientific, industrial and medical equipment, such as arc welding. Arc welding is characteristic of maintenance operations at any industrial site, and is a major source of radio interference. The expected emissions, as prescribed in the standard, are shown in Figure 3 as a function of frequency in units of dBW/Hz.

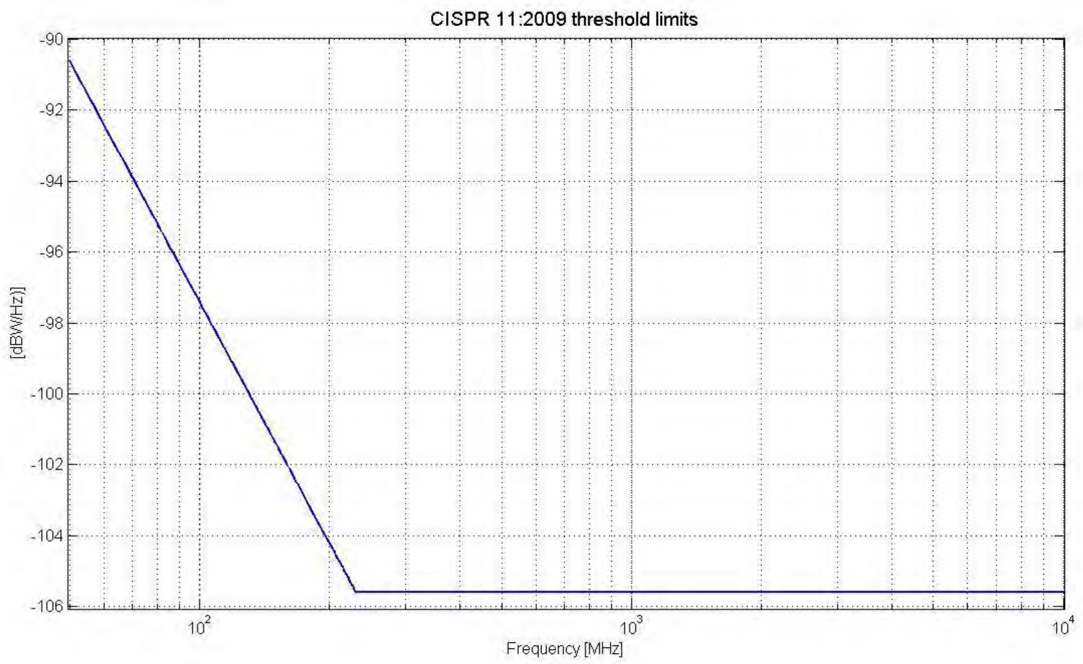

Figure 3: CISPR 11:2009 threshold limits.

5.1.1.2. CISPR 14-1:2009

CISPR 14-1:2009 covers the use of electrical appliances and tools. Use of power tools is common at any industrial site. The expected emissions as prescribed are shown in Figure 4. The interference is characterised by power ratings for the difference appliances.

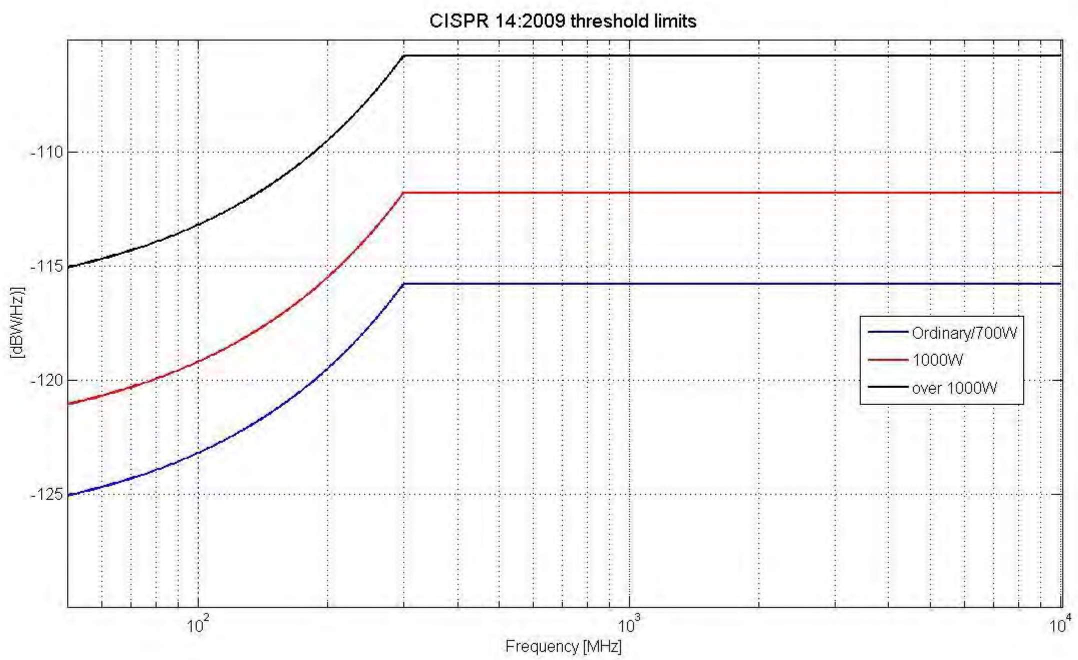

Figure 4: CISPR 14-1:2009 threshold limits

5.1.1.3. CISPR 22:2009

CISPR 22:2009 covers the use of Information Communication Technology (ICT) equipment, such as laptops and similar electronic devices. The expected emissions are shown in Figure 5.

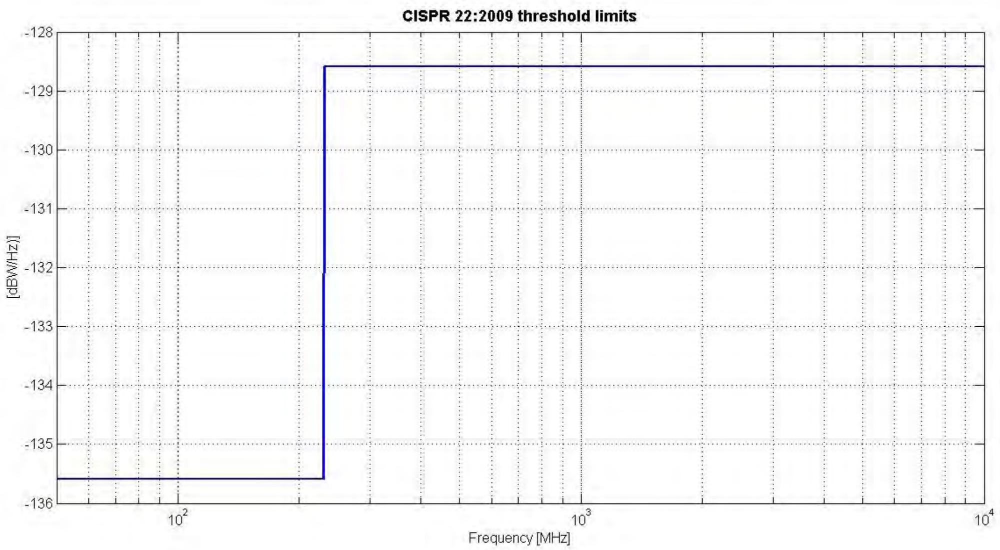

Figure 5: CISPR 22:2009 threshold limits.

5.1.1.4. CISPR 12:2009

CISPR 12:2009 covers the use of a variety of equipment, as summarised in the table below.

Examples of equipment included in the scope of CISPR 12				
Air Compressor	Concrete Grinder	Garden Trimmer	Moped	Quad Bike
Blower Vacuum	Concrete Mixer	Generator	Motor Bike	Snow Blower
Boat (< 15m)	Concrete Saw	Go Cart	Motorised Bike	Snow Mobile
Bus	Concrete Trowel	Golf Buggy	Motorised Scooter	Stump Grinder
Car	Concrete Vibrator	Hedge Trimmer	Outboard Engine	Tractor
Chain Saw	Dune Buggy	Jet Ski	Post Hole Digger	Truck
Compactor	Garden Mulcher	Lawn mower	Pressure Washer	Water Pump

This table covers a large part of the expected on-site and off-site equipment associated with 'fracking' operations, including cars, trucks, generators and water pumps. The expected electromagnetic emissions characterised by CISPR 12:2009 is shown in Figure 6.

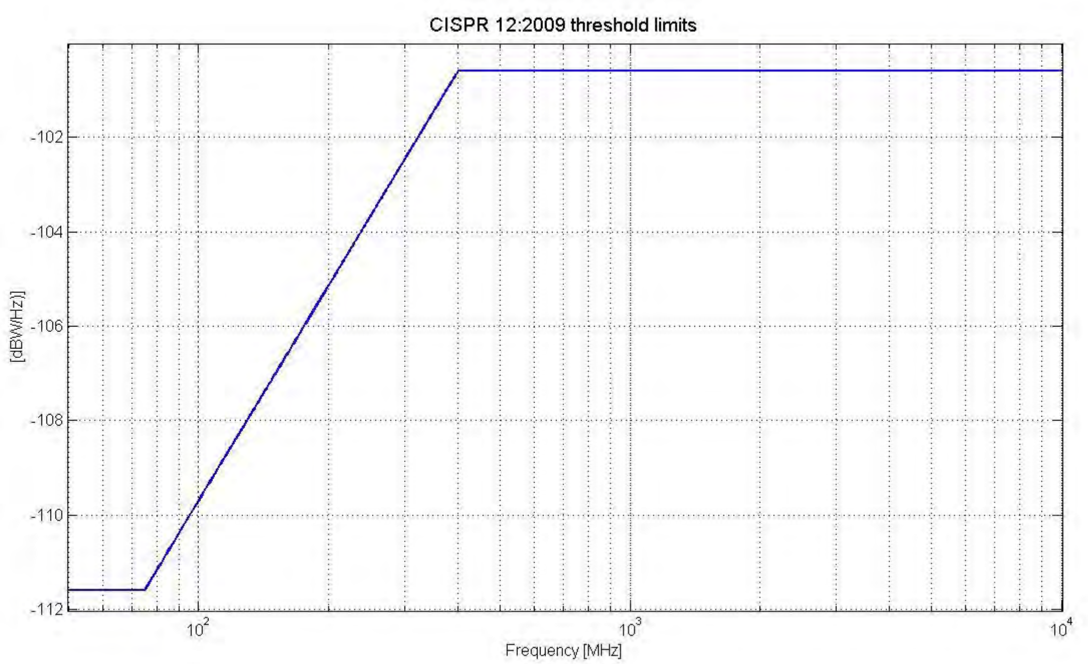

Figure 6: CISPR 12:2009 threshold limits.

