



Aeronautical Radio Frequency Interference Characterisation for the Square Kilometre Array

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Abstract

The radio frequency interference of various types of aircraft typical to the Square Kilometre Array South Africa environment were investigated. High-resolution time domain data of aeronautical navigation signals, mainly as a result of distance measuring equipment and secondary surveillance radar, were captured at the SKA-SA RFI monitoring station on top of Losberg hill overlooking the core-site.

1. Introduction

The Square Kilometre Array (SKA) is an international effort that is set to be the largest and most sensitive radio telescope ever built, consisting of an extraordinary large collecting area. It is a project shared between South Africa and Australia that, once completed, will be 50 times more sensitive and have a 10 000 times faster survey speed than the best radio telescope today [1]. SKA Phase 1 will consist of approximately 200 dishes deployed at various spiral arm locations surrounding the core, incorporating the 64-dish MeerKAT precursor [2].

The location of the core-site is fairly close to a busy air traffic route, between Johannesburg and Cape Town. This route operates from 05h45 and 23h00 daily with approximately 700 flights from 6 different airlines per week. The impact of aeronautical radio navigation signals, especially the secondary surveillance radar (SSR) and distance measuring equipment (DME), from commercial aviation on the SKA project is therefore very important.

A study to characterise the radio frequency interference (RFI) emissions from a variety of small to medium size aircraft was conducted during the September 2016 period. The list of aircraft considered, together with their call signs, materials and descriptions, are given in Table 1. Measurements made during the campaign included: 1) ground based RFI emissions of various aircraft; 2) aircraft tracking using commensal radar; 3) aircraft tracking in close proximity of the core-site using MeerKAT; and 4) high time resolution DME and SSR at the RFI monitoring station on Losberg hill. The detail of the aircraft tracking does not form part of this paper.

2. SARAS Protection Levels

As with all other RFI interference sources in the defined Astronomy Geographic Advantage (AGA) area, the emissions from the aircraft as measured by the telescope

Table 1. Various aircraft that took part in the RFI characterisation and aircraft tracking campaign in September 2016 together with their call signs, materials and descriptions.

Aircraft Type	Aircraft Call Sign	Aircraft Material/Description
Whisper	ZU-GBBA	Composite, Glider
Cessna 206	ZU-SED	Metal, Single Propeller
Beechcraft King Air	ZS-LFU	Metal, Twin Propeller
Cessna 172	ZS-SCE	Metal, Single Propeller
Bushbaby Explorer	ZU-NRW	Tube & Cloth, Microlight
Challenger	ZU-CBY	Composite, Microlight
Jabiru	ZU-ZGT	Composite, Single Propeller
Van's Aircraft RV-7	ZU-IEJ	Metal, Single Propeller
Trike	ZU-IEJ	Cloth, Microlight
Raven	ZU-IAV	Metal, Single Propeller
Lancair	ZU-LNC	Composite, Single Propeller
Albatross	ZU-ACI	Metal, Twin Propeller
Bosbok AM3	ZU-ADI	Metal, Single Propeller
Gyrocopter	ZU-RJU	Composite Material
Pilatus PC-12	-	Metal, Single Propeller
Commercial Airliners	Various	Metal

receivers need to adhere to the South African Radio Astronomy Services (SARAS) protection levels defined in [3] and enforced by [4]. It also needs to adhere to the defined SKA saturation limit to ensure that no damage is done to the telescope's low noise amplifiers (LNA's). The power spectral density (PSD) given in [dBm/Hz] of the SARAS protection levels are shown in Figure 1. These levels are derived using the ITU-R RA.769 recommended 1% bandwidth and are effectively for *continuum* levels. Although the AGA Act only defines *continuum* levels, SKA-SA has adopted a 0.001% of the resolution bandwidth for *spectral line* levels. This results in spectral line levels such that $SARAS_{Spectral\ Line} = SARAS_{Continuum} + 15\text{ dB}$. The SKA saturation limit is defined at -100 dBm at the spiral arm location receivers, and the permanent damage level is +12 dBm. There are, however, substantial impacts on the operation of the telescope receivers long before permanent damage levels are reached.