6. Impact Analysis

This section considers the characteristic EMI profiles provided in Section 5 and determines the required attenuation, and hence geographic separation distance, in order to meet the protection threshold limits of radio astronomy. This attenuation can be achieved in other ways for particular sources of RFI. As this method is very specific on the technology being used, it will not be addressed in detail but instead will be commented on later in the report.

A detailed impact assessment should consider the operational scenario of the ‘fracking’ activity over installation, commissioning and operations. This will enable the development of a comprehensive EMI profile over time. By doing this, one may consider peak usage, and standard operations. Time constraints, and the lack of an operational model for the ‘fracking’ activity, did not allow for a full detailed assessment. However, references are made where the transient nature of the EMI source would require a modified assessment.

6.1. Modelling

Following the identification of sources of EMI, and obtaining either the relevant CISPR standards or measurement reports, the attenuation required to meet the radio astronomy protection threshold limits are calculated. In the case of the CISPR standards identified in Section 5, this is shown in Figure 7 as a function of frequency. For the purposes of this report, and as a result of the short timescales available, the relaxed protection threshold limits have been used.

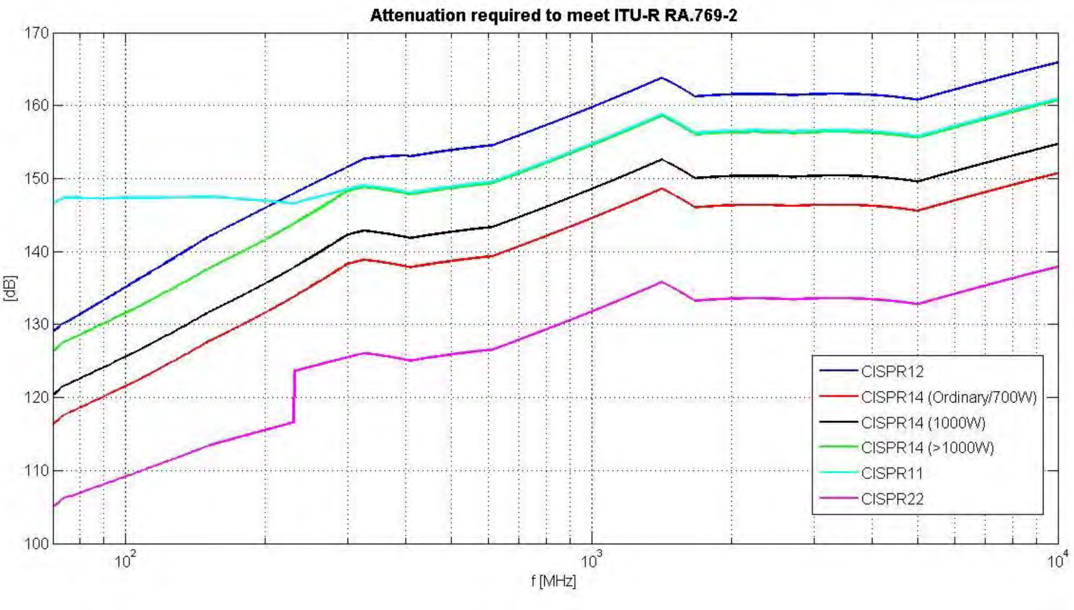

Figure 7: Attenuation required to meet the required radio astronomy protection threshold limits.

To perform the impact analysis, a path loss budget is developed. In order for the relevant sources of interference to be compliant with radio astronomy protection requirements, it should equal the total amount of attenuation required as shown in Figure 7. This path loss budet can be written as follows:

$$L(total) = L(free\ space) + L(topography) + L(other)$$

where *L(total)* is the total attenuation obtained, *L(free space)* is the attenuation due to free space propagation of the radio signal, *L(topography)* is the attenuation as a result of topographic shielding and other diffraction effects, and *L(other)* is attenuation due to other mitigation measures (discussed later). The analysis presented in the following sections only considers *L(free space)*, and a statistical component of *L(topography)*. What this means is that the model used to determine the attenuation as a result of propagation of the radio signal across terrain assumes a reasonably flat terrain with some variance of a couple meters. No large variations in topography are taken into account, and would need to be following the identification of exact geographic locations of 'fracking' sites. *L(other)* is taken to be zero at this stage. The results presented can therefore be seen as a guide to inform the reader, and cannot be taken as definitive in terms of separation distances at this stage.

6.2. Analysis

The radio frequency propagation model ITU Recommendation ITU-R P.1546-3 is used to determine the required separation distance between the sources of interference and radio astronomy receiver to meet the radio astronomy protection threshold limits. The model is highly dependent on the following:

i. Relative heights of the receiver and transmitter;
ii. Frequency of transmitter;
iii. Percentage of time that the radio signal power level exceeds that predicted.

As it is a statistical model, it is relatively insensitive to the actual topography in the surrounding area. It is recommended that in future a more detailed model is used that considers as input a high resolution digital elevation model. For the purposes of this analysis, an approximate height of 2m is assumed for the relevant transmitters. The receiver height is frequency dependent, due to the hybrid mix of receiver technologies used in the SKA. Conservatively, frequencies below 300 MHz will be received by aperture array stations, positioned 1m above the ground. Above 300 MHz, dishes will be used that have a maximum receive height of 15m. In all cases, the percentage of time allowed for which the radio signal exceeds the level predicted is 5%.

The analysis that follows considers two scenarios. Firstly, a scenario in which the sources of interference are present for more than 5% of the day. Note that this is an integrated effect ie. multiple arc welders, although individually used less than 5% of the day can result in greater than 5% if multiple arc welders are used, or other devices of the same CISPR class. The second scenario considers interference that is transient in nature – this could be as a result of the use profile of the equipment (only being used for a certain time period), or the fact that the source of interference is not in a fixed location but instead is moving.

6.2.1.Permanent and Semi-Permanent Sources of Interference

This subsection considers the separation distance required for equipment meeting CISPR recommendations to ensure protection of radio astronomy facilities. The separation distance as a function of frequency required to ensure protection from the use of arc welders, and other equipment meeting CISPR 11:2009 specifications, is indicated in Figure 8. The maximum separation distance of 20km is used as a specification.

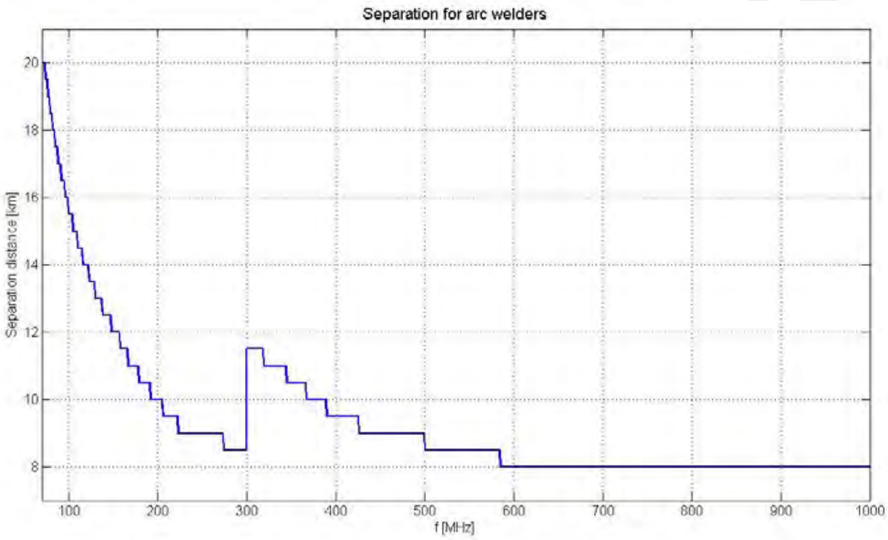

Figure 8: Required separation distance between devices meeting CISPR 11:2009 specifications, such as arc welders, and radio astronomy facility.

The required separation distance for ICT equipment meeting CISPR 22:2009 specifications is shown in Figure 9, with a maximum separation distance of 3.5km. A cautionary note – this result is for a single piece of ICT equipment. A large amount of ICT equipment would result in an integrated effect, and increase the required separation distance.

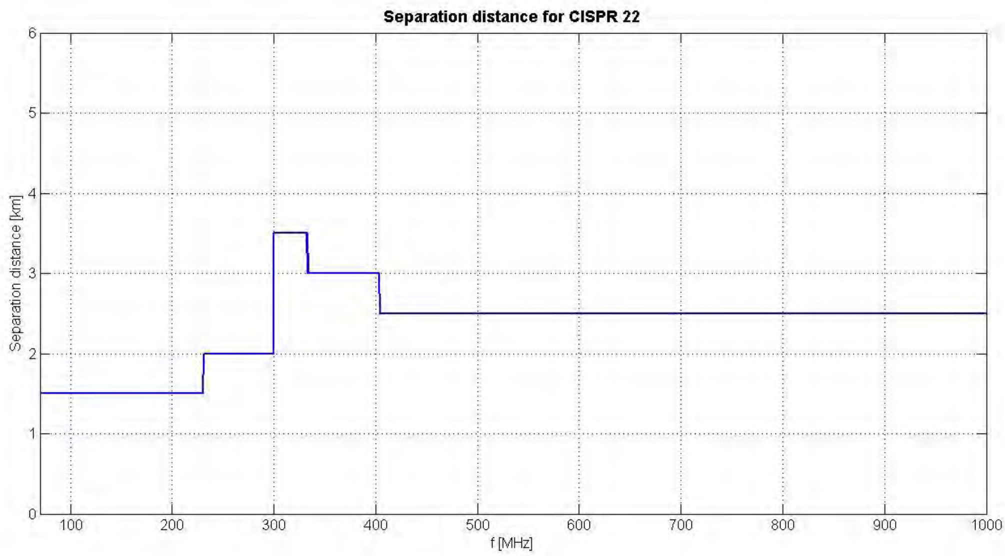

Figure 9: Required separation distance for ICT equipment meeting CISPR 22:2009 specifications.

If we consider equipment such as onsite vehicles, generators, water pumps and similar, all of which meets the CISPR 12:2009 specification, then the required separation distance has a maximum of 13.5km, as shown in Figure 10.