3. Ground Based RFI Characterisation

Radiated emissions were measured using a log-periodic dipole array (LPDA) antenna and Rohde & Schwarz FSH-8 spectrum analyser at a distance of 3 m from the aircraft and a height of 1.5 m above the ground. For each of the aircraft the following sets of measurements were made: 1) background (baseline) RFI measurements with everything switched off; 2) avionics start-up (engines switched off); and 3) engine start-up (avionics and engines switched on).

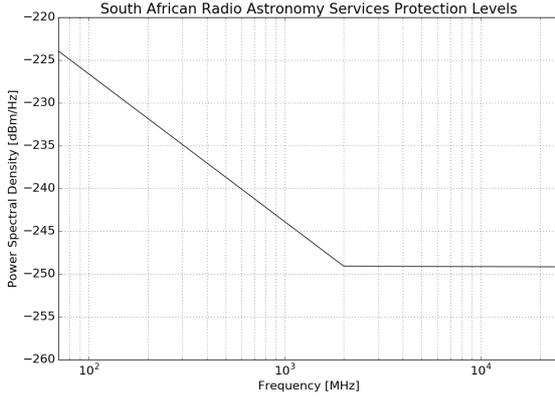


Figure 1. South African Radio Astronomy Services (SARAS) protection levels for *continuum* levels in power spectral density.

The FSH-8 was used in a max-hold setting to enable capturing the impulsive nature of the RFI during start-ups. A typical measurement off the *Van's Aircraft RV-7* is shown in Figure 2, while the measured power spectrum taking into account antenna gain and cable loss between 400 MHz and 2 GHz, for the baseline (*black trace*), avionics start-up (*red trace*) and engine start-up (*blue trace*) are given in Figure 3.



Figure 2. Terrestrial radiated emissions measurements of the RV-7 using an FHS-8 spectrum analyser and LPDA.

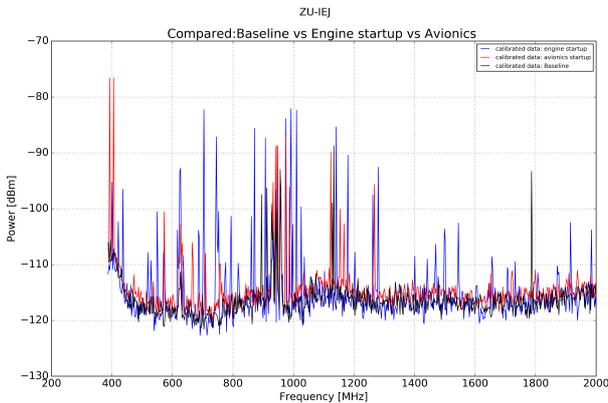


Figure 3. Radiated emissions spectrum of RV-7 ground based measurements showing the baseline (*black trace*), avionics start-up (*red trace*) and engine start-up (*blue trace*) with the FSH-8 in max-hold setting.

From these results, as an example, a worst case level for general emissions from the RV-7 aircraft of -75 dBm at

400 MHz was used to calculate the impact on the SKA telescope receivers and required minimum clearance distances. The electric field measured with the LPDA with an antenna factor (AF) at 400 MHz of $AF_{400\text{MHz}} = 24$ dB/m at a distance of $D = 3$ m is $E_0 = (-75 \text{ dBm} + 106.9 \text{ dB}) + 24 \text{ dB/m} = 56 \text{ dB}\mu\text{V/m}$. This results in an effective isotropic radiated power (EIRP) level in [dBm] given by Equation (1) of $EIRP = -39$ dBm.

$$EIRP = E_0 + 20 \log_{10} D - 104.8 \quad (1)$$

Unlike land propagation where terrain loss contributes to the total path loss experienced by a signal, the attenuation of aeronautical signals is a combination of free space path loss (FSPL) given by the *Friis* transmission formula [5] in Equation (2), tropospheric effects as well as atmospheric absorption and multipath fading [6].