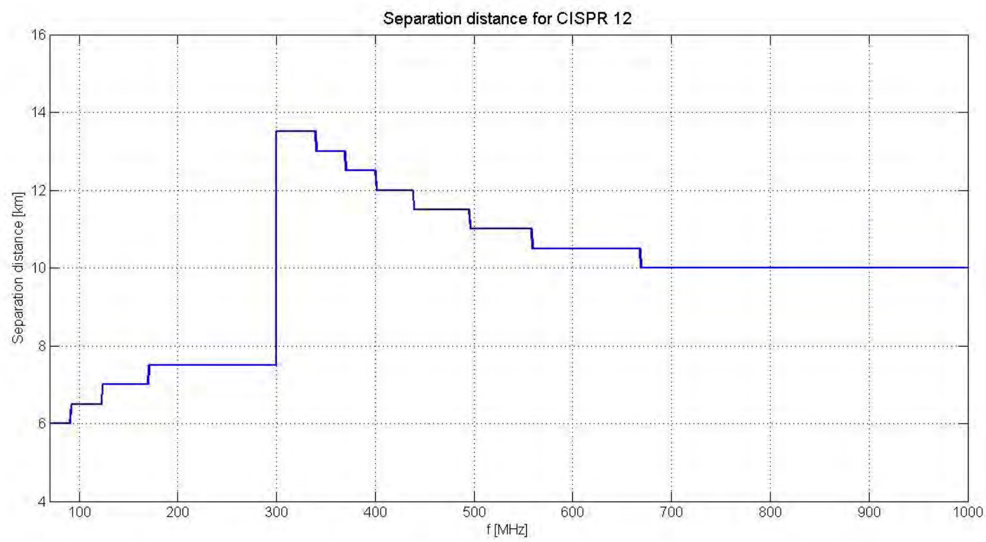

Figure 10: Required separation distance for equipment meeting CISPR 12:2009 specifications, such as vehicles, generators, water pumps and air compressors.

Finally, an operational mix of equipment is considered, shown in Figure 11. This mix includes an assortment of power tools, well maintained diesel vehicle, or generator, with no engine management systems. The required separation distance is of the order 13.5km.

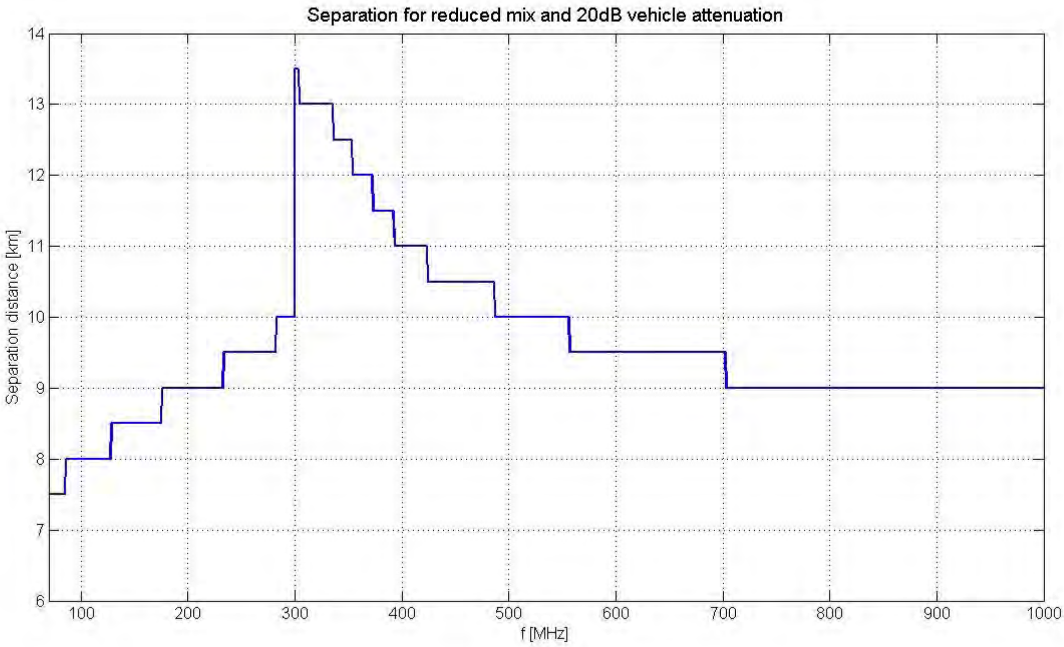

Figure 11: Separation distance for a typical operational unit, with well maintained diesel vehicle and some power tools.

6.2.2.Transient Sources of Interference

Transient sources of interference are sources that would result in a time dependant separation distance requirement. This would occur when either the equipment that that is producing the source of interference is operated for partial amounts of time, or the source of interference is moving (such as a vehicle). Both these scenarios are considered in the subsections that follow.

ITU Recommendation ITU-R RA.1513-1 (draft 2 in revision) considers the acceptable loss of data for a radio astronomy facility as a result of RFI. This is expressed as a percentage of time, with no single network of interference resulting in greater than 2% data loss, and a total data loss of no more than 5% tolerated for all sources.

Consider sources that are transient in time, taking 24 hours as a reasonable timescale for analysis. A full operations model is required in order to fully understand the EMI profile of a ‘fracking’ location with time. This would enable the accurate assessment of required separation distances as a statistical model. As this information is not yet known, or is unavailable, it is recommended that a study is undertaken on the full operational model of a ‘fracking’ site, to inform the detailed analysis.

The analysis of moving sources of interference takes into consideration the allowable time in which the source may be incompliant with the required separation distance, to ensure that data loss does not exceed the recommendations. The case of vehicles is used as a case study, which can be a complex modelling exercise. The primary input to this model is traffic volume, and we consider two cases: minor traffic, where each vehicle can be treated as an individual source of interference in time and space; and major traffic, where the density of vehicles is sufficient to treat as a constant source of interference.

The case of major traffic is dealt with as a permanent, or semi-permanent, source of interference as illustrated in Section 6.2.1. The case of minor traffic is dealt with below.

6.2.2.1. Minor Traffic

Figure 12 is a schematic that illustrates the case of travelling vehicles. We consider *n* vehicles per day, travelling at 100 km/hr. Each vehicle, meeting CISPR 12:2009 specifications, as a stationary source would result in a required separation distance of *r1* km. However, for sufficiently low vehicular volumes, a relaxation on *r1* can be accommodated, as defined by the equation:

$$r2 = \sqrt{r1^2 - \left(\frac{y}{2}\right)^2}$$

where *r1* is the separation distance required for a permanent device meeting CISPR 12:2009 specifications, *r2* is the relaxed separation distance, and *y* is the path length that a vehicle may be within the separation distance *r1*, as defined by the equation:

$$y = v \times t = v \times \frac{T}{n}$$

where *v* is the average velocity of the vehicle, *T* is the total allowable time in which data loss occurs, as defined by a percentage data loss over an acceptable timescale (nominally 24 hours), and *n* is the number of vehicles that pass by in the relevant time period.

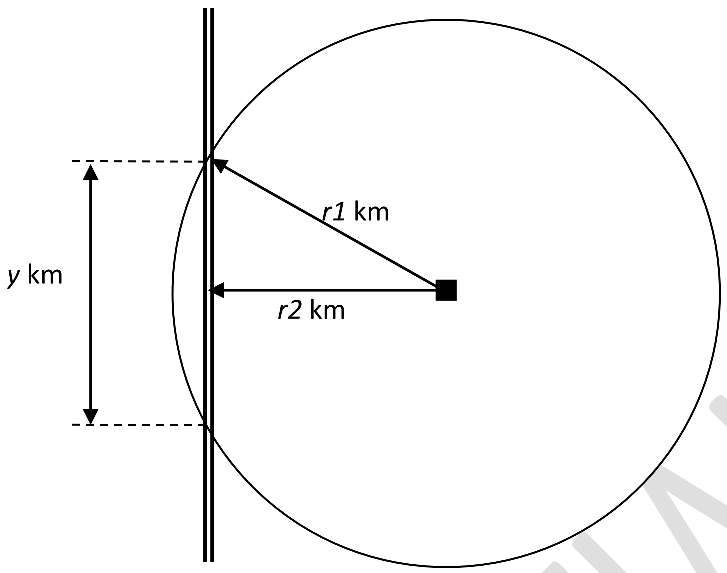

Figure 12: Schematic diagram for determination of separation distance for minor traffic.

Figure 13 describes the required separation distance for a road carrying 10 vehicles per day, travelling at an average of 100 km/hr.

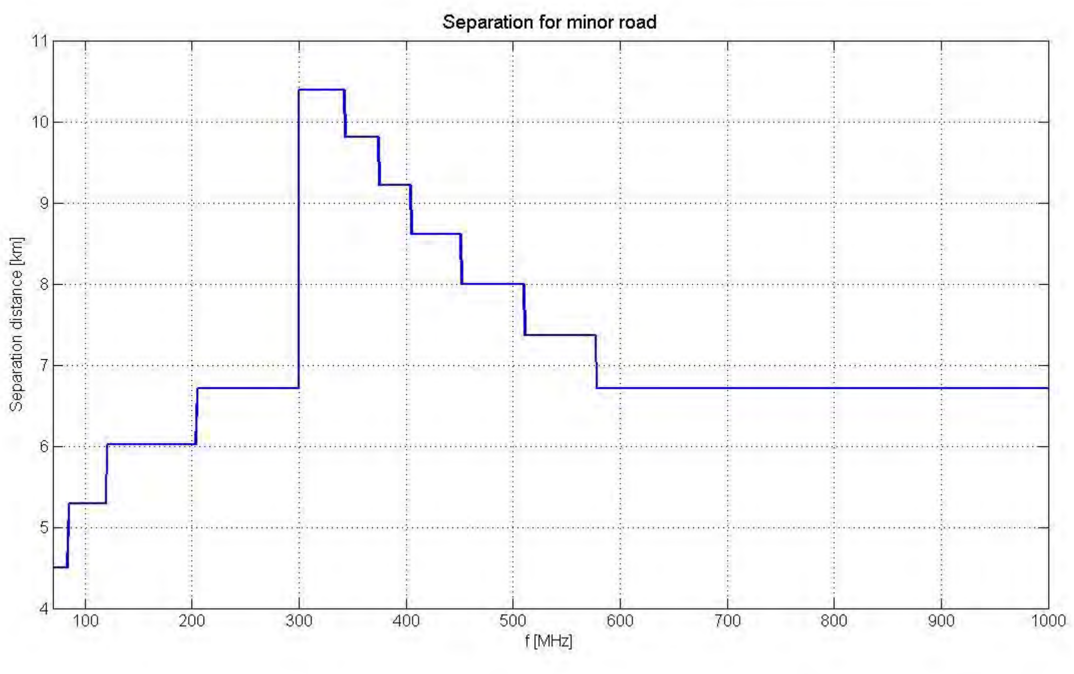

Figure 13: Separation distance for transport route carrying minor traffic, with a total volume of 10 vehicles per day, travelling at an average of 100 km/hr.