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi R} \right)^2 \quad (2)$$

In Equation (2) P_r and P_t are the receive and transmit power levels in [W] respectively; G_r and G_t are the receive and transmit antenna gains respectively; λ is the wavelength in [m]; and R is the distance between the transmitter and receiver in [m]. Table 2 provides the minimum required clearance distances required for an EIRP level of -39 dBm at 400 MHz to meet the SARAS protection levels, SKA saturation limits and LNA damage levels into a 0 dBi sidelobe of the telescope receiver. These distances are calculated using FSPL only, as well as interpolated aeronautical radio-navigation propagation curves recommended by ITU-R P.528-2 [7] based on the IF-77 propagation model for air-to-ground systems [6]. The PSD of the *continuum* and *spectral line* levels were converted to received power levels by taking into account the 1% and 0.001% telescope receiver resolution bandwidths respectively as discussed in Section 2.

Table 2. Example of minimum clearance distances calculated using FSPL and IF-77 for RFI from the RV-7 at 400 MHz to meet SARAS Protection Levels, SKA Saturation Limits and LNA Damage Levels.

	SARAS Protection Levels		SKA Saturation Limits	LNA Damage Levels
	Continuum	Spectral Line		
Transmit Power of -39 dBm	Received Power of -170 dBm	Received Power of -185 dBm	Received Power of -100 dBm	Received Power of +12 dBm
Minimum Clearance Distance	227 km	1274 km (FSPL)	64 m	N/A
	-	400 km (IF-77)	-	N/A

4. High Time Resolution Pulsed RFI

High time resolution data of aeronautical navigational signals as a result of the DME and SSR were measured at the Losberg RFI monitoring station using the *MESA Product Solutions RTA-3* and *iCOM AH-8000* discone omnidirectional antenna (Figure 4).

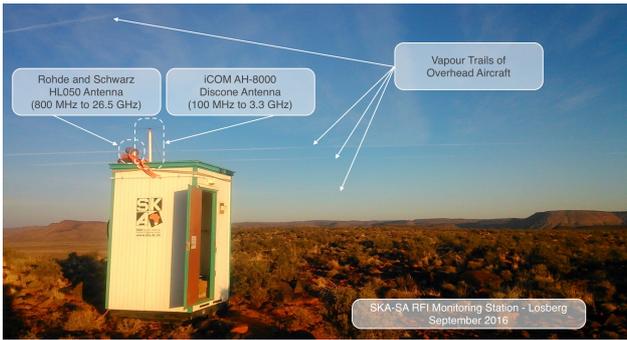


Figure 4. RFI monitoring station on top of Losberg overlooking the MeerKAT core. Vapour trails of overhead aircraft are visible.

SSR operates on an interrogation-reply basis, where the directional ground base station emits the interrogation signal at 1030 MHz, to which the aircraft transponder replies using an omnidirectional antenna at 1090 MHz. There are various modes of secondary surveillance, including mono-pulse secondary surveillance radar (MSSR), Mode-S, traffic collision avoidance system (TCAS) and automatic dependent surveillance broadcast (ADS-B). The aircraft position, velocity and identification are transmitted through Mode-S Extended Squitter [8]. The majority of aircraft today are constantly broadcasting ADS-B messages, an example of which is shown in Figure 5 captured at the Losberg RFI monitoring station. The top image is the triggered time domain (TD) capture forming part of the 112-bit ADS-B binary message, while the bottom image is the corresponding frequency domain (FD) data of the 1090 MHz air-to-ground reply.

The DME airborne transmitter power ranges from 50 W on small aircraft to 300 W on airliners. DME signals are transmitted as pulse-pairs, with a separation depending on transmit direction and mode. Typically, the duration of a transmission is in the order of $3.5 \mu\text{s}$, as measured at the half amplitude Gaussian envelope of the signal. An example of a triggered DME capture at the Losberg RFI monitoring station is shown in Figure 6. The top image gives the triggered TD capture with the theoretical Gaussian distribution overlaid, while the bottom image is again the corresponding FD data of the air-to-ground signal at 1062 MHz. The time domain noise envelope was approximately $\pm 50 \mu\text{V}$ peak with a standard deviation of $\sigma = 32 \mu\text{V}$ and mean of $\mu = 0.2 \mu\text{V}$. The trigger threshold was set to a value greater than 3σ (between 100 and 120 μV), and false detections were ruled out by confirming the presence of DME or SSR frequencies in the FFT of the triggered TD data.

5. Channel Time Occupancy

The air-to-ground DME signals, as well as SSR, falls within the 1025 MHz and 1150 MHz band. An example of triggered events in this band over a period of 12h57 and 16h36 on Monday 19 September 2016 is shown in Figure 7. The channel time occupancy of the SSR and DME data over this short period is given in Figure 8.

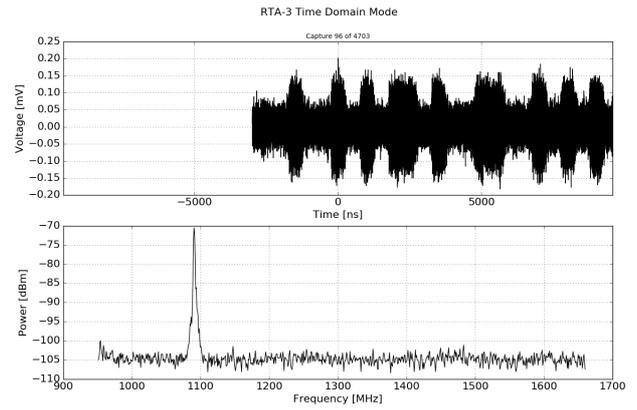


Figure 5. A typical SSR air-to-ground reply captured at 1090 MHz. Top image is the TD binary bit stream and bottom is the resulting FD spectrum.

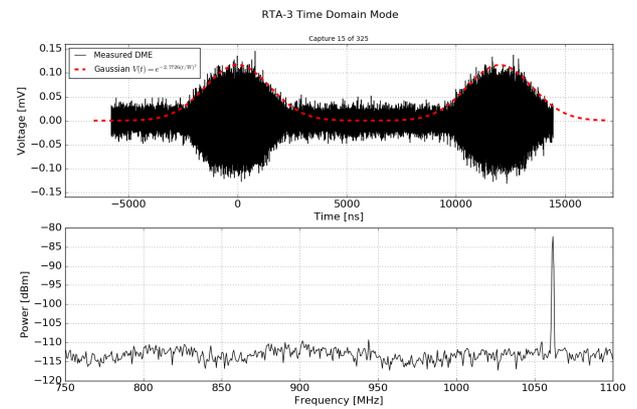


Figure 6. Measured 1062 MHz DME pulse-pair each with $3.5 \mu\text{s}$ half amplitude Gaussian envelope and $12 \mu\text{s}$ separation.

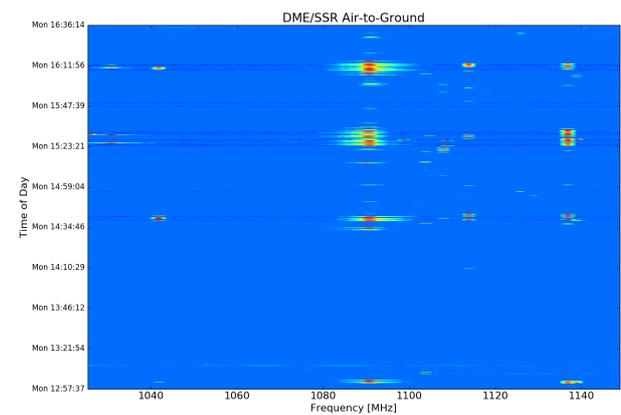


Figure 7. Example of continuous DME/SSR high time resolution data from Monday 19 Sept. 2016 at 12h57 until Monday 19 Sept. 2016 at 16h36.