6.3. Impact on the SKA

The finalised SKA configuration is shown in Figure 14. This configuration has been developed together with the international SKA Program Development Office (SPDO), and is considered the final configuration to be submitted by South Africa for its proposal to host the SKA. A closeup of the configuration is shown in Figure 15. This figure not only shows the inner 180 km of the optimised configuration, it also shows the buffer zones that have been developed following a similar impact assessment as presented in this report. These buffer zones surround towns, mines, power infrastructure and transport routes deemed to be carrying sufficient vehicular traffic. An increase in vehicular traffic volumes on roads that do not currently have prescribed buffer zones would result in a major detrimental impact on the current optimised configuration, due to the resulting buffer zone requirement.

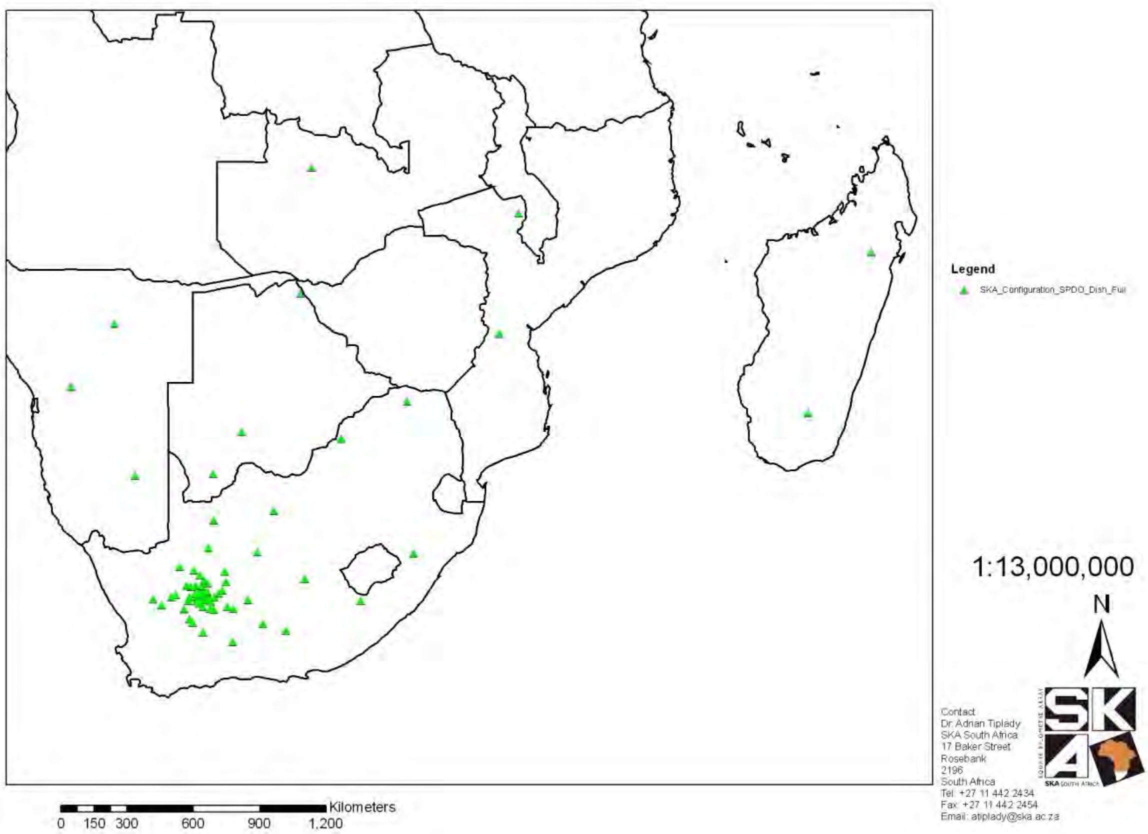

Figure 14: SKA configuration.

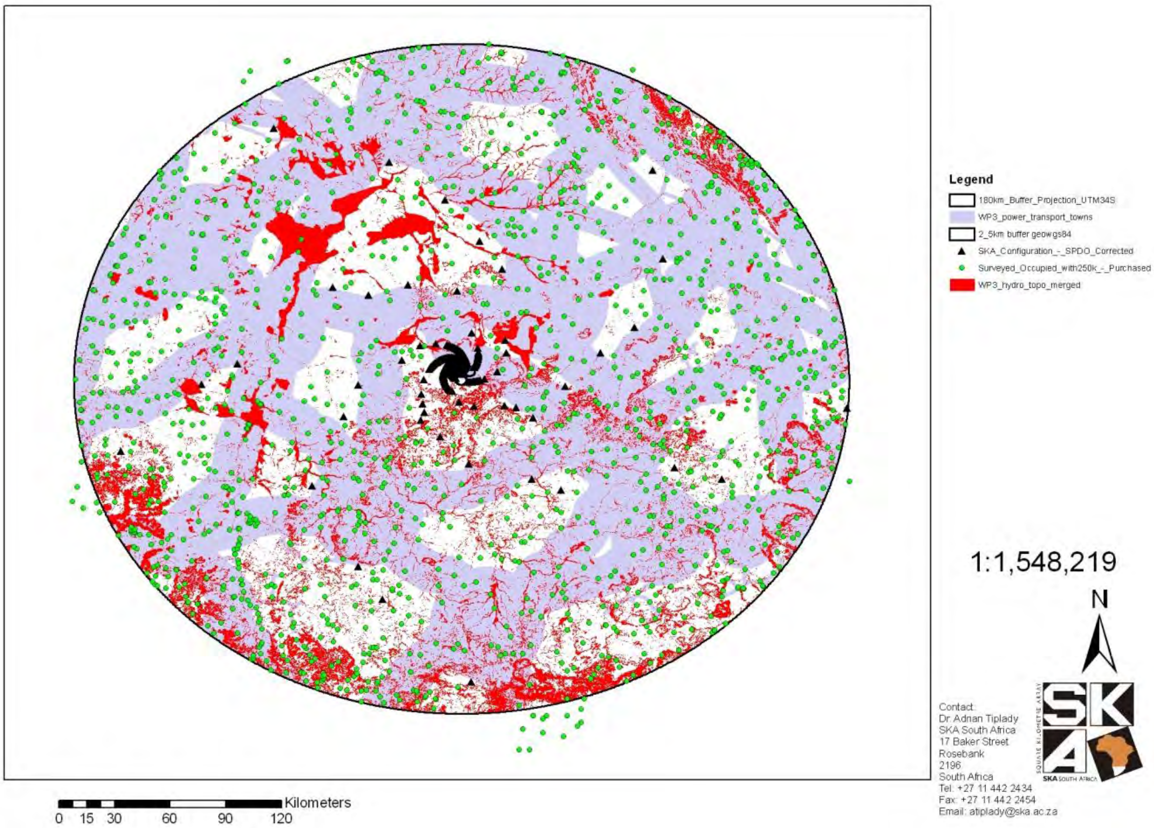

Figure 15: Closeup of SKA configuration, with buffer zones derived using a similar impact assessment as presented in this report. No SKA stations lie within existing buffer zones.

By way of illustration, the SKA configuration is illustrated in Figure 16. Each SKA station is surrounded by a 30 km buffer zone. Based on the analysis contained in this report, a conservative assessment would be that no 'fracking' activity takes places within the 30 km buffer zone, and that any locations within 50 kms of an SKA station be analysed with a detailed impact assessment prior to 'fracking' operations. Figure 17 shows a closeup of the SKA configuration in the Northern Cape Province. This area has been declared an Astronomy Advantage Area by the Minister of Science and Technology, in terms of the AGA Act. This area is most sensitive to 'fracking activities' due to the high density of stations.

The detailed coordinates for the SKA stations have been supplied to the Inter-Ministerial Task Team under conditions of non-disclosure.

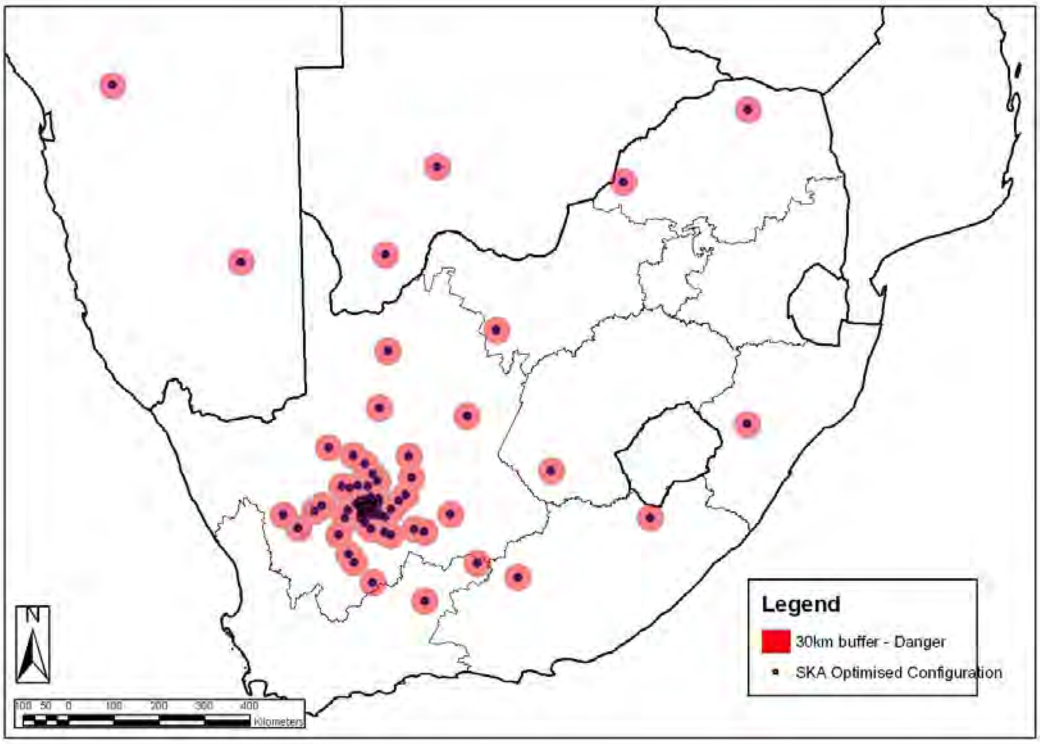

Figure 16: SKA Configuration, with each station surrounded by a 30km ‘no-fracking’ zone.

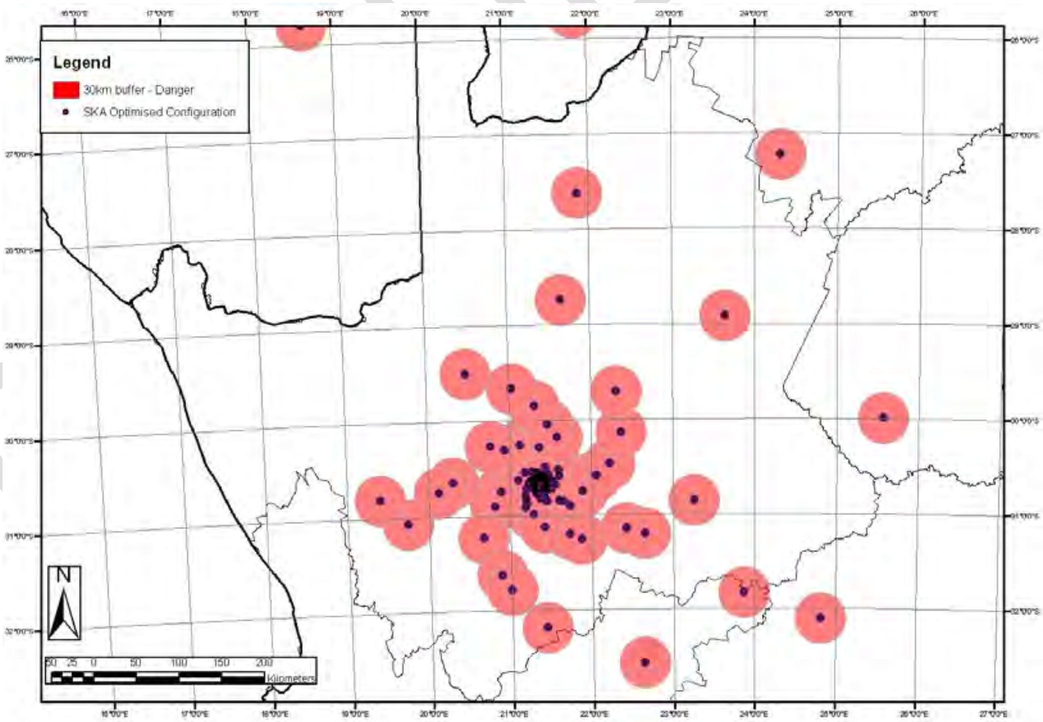

Figure 17: Closeup of the SKA Configuration in the Northern Cape Province, with each station surrounded by a 30km ‘no-fracking’ zone..

7. Mitigation Measures

The modelling undertaken in Section 6.1 assumes no further attenuation as a result of other mitigation measures, over and above that attenuation obtained from radio propagation loss. Various measures are available to increase the other attenuation, and thereby reduce the required separation distance. For example, the all onsite equipment at a radio astronomy facility is housed within a shielded environment, which produces up to 120 dB of attenuation of radio signals. The design of power lines ensures that any sparking on the power line, which produces EMI, is reduced to a minimum. Power filters are used on almost all equipment on site.

Various mitigation measures can be employed at 'fracking' sites to reduce required separation distances. However, a detailed technical analysis of all equipment, and operational model, is required before mitigation measures can be investigated. This technical analysis should not only include operations at the 'fracking' site, but also on supporting infrastructure such as regularly used transport routes.

8. Conclusion and Recommendations

This report considers a methodology to determine the potential impact of ‘fracking’ activities on the SKA. The methodology is based on sound, internationally accepted principles. The technical details assumed in the report have been used as a guide, and are not definitive, due to a lack of technical information on the ‘fracking’ activity. As a result, the author recommends that a more detailed study is commissioned over a period of 6-12 months. This study should consider the following:

i. Determination of the full range of equipment to be used in the commissioning and operation of ‘fracking’ sites by the various applicants. This list of equipment should be made available by the relevant applicants upon request;
ii. Field work study to characterise any relevant equipment in terms of its EMI characteristics if no appropriate national, or international standards exist. This may require field work at representative sites operated by the applicants;
iii. Determination of detailed operational scenario, including commissioning and operations;
iv. Determination of a detailed model to be used in analysing radio propagation;
v. Determination of a detailed impact assessment methodology, to be carried out once exact locations for ‘fracking’ activities are known.

Addendum to Report on Impact Analysis of Hydraulic Fracturing on the SKA:

Impact of SKA Site Decision of 25th May 2012

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21-06-2012

Addendum compiled for the South African Task Team on Hydraulic Fracturing

Contents

1. Preamble

On the 25th May 2012, the international Square Kilometre Array (SKA) Board publically announced the outcome of the SKA Site Selection process. Following the recommendation of the SKA Site Advisory Committee (SSAC) to appoint South Africa and its African Partner Countries as the sole host of the SKA, the Board decided to maximise the investment made by both site proponents. In so doing, two of the three SKA receptor technologies (the high-frequency dish receptors, and the mid-frequency dense aperture array receptors) were to be built in Southern Africa, and the remaining receptor technology (sparse aperture array) was to be built in Western Australia.

This addendum to the *Report on Impact Analysis of Hydraulic Fracturing on the SKA* (referred to as the *Report* from hereon), submitted as part of the report by the Working Group of the Task Team on Hydraulic Fracturing, considers the implications of this 'split-site' decision on the analysis performed in the original *Report*.

2. Introduction

The SKA, although a single radio astronomy observatory, is based on the use of three receptor technologies. Each technology will receive and process radio signals in a different part of the radio frequency spectrum. The frequency ranges for each of the receptor technologies is currently defined by the international SKA Project Office (SPO) as follows:

- 70 MHz to 200 MHz – Sparse aperture array receptors at a height of 1m above ground level, located in a dense core and distributed along spiral arms out to 180km from the SKA core site;
- 200 MHz to 500 MHz – Dense aperture array receptors at a height of 1m above ground level, located in a dense core and distributed along spiral arms out to 180km from the SKA core site;
- 500 MHz to 10 GHz – Dish receptors at a height of 15m above ground level, located in a dense core and distributed along spiral arms out to 180km from the SKA core site, and a further 25 remote stations within South Africa and its eight African Partner Countries;

A low frequency limit of 300 MHz for the dish receptors has been used to determine required separation distances in the finalisation of the SKA configuration in Africa to ensure protection from electromagnetic interference generated from standard electrical appliances and equipment.

The *Report* shows that the required maximum separation distance to ensure the protection of the SKA from electromagnetic interference as a result of hydraulic fracturing operations and associated activities is largely dependent on the lowest operational frequency of the dish receptors (except for a small number of industrial devices). This is due to the increased receiver height over the aperture arrays (sparse and dense), where a higher receiver will be more sensitive to potential electromagnetic interference.

The *Report* also notes that any transmitters that are established to provide mobile telecommunication services would be required to comply with declarations and regulations governing use of the radio frequency spectrum, as promulgated in terms of the Astronomy Geographic Advantage Act.

3. Impact of SKA Site Decision on Results of the *Report*

The SKA site decision of May 2012 means that the receptor technologies, dense aperture arrays and high frequency dishes, to be established in Africa will operate from 200 MHz (minimum) up to 10 GHz (expandable). With a low frequency limit of 200 MHz, the key factor that determines the maximum required separation distance from hydraulic fracturing operations and associated activities is the low frequency limit of the dishes (300 MHz to 500 MHz [TBD]).

The SKA site decision will not result in a significant material change on the impact analysis in the *Report*. Determination of the maximum required separation distance in the *Report* adopted a minimum risk approach to ensure the complete protection of the SKA stations, using a 300 MHz low frequency limit for the dishes. An increase in this limit to 500 MHz may result in an overall decrease of 25% in the maximum required separation distance. However, this is still to be confirmed by the international SKA Project Office over the next 24-48 months during the Pre-construction Engineering Program (PEP).

Although the use of arc welders resulted in a large maximum separation distance requirement at frequencies below 200 MHz in the Report, it would not be appropriate to reduce the overall protection requirements as a result of the site decision at this stage. This is mainly as a result of the associated uncertainties as described in the impact analysis contained in the *Report*.

4. Conclusion and Recommendations

The Conclusions and Recommendations as provided in Section 8 of the Report still stand. The following recommendations should be considered in addendum, or over-riding where there is conflict, to the original Conclusions and Recommendations:

- A mandatory separation distance of 30km is to be adopted as a requirement around each SKA station. No hydraulic fracturing, or associated activities, should take place within this distance to an SKA station;
- The separation distance may be subject to detailed site specific impact assessments and measurements, on request to the relevant responsible coordinating body, following the use of site specific techniques and equipment that may be adopted by the persons responsible for hydraulic fracturing operations and associated activities in mitigation of potential detrimental effects;
- The establishment or use of any telecommunication service at a hydraulic fracturing site, if located within a Central Astronomy Advantage Area as declared in terms of the Astronomy Geographic Advantage Act, will be required to comply with the necessary declarations and regulations governing the restricted use of the radio frequency spectrum.