6. Minimum Required Clearance Distance

Flightradar24 data [9] was used to identify one of the aircraft captured in Figure 7 at 14h37 as a *Comair/Kulula* flight *MN454* flying at an altitude of 11.3 km and ground distance from the monitoring station of 40 km. Assuming the transmit power level of $P_t = 300 \text{ W}$ (+54.7 dBm) for

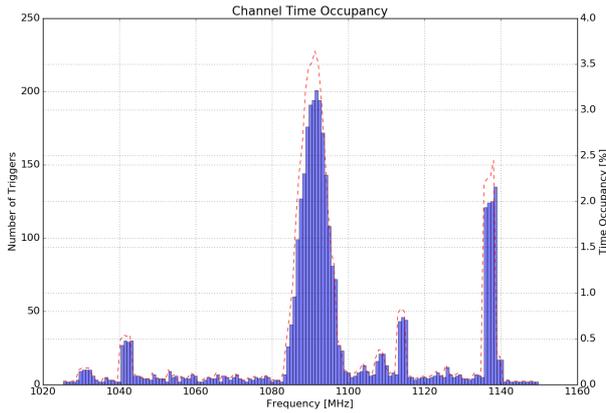


Figure 8. Example of channel time occupancy data from Monday 19 Sept. 2016 at 12h57 until Monday 19 Sept. 2016 at 16h36.

commercial airliners, a wavelength at $f = 1090$ MHz of $\lambda = 0.275$ m and the slant distance between the receiver and airline of 41.5 km (Figure 9), the predicted receive power level using Equation (2) is $P_r = -71$ dBm. This agrees well with the measured level of $P_r = -70$ dBm at the Losberg monitoring station.

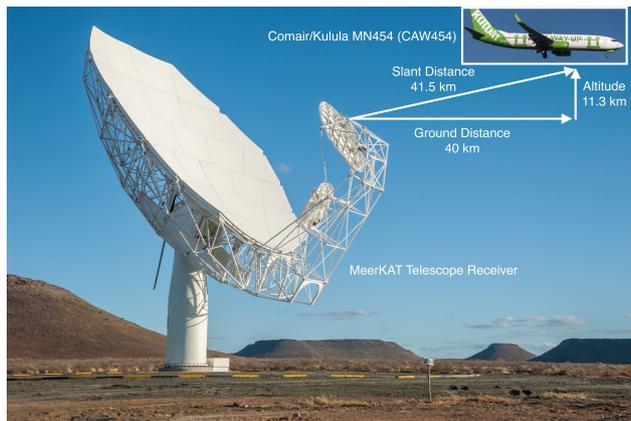


Figure 9. Slant distance calculations between overhead aircraft and the MeerKAT telescope receiver.

The equivalent *continuum* PSD measured by a telescope receiver will be -141 dBm/Hz (approximately 103 dB higher than the SARAS level of -244 dBm/Hz), while the *spectral line* PSD is -111 dBm/Hz (118 dB higher than the required -229 dBm/Hz). The minimum clearance distances required calculated using both FSPL and IF-77 for a transmit power of $+54.7$ dBm at 1090 MHz to meet the SARAS protection levels, SKA saturation limits and LNA damage levels into a 0 dBi sidelobe of the telescope receiver are given in Table 3.

7. Conclusions

The SSR transponders on commercial aircraft can be between 50 and 300 W. General aviation aircraft, like SKA-SA charter planes, will typically have Mode-C transponders with DME and ADS-B. Small aircraft used by local farmers in the surrounding areas will typically have VHF radios and GPS. From the presented results it is clear that enforcing the minimum clearance distances

Table 3. Minimum clearance distances calculated using FSPL and IF-77 for commercial aircraft SSR example transmitting $+54.7$ dBm at a frequency of 1090 MHz to meet SARAS Protection Levels, SKA Saturation Limits and LNA Damage Levels.

	SARAS Protection Levels		Saturation Limits	LNA Damage Levels
	Continuum	Spectral Line		
Transmit Power of $+54$ dBm	Received Power of -174 dBm	Received Power of -189 dBm	Received Power of -100 dBm	Received Power of $+12$ dBm
Minimum Clearance Distance	6,109,208 km (FSPL)	34,354,606 km (FSPL)	1197 km (FSPL)	3 m
	900 km (IF-77)	1200 km (IF-77)	400 km (IF-77)	-

to meet the SARAS protection levels with free space path loss alone are unrealistic for in-channel interference. Although the ITU-R P.528-2 recommended propagation curves provide more realistic clearance distances, SKA-SA will need to engage with the various stakeholders for the groups of aircraft to work together toward RFI risk mitigation and minimizing the impact on the SKA project.

8. References

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