RECOMMENDATION ITU-R RA.769-2

Protection criteria used for radio astronomical measurements

(Question ITU-R 145/7)

(1992-1995-2003)

The ITU Radiocommunication Assembly,

considering

a) that many of the most fundamental astronomical advances made in the past five decades, (e.g. the discovery of radio galaxies, quasars, and pulsars, the direct measurement of neutral hydrogen, the direct measurement of distances of certain external galaxies, and establishment of a positional reference frame accurate to ~20 arc µs) have been made through radio astronomy, and that radio astronomical observations are expected to continue making fundamental contributions to our understanding of the Universe, and that they provide the only way to investigate some cosmic phenomena;

b) that the development of radio astronomy has also led to major technological advances, particularly in receiving and imaging techniques, and to improved knowledge of fundamental radio-noise limitations of great importance to radiocommunication, and promises further important results;

c) that radio astronomers have made useful astronomical observations from the Earth's surface in all available atmospheric windows ranging from 2 MHz to 1000 GHz and above;

d) that the technique of space radio astronomy, which involves the use of radio telescopes on space platforms, provides access to the entire radio spectrum above about 10 kHz, including parts of the spectrum not accessible from the Earth due to absorption in atmosphere;

e) that protection from interference is essential to the advancement of radio astronomy and associated measurements;

f) that radio astronomical observations are mostly performed with high-gain antennas or arrays, to provide the highest possible angular resolution, and consequently main beam interference does not need to be considered in most situations, except when there is the possibility of receiver damage;

g) that most interference that leads to the degradation of astronomical data is received through the far side lobes of the telescope;

h) that the sensitivity of radio astronomical receiving equipment, which is still steadily improving, particularly at millimetre wavelengths, and that it greatly exceeds the sensitivity of communications and radar equipment;

j) that typical radio astronomical observations require integration times of the order of a few minutes to hours, but that sensitive observations, particularly of spectral lines, may require longer periods of recording, sometimes up to several days;

k) that some transmissions from spacecraft can introduce problems of interference to radio astronomy and that these cannot be avoided by choice of site for an observatory or by local protection;

l) that interference to radio astronomy can be caused by terrestrial transmissions reflected by the Moon, by aircraft, and possibly by artificial satellites;

m) that some types of high spatial-resolution interferometric observations require simultaneous reception, at the same radio frequency, by widely separated receiving systems that may be located in different countries, on different continents, or on space platforms;

n) that propagation conditions at frequencies below about 40 MHz are such that a transmitter operating anywhere on the Earth might cause interference detrimental to radio astronomy;

o) that some degree of protection can be achieved by appropriate frequency assignments on a national rather than an international basis;

p) that WRCs have made improved allocations for radio astronomy, particularly above 71 GHz, but that protection in many bands, particularly those shared with other radio services, may still need careful planning;

q) that technical criteria concerning interference detrimental to the radio astronomy service (RAS) have been developed, which are set out in Tables 1, 2, and 3,

recommends

1 that radio astronomers should be encouraged to choose sites as free as possible from interference;

2 that administrations should afford all practicable protection to the frequencies and sites used by radio astronomers in their own and neighbouring countries and when planning global systems, taking due account of the levels of interference given in Annex 1;

3 that administrations, in seeking to afford protection to particular radio astronomical observations, should take all practical steps to reduce all unwanted emissions falling within the band of the frequencies to be protected for radio astronomy to the absolute minimum. Particularly those emissions from aircraft, high altitude platform stations, spacecraft and balloons;

4 that when proposing frequency allocations, administrations take into account that it is very difficult for the RAS to share frequencies with any other service in which direct line-of-sight paths from the transmitters to the observatories are involved. Above about 40 MHz sharing may be practicable with services in which the transmitters are not in direct line-of-sight of the observatories, but coordination may be necessary, particularly if the transmitters are of high power.

Annex 1

Sensitivity of radio astronomy systems

1 General considerations and assumptions used in the calculation of interference levels

1.1 Detrimental-level interference criterion

The sensitivity of an observation in radio astronomy can be defined in terms of the smallest power level change ΔP in the power level P at the radiometer input that can be detected and measured. The sensitivity equation is:

$$\frac{\Delta P}{P} = \frac{1}{\sqrt{\Delta f_0 t}} \tag{1}$$

where:

P and ΔP: power spectral density of the noise

Δf_0: bandwidth

t: integration time. P and ΔP in equation (1) can be expressed in temperature units through the Boltzmann's constant, k:

$$\Delta P = k \, \Delta T; \quad \text{also} \quad P = k \, T \tag{2}$$

Thus we may express the sensitivity equation as:

$$\Delta T = \frac{T}{\sqrt{\Delta f_0 t}} \tag{3}$$

where:

$$T = T_A + T_R$$

This result applies for one polarization of the radio telescope. T is the sum of T_A (the antenna noise temperature contribution from the cosmic background, the Earth's atmosphere and radiation from the Earth) and T_R, the receiver noise temperature. Equations (1) or (3) can be used to estimate the sensitivities and interference levels for radio astronomical observations. The results are listed in Tables 1 and 2. An observing (or integration) time, t, of 2000 s is assumed, and interference threshold levels, ΔP_H, given in Tables 1 and 2 are expressed as the interference power within the bandwidth Δf that introduces an error of 10% in the measurement of ΔP (or ΔT), i.e.:

$$\Delta P_H = 0.1 \, \Delta P \, \Delta f \tag{4}$$

In summary, the appropriate columns in Tables 1 and 2 may be calculated using the following methods:

– ΔT, using equation (3),

– ΔP, using equation (2),

– ΔP_H, using equation (4).

The interference can also be expressed in terms of the pfd incident at the antenna, either in the total bandwidth or as a spectral pfd, S_H, per 1 Hz of bandwidth. The values given are for an antenna having a gain, in the direction of arrival of the interference, equal to that of an isotropic antenna (which has an effective area of $c^2/4\pi f^2$, where c is the speed of the light and f the frequency). The gain of an isotropic radiator, 0 dBi, is used as a general representative value for the side-lobe level, as discussed under § 1.3.

Values of $S_H \Delta f$ (dB(W/m^2)), are derived from ΔP_H by adding:

$$20 \log f - 158.5 \qquad \text{dB} \tag{5}$$

where f (Hz). S_H is then derived by subtracting 10 log Δf (Hz) to allow for the bandwidth.

1.2 Integration time

The calculated sensitivities and interference levels presented in Tables 1 and 2 are based on assumed integration times of 2000 s. Integration times actually used in astronomical observations cover a wide range of values. Continuum observations made with single-antenna telescopes (as distinct from interferometric arrays) are well represented by the integration time of 2000 s, typical of good quality observations. On the other hand 2000 s is less representative of spectral line observations. Improvements in receiver stability and the increased use of correlation spectrometers have allowed more frequent use of longer integration times required to observe weak spectral lines, and spectral line observations lasting several hours are quite common. A more representative integration time for these observations would be 10 h. For a 10 h integration, the threshold interference level is 6 dB more stringent than the values given in Table 2. There are also certain observations of time varying phenomena, e.g. observations of pulsars, stellar or solar bursts, and interplanetary scintillations for which much shorter time periods may be adequate.

1.3 Antenna response pattern

Interference to radio astronomy is almost always received through the antenna side lobes, so the main beam response to interference need not be considered.

The side-lobe model for large paraboloid antennas in the frequency range 2 to 30 GHz, given in Recommendation ITU-R SA.509 is a good approximation of the response of many radio astronomy antennas and is adopted throughout this Recommendation as the radio astronomy reference antenna. In this model, the side-lobe level decreases with angular distance (degrees) from the main beam axis and is equal to $32 - 25 \log \varphi$ (dBi) for $1° < \varphi < 48°$. The effect of an interfering signal clearly depends upon the angle of incidence relative to the main beam axis of the antenna, since the side-lobe gain, as represented by the model, varies from 32 to –10 dBi as a function of this angle. However, it is useful to calculate the threshold levels of interference strength for a particular value of side-lobe gain, that we choose as 0 dBi, and use in Tables 1 to 3. From the model, this side-lobe level occurs at an angle of 19.05° from the main beam axis. Then a signal at the detrimental threshold level defined for 0 dBi side-lobe gain will exceed the criterion for the detrimental level at the receiver input if it is incident at the antenna at an angle of less than 19.05°. The solid angle within a cone of angular radius 19.05° is 0.344 sr, which is equal to 5.5% of the 2π sr of the sky above the horizon that a radio telescope is able to observe at any given time. Thus if the probability of the angle of incidence of interference is uniformly distributed over the sky, about 5.5% of interfering signals would be incident within 19.05° of the main beam axis of an antenna pointed towards the sky. Note also that the 5.5% figure is in line with the recommended levels of data loss to radio astronomy observations in percentage of time, specified in Recommendation ITU-R RA.1513.

The particular case of non-GSO satellites presents a dynamic situation, that is, the positions of the satellites relative to the beam of the radio astronomy antenna show large changes within the time scale of the 2000 s integration time. Analysis of interference in this case requires integrating the response over the varying side-lobe levels, for example, using the concept of epfd defined in No. 22.5C of the Radio Regulations (RR). In addition it is usually necessary to combine the responses to a number of satellites within a particular system. In such calculations it is suggested that the antenna response pattern for antennas of diameter greater than 100 λ in Recommendation ITU-R S.1428 be used to represent the radio astronomy antenna, until a model based specifically on radio astronomy antennas is available; see § 2.2 for further discussion.

1.4 Bandwidth

Equation (1) shows that observations of the highest sensitivity are obtained when radio astronomers make use of the widest possible bandwidth. Consequently, in Table 1 (continuum observations), Δf is assumed to be the width of the allocated radio astronomy bands for frequencies up to 71 GHz. Above 71 GHz a value of 8 GHz is used, which is a representative bandwidth generally used on radio astronomy receivers in this range. In Table 2 (spectral line observations) a channel bandwidth Δf equal to the Doppler shift corresponding to 3 km/s in velocity is used for entries below 71 GHz. This value represents a compromise between the desired high spectral resolution and the sensitivity. There are a very large number of astrophysically important lines above 71 GHz, as shown in Recommendation ITU-R RA.314 and only a few representative values for the detrimental levels are given in Table 2 for the range 71-275 GHz. The channel bandwidth used to compute the detrimental levels above 71 GHz is 1000 kHz (1 MHz) in all cases. This value was chosen for practical reasons. While it is slightly wider than the spectral channel width customary in radio astronomy receivers at these frequencies, it is used as the standard reference bandwidth for space services above 15 GHz.

1.5 Receiver noise temperature and antenna temperature

The receiver noise temperatures in Tables 1 and 2 are representative of the systems in use in radio astronomy. For frequencies above 1 GHz these are cryogenically cooled amplifiers or mixers. The quantum effect places a theoretical lower limit of hf/k on the noise temperature of such devices, where h and k are Planck's and Boltzmann's constants, respectively. This limit becomes important at frequencies above 100 GHz, where it equals 4.8 K. Practical mixers and amplifiers for bands at 100 GHz and higher provide noise temperatures greater than hf/k by a factor of about four. Thus, for frequencies above 100 GHz, noise temperatures equal to $4hf/k$ are used in Tables 1 and 2.

The antenna temperatures in the Tables are also representative of practical systems in use in radio astronomy. They include the effects of the ionosphere or the neutral atmosphere, ground pickup in side lobes resulting from spillover or scattering, ohmic losses, and the cosmic microwave background. At frequencies above 100 GHz the atmospheric losses due to water vapour in the neutral atmosphere become very important. For these frequencies the values given are typical of the terrestrial sites used for major millimetric-wave radio astronomy facilities, such as Mauna Kea, Hawaii, or the Llano de Chajnantor at an elevation of 5 000 m in Chile, which is the site chosen for a major international radio astronomy array for frequencies in the range 30 GHz to 1 THz.

2 Special cases

The levels given in Tables 1 and 2 are applicable to terrestrial sources of interfering signals. The detrimental pfd and spectral pfd shown in Tables 1 and 2 assume that interference is received through a 0 dBi side lobe, and should be regarded as the general interference criteria for high sensitivity radio astronomy observations, when the interference does not enter the near side lobes.

2.1 Interference from GSO satellites

Interference from GSO satellites is a case of particular importance. Because the power levels in Tables 1 and 2 were calculated based on a 0 dBi antenna gain, interference detrimental to radio astronomy will be encountered when a reference antenna, such as described in Recommendation ITU-R SA.509, is pointed within 19.05° of a satellite radiating at levels in accordance with those listed in the Tables. A series of such transmitters located around the GSO would preclude radio astronomy observations with high sensitivity from a band of sky 38.1° wide and centred on the orbit. The loss of such a large area of sky would impose severe restrictions on radio astronomy observations.

In general, it would not be practical to suppress the unwanted emissions from satellites to below the detrimental level when the main beam of a radio telescope is pointed directly towards the satellite. A workable solution is suggested by observing the projection of the GSO in celestial coordinates as viewed from the latitudes of a number of major radio astronomy observations (see Recommendation ITU-R RA.517). If it were possible to point a radio telescope to within 5° of the GSO without encountering detrimental interference, then for that telescope a band of sky 10° wide would be unavailable for high-sensitivity observations. For a given observatory this would be a serious loss. However, for a combination of radio telescopes located at northern and southern latitudes, operating at the same frequencies, the entire sky would be accessible. A value of 5° should therefore be regarded as the requirement for minimum angular spacing between the main beam of a radio astronomy antenna and the GSO.

In the model antenna response of Recommendation ITU-R SA.509, the side-lobe level at an angle of 5° from the main beam is 15 dBi. Thus, to avoid interference detrimental to a radio telescope meeting the antenna side-lobe performance of Recommendation ITU-R SA.509, pointed to within 5° of the transmitter, it is desirable that the satellite emissions be reduced 15 dB below the pfd given in Tables 1 and 2. When satellites are spaced at intervals of only a few degrees along the GSO, the emission levels associated with the individual transmitters must be even lower to meet the requirement that the sum of the powers of all the interfering signals received should be 15 dB below ΔP_H in Tables 1 and 2.

It is recognized that the emission limitations discussed above cannot, in practice, be achieved so as to enable sharing of the same frequency band between radio astronomy and down-link transmissions from satellites to take place. The limitations are, however, applicable to unwanted emission from the satellite transmitters, which fall within the radio astronomy bands listed in Tables 1 and 2. These emission limitations have implications for the space services responsible for the interference, which require careful evaluation. Furthermore, the design of new radio astronomy antennas should strive to minimize the level of side-lobe gain near the main beam as an important means of reducing interference from transmitters in the GSO.

2.2 Interference from non-GSO satellites

In the case of non-GSO satellites, and in particular for low-Earth orbit satellites, the systems usually involve constellations of many individual satellites. Thus determination of interference levels requires analysis of the combined effect of many signals, most of which are received through far side lobes of the radio astronomy antenna. A more detailed side-lobe model than that of Recommendation ITU-R SA.509 is therefore desirable, and it is proposed that the model in Recommendation ITU-R S.1428 be used until such time as a more representative model for radio astronomy antennas is obtained. In using this proposed model the case for antennas with diameter greater than 100 λ is generally appropriate for radio astronomy applications. It should be noted that Note 1 of Recommendation ITU-R S.1428, which allows cross-polarized components to be ignored, cannot be applied since radio astronomy antennas generally receive signals in two orthogonal polarizations simultaneously. The motion of non-GSO satellites across the sky during a 2 000 s integration period requires that the interference level be averaged over this period, that is, the response to each satellite must be integrated as the satellite moves through the side-lobe pattern. One system of analysis that includes these requirements is the epfd method described in RR No. 22.5C. Values of epfd represent the pfd of a signal entering the antenna through the centre of the main beam that would produce an equivalent level of interference power. Since the threshold levels of detrimental interference in Tables 1 and 2 correspond to pfd received with an antenna gain of 0 dBi, it is necessary to compare them with values of ($epfd + G_{mb}$), where G_{mb} is the main beam gain, to determine whether the interference exceeds the detrimental level. Making use of the epfd method, Recommendation ITU-R S.1586 has recently been developed for interference calculations between radio astronomy telescopes and FSS non-GSO satellite systems. A similar Recommendation, Recommendation ITU-R M.1583 was developed for interference calculations between radio astronomy telescopes and MSS and radionavigation-satellite service non-GSO satellite systems. The applicability of the protection criteria given in Tables 1 and 2 is described in Recommendation ITU-R RA.1513.

2.3 The response of interferometers and arrays to radio interference

Two effects reduce the response to interference. These are related to the frequency of the fringe 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. The treatment of these effects is more complicated than that for single antennas in § 1. Broadly speaking, if the strength of the received interfering signal remains constant, the effect is reduced by a factor roughly equal to the mean time of one natural fringe oscillation divided by the data averaging time. This typically ranges from some seconds for a compact array with the longest projected spacing $L' \sim 10^3\ \lambda$, where λ is the wavelength, to less than 1 ms for intercontinental arrays with $L' \sim 10^7\ \lambda$. Thus, compared to a single radio telescope, the interferometer has a degree of immunity to interference which, under reasonable assumptions increases with the array size expressed in wavelengths.

The greatest immunity from interference occurs for interferometers and arrays in which the separation of the antennas is sufficiently great that the chance of occurrence of correlated interference is very small (e.g. for very long baseline interferometry (VLBI)). In this case, the above considerations do not apply. The tolerable interference level is determined by the requirement that the power level of the interfering signal should be no more than 1% of the receiver noise power to prevent serious errors in the measurement of the amplitude of the cosmic signals. The interference levels for typical VLBI observations are given in Table 3, based on the values of T_A and T_R given in Table 1.

It must be emphasized that the use of large interferometers and arrays is generally confined to studies of discrete, high-brightness sources, with angular dimensions no more than a few tenths of a second of arc for VLBI. For more general studies of radio sources, the results in Tables 1 and 2 apply and are thus appropriate for the general protection of radio astronomy.

TABLE 1

Threshold levels of interference detrimental to radio astronomy continuum observations

Centre frequency [(1)] f_c (MHz)	Assumed bandwidth Δf (MHz)	Minimum antenna noise temperature T_A (K)	Receiver noise temperature T_R (K)	System sensitivity[(2)] (noise fluctuations)		Threshold interference levels[(2) (3)]		
				Temperature ΔT (mK)	Power spectral density ΔP (dB(W/Hz))	Input power ΔP_H (dBW)	pfd $S_H \Delta f$ (dB(W/m^2))	Spectral pfd S_H (dB(W/(m^2 · 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

(1) Calculation of interference levels is based on the centre frequency shown in this column although not all regions have the same allocations.

(2) An integration time of 2 000 s has been assumed; if integration times of 15 min, 1 h, 2 h, 5 h or 10 h are used, the relevant values in the Table should be adjusted by +1.7, –1.3, –2.8, –4.8 or –6.3 dB respectively.

(3) The interference levels given are those which apply for measurements of the total power received by a single antenna. Less stringent levels may be appropriate for other types of measurements, as discussed in § 2.2. For transmitters in the GSO, it is desirable that the levels be adjusted by –15 dB, as explained in § 2.1.

TABLE 2*

Threshold levels of interference detrimental to radio astronomy spectral-line observations

frequency f (MHz)	Assumed spectral line channel bandwidth Δf (MHz)	Minimum antenna noise temperature T_A (K)	Receiver noise temperature T_R (K)	System sensitivity[2] (noise fluctuations)		Threshold interference levels[1] [2]		
				Temperature ΔT (mK)	Power spectral density ΔP_S (dB(W/Hz))	Input power ΔP_H (dBW)	pfd $S_H\,\Delta f$ (dB(W/m^2))	Spectral pfd S_H (dB(W/(m^2 · Hz)))
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
327	10	40	60	22.3	–245	–215	–204	–244
1 420	20	12	10	3.48	–253	–220	–196	–239
1 612	20	12	10	3.48	–253	–220	–194	–238
1 665	20	12	10	3.48	–253	–220	–194	–237
4 830	50	12	10	2.20	–255	–218	–183	–230
14 488	150	15	15	1.73	–256	–214	–169	–221
22 200	250	35	30	2.91	–254	–210	–162	–216
23 700	250	35	30	2.91	–254	–210	–161	–215
43 000	500	25	65	2.84	–254	–207	–153	–210
48 000	500	30	65	3.00	–254	–207	–152	–209
88 600	1 000	12	30	0.94	–259	–209	–148	–208
150 000	1 000	14	30	0.98	–259	–209	–144	–204
220 000	1 000	20	43	1.41	–257	–207	–139	–199
265 000	1 000	25	50	1.68	–256	–206	–137	–197

* This Table is not intended to give a complete list of spectral-line bands, but only representative examples throughout the spectrum.

(1) An integration time of 2 000 s has been assumed; if integration times of 15 min, 1 h, 2 h, 5 h or 10 h are used, the relevant values in the Table should be adjusted by +1.7, –1.3, –2.8, –4.8 or –6.3 dB respectively.

(2) The interference levels given are those which apply for measurements of the total power received by a single antenna. Less stringent levels may be appropriate for other types of measurements, as discussed in § 2.2. For transmitters in the GSO, it is desirable that the levels need to be adjusted by –15 dB, as explained in § 2.1.

COLUMN DESCRIPTIONS FOR TABLES 1 AND 2

Column

(1) Centre frequency of the allocated radio astronomy band (Table 1) or nominal spectral line frequency (Table 2).

(2) Assumed or allocated bandwidth (Table 1) or assumed typical channel widths used for spectral line observations (Table 2).

(3) Minimum antenna noise temperature includes contributions from the ionosphere, the Earth's atmosphere and radiation from the Earth.

(4) Receiver noise temperature representative of a good radiometer system intended for use in high sensitivity radio astronomy observations.

(5) Total system sensitivity (mK) as calculated from equation (1) using the combined antenna and receiver noise temperatures, the listed bandwidth and an integration time of 2 000 s.

(6) Same as (5) above, but expressed in noise power spectral density using the equation $\Delta P = k\, \Delta T$, where $k = 1.38 \times 10^{-23}$ (J/K) (Boltzmann's constant). The actual numbers in the Table are the logarithmic expression of ΔP.

(7) Power level at the input of the receiver considered harmful to high sensitivity observations, ΔP_H. This is expressed as the interference level which introduces an error of not more than 10% in the measurement of ΔP; $\Delta P_H = 0.1\ \Delta P\ \Delta f$: the numbers in the Table are the logarithmic expression of ΔP_H.

(8) pfd in a spectral line channel needed to produce a power level of ΔP_H in the receiving system with an isotropic receiving antenna. The numbers in the Table are the logarithmic expression of $S_H\ \Delta f$.

(9) Spectral pfd needed to produce a power level ΔP_H in the receiving system with an isotropic receiving antenna. The numbers in the Table are the logarithmic expression of S_H. To obtain the corresponding power levels in a reference bandwidth of 4 kHz or 1 MHz add 36 dB or 60 dB, respectively.

TABLE 3

Threshold interference levels for VLBI observations

Centre frequency (MHz)	**Threshold level (dB(W/m^2 · Hz)))**
325.3	–217
611	–212
1 413.5	–211
2 695	–205
4 995	–200
10 650	–193
15 375	–189
23 800	–183
43 000	–175
86 000	–172

No. R. 90 **10 February 2012**

REGULATIONS ON RADIO ASTRONOMY PROTECTION LEVELS IN ASTRONOMY ADVANTAGE AREAS DECLARED FOR THE PURPOSES OF RADIO ASTRONOMY

In terms of section 37, read with section 50, of the Astronomy Geographic Advantage Act, 2007 (Act No. 21 of 2007), I, Grace Naledi Mandisa Pandor, Minister of Science and Technology, having obtained the concurrence of the Independent Communications Authority of South Africa as required by the Act, hereby make regulations on radio astronomy protection levels in astronomy advantage areas declared for the purposes of radio astronomy, as set out in the Schedule.

G. N. M. Pandor

MRS GNM PANDOR, MP

MINISTER OF SCIENCE AND TECHNOLOGY

SCHEDULE

1. Definitions

In these regulations any word or expression to which a meaning has been assigned in the Act has the meaning so assigned and, unless the context otherwise indicates –

"ITU" means the International Telecommunications Union;

"SPDF" means Spectral Power Flux Density;

"the Act" means the Astronomy Geographic Advantage Act, 2007 (Act No. 21 of 2007).

2. Protection levels

(1) The origin, derivation and references for the protection levels to be applied in astronomy advantage areas declared for the purposes of radio astronomy are as follows:

(a) The protection levels are derived using the methodology described in ITU Recommendation ITU-R RA.769.

(b) The technical assumptions made in the derivation are that receiver and sky temperatures are linearly interpolated from those values found in ITU-R RA.769, and that receiver bandwidth is assumed to be 1% of the observing frequency.

(c) Derived protection levels, which are equivalent to threshold levels of interference for new generation radio astronomy observatories and are based on the methodology outlined in ITU-R RA.769, are depicted in Figure 1.

(2) The protection levels to be applied in astronomy advantage areas declared for the purposes of radio astronomy shall be as follows:

(a) The values of the protection levels at the applicable frequencies are determined by means of a linearly piecewise function.

(b) The said function is described by the following equations, which are to be used to calculate the required protection level at any frequency in the spectrum from 70 MHz to 25,5 GHz:

SARAS [dBm / Hz] = - *17.2708* $\log_{10}(f)$ – *192.0714 for* $f < 2$ *GHz.*

SARAS [dBm / Hz] = - *0.065676* $\log_{10}(f)$ – *248.8661 for* $f \geq 2$ *GHz.*

The values of (f) are to be in MHz.

(c) The function is designated as the South African Radio Astronomy Service ("SARAS") protection levels.

(d) The SARAS protection levels are reflected in Figure 1 below, together with the ITU interpolated continuum threshold levels of interference.

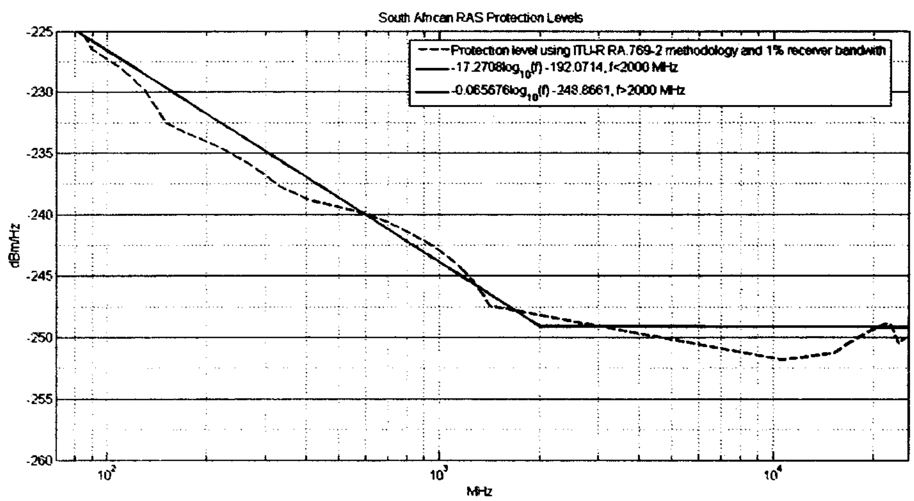

Figure 1. SARAS Protection Levels

(e) Owing to the variety of units used within the electronic communications sector, the following list of unit conversions is provided (assuming an isotropic radiator):

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

$$dBm \rightarrow dBm/Hz \quad : \quad dBm - 10\log_{10}(\Delta f)$$

$$dBW \rightarrow dBm \quad : \quad dBW + 30$$

$$dBW \rightarrow dB(W/m^2) \quad : \quad dBW + 20\log_{10}(f) - 158.5$$

The values of "f" and "Δf" are to be in Hz.

3. Short title

These regulations are called the Radio Astronomy Protection Levels Regulations.

RFI and EMI Assessment Methodology

1. Preamble

The purpose of this document is to provide the mathematical framework to conduct an impact assessment of RFI and EMI on the risk of detrimental impact on radio astronomy receivers.

2. Generalised Assessment Methodology

In the generalised case to assess the risk of detrimental impact of radio interference at each frequency f_i on radio astronomy receivers, we require the following condition to be true:

$$\text{Compliance} \rightarrow Loss_{det} \geq Loss_{required}$$

where:

$$Loss_{required} = ProtectLevel - SPD$$

- SPD = spectral power density of transmitted RF signal [dB(W/Hz)]
- $ProtectLevel$ = Required protection threshold level. Unless otherwise determined, the default level shall be defined as
    - SARAS [dBm/Hz] = $-17.2708\ log10\ (f) - 192.0714$ for $f < 2\ GHz$,
      $-0.065676\ log10\ (f) - 248.8661$ for $f > 2\ GHz$

    where f is in MHz.

and where:

$$Loss_{det} = Path\ Loss + Shielding$$

- $Loss_{det}$ = total attenuation of transmitted RF signal [dB]
- $Path\ Loss$ = attenuation resulting from RF propagation, including free space loss and diffraction losses [dB]. These losses may be determined via the following methods, in order from most conservative to least conservative:
    - Free space loss;
    - Free space loss + diffraction model
    - Measurement;

- $Shielding =$ attenuation resulting from additional physical shielding [dB]

The spectral power density of the transmitted signal (*SPD*) can be determined either through transmitter specifications, where available, or via measurement. In the case that measurements of field strength are conducted, the *SPD* is calculated as follows:

$$SPD = EIRP - 10\log_{10} BW$$

where

- $SPD =$ spectral power density [dB(W/Hz)]
- $BW =$ bandwidth of signal [Hz]

and

$$EIRP = E + 20\log_{10} D - 74.8$$

where

- $EIRP =$ istropically radiated power [dB(W)]
- $E =$ electric field strength [dB(uV/m)]
- $D =$ measurement distance [km]

Minimum Attenuation Required			
Phase		Frequency [MHz]	Predicted Attenuation [dB]
On-Site (excl. Communication Service)			
Construction	Site Preparations	350	*155*
	Drilling Securing	350	*153*
Operations	Stimulation & Well Test	350	*149*
Decommissioning	Site Preparations	350	*155*
On-Site			
Construction	Site Preparations	350	*155*
	Drilling Securing	350	*155*
Operations	Stimulation & Well Test	350	*155*
Decommissioning	Site Preparations	350	*155*
On Road			
Construction	Site Preparations	350	*145*
	Drilling Securing	350	*143*
Operations	Stimulation & Well Test	350	*143*
Decommissioning	Site Preparations	350	*145*

		Measured Results and Impact Analysis o			
Additional Shielding [dB]		**Frequency [MHz]**	**Max Radiated dB(W/Hz)**	**Min Radiated dB(W/Hz)**	**CISPR-22 Class B [dB(W/Hz)]**
		On-Site (excl. Com			
0		**350**	*-111.3685744*	*-111.3685744*	*-135.6*
0		**350**	*-113.7190395*	*-113.7190395*	*-135.6*
0		**350**	*-117.8988769*	*-117.8988769*	*-128.6*
0		**350**	*-111.3685744*	*-111.3685744*	*-128.6*
		On-			
61		**350**	*-50.59181246*	*-50.59181246*	*-135.6*
61		**350**	*-50.59181246*	*-50.59181246*	*-135.6*
61		**350**	*-50.59181246*	*-50.59181246*	*-128.6*
61		**350**	*-50.59181246*	*-50.59181246*	*-128.6*
		On			
0		**350**	*-121.6018953*	*-121.6018953*	*-135.6*
0		**350**	*-123.8205999*	*-123.8205999*	*-135.6*
0		**350**	*-123.8205999*	*-123.8205999*	*-128.6*
0		**350**	*-121.6018953*	*-121.6018953*	*-128.6*

of Gemsbok PV1 on Nearest SKA Location		
SARAS [dB(W/Hz)]	Max Required Path Loss [dB]	Additional Mitigation [Required - Calculated Path Loss] [dB]
munication Service)		
-266.0094904	154.640916	-0.359084049
-266.0094904	152.2904509	-0.709549117
-266.0094904	148.1106135	-0.889386499
-266.0094904	154.640916	-0.359084049
-Site		
-266.0094904	215.4176779	-0.58232208
-266.0094904	215.4176779	-0.58232208
-266.0094904	215.4176779	-0.58232208
-266.0094904	215.4176779	-0.58232208
Road		
-266.0094904	144.4075951	-0.5924049
-266.0094904	142.1888905	-0.811109533
-266.0094904	142.1888905	-0.811109533
-266.0094904	144.4075951	-0.5924049