PROCEEDINGS OF SCIENCE

Integrated Radio Frequency Attenuation Maps for RFI Impact Assessments

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The management and control of radio frequency interference (RFI) for radio astronomy observatories, especially those with operational telescopes as neighbours to large-scale construction activities such as the international Square Kilometre Array (SKA) project, are critical. Numerous interfering sources can impact operational telescopes during construction, and ensuring the adverse impacts from these sources on sensitive telescope receivers are minimized can be a challenging and time consuming effort. Interference management is done through RFI impact assessments that, considering the source location as well as frequencies and levels of radiated emission, make use of radio frequency (RF) propagation modelling to determine path loss between the interference source and a sensitive telescope receiver. Considering the reciprocity in electromagnetic and antenna theory, this paper considers the use of pre-generated, integrated RF attenuation maps to streamline radio frequency interference impact assessments of large, complex telescope sites.

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1. Introduction

The SKA Observatory's mid-frequency radio telescope (SKA-MID) will consist of 197 15 m-diameter dishes operating between 350 MHz and 15.4 GHz. Construction of SKA-MID is currently underway in the Northern Cape of South Africa and will eventually integrate the existing 64-element MeerKAT array. The pristine radio-quiet MeerKAT National Park in the Karoo is home to a number of operational telescopes. The management and control of RFI during the SKA-MID construction phase is, therefore, critical. This paper proposes the use of pre-generated integrated RF attenuation maps to streamline interference impact assessments of large, complex telescope sites.

2. RFI Controls Process

The South African Radio Astronomy Observatory (SARAO) RFI team is responsible for establishing controls to minimise interference and maximise the scientific return of the radio astronomy telescopes in the MeerKAT National Park. One such RFI control is the issuing of valid RFI permits or Certificates of Compliance (CoC) for temporary or permanent equipment to be installed on the observatory site. Interference management is done through RFI impact assessments that make use of RF propagation modelling to determine path loss between an interference source and a sensitive telescope receiver. Eligibility of RFI permits, or CoCs, are dependent on predicted receive levels of characterised emissions. For CoCs, the predicted receive levels must be below the telescope protection thresholds [1, 2] as discussed in Section 3. This is determined by evaluating the path loss available at a device's intended location, given the frequencies and levels of radiated emissions, toward any telescope receiver. With several operational radio telescopes in the MeerKAT National Park, and more set to be built in the near future, the required number of RFI impact assessments and path losses calculated drastically increase as construction continues. Pre-calculated integrated RF attenuation maps provide a more efficient way of determining where a device is likely to interfere with surrounding sensitive receivers.

3. Telescope Protection Levels

The SKA Observatory (SKAO) and SARAO have defined telescope protection levels as the threshold levels for interference deemed harmful for scientific observations [1, 2]. These threshold levels were initially derived from the frequency bands where radio astronomy has protected status as per the International Telecommunications Union (ITU) Recommendation ITU-R RA.769 [3]. The telescope protection levels are derived by considering the radio telescope sensitivities separately for both continuum and spectral line observations and is defined as the interference power within the chosen bandwidth that would produce an error of 10% in the smallest power detectable by the receiver. An integration time of 2000 seconds is assumed, together with internationally agreed appropriate values for antenna noise and receiver noise temperatures at the frequencies under consideration.

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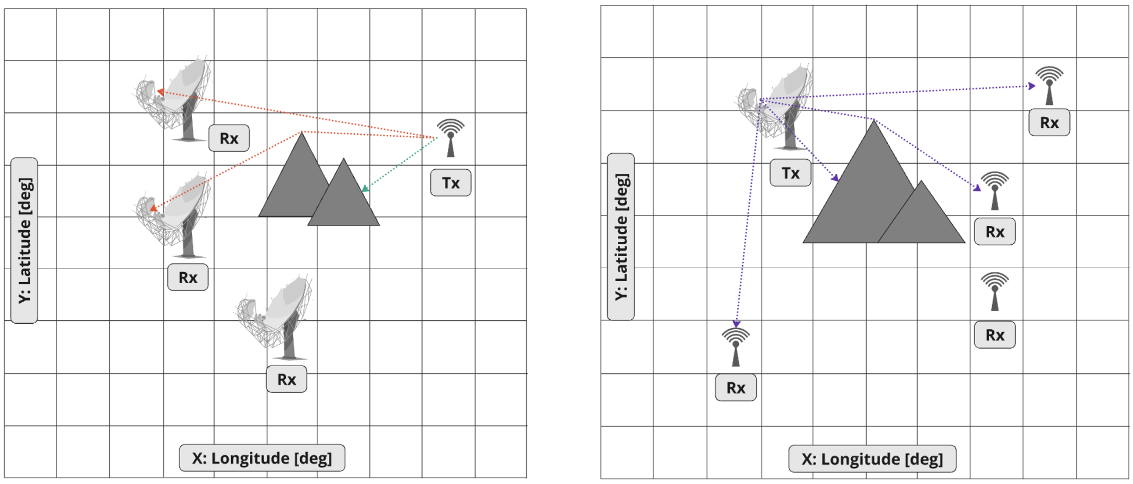
4. Electromagnetic Reciprocity and Integrated RF Attenuation Maps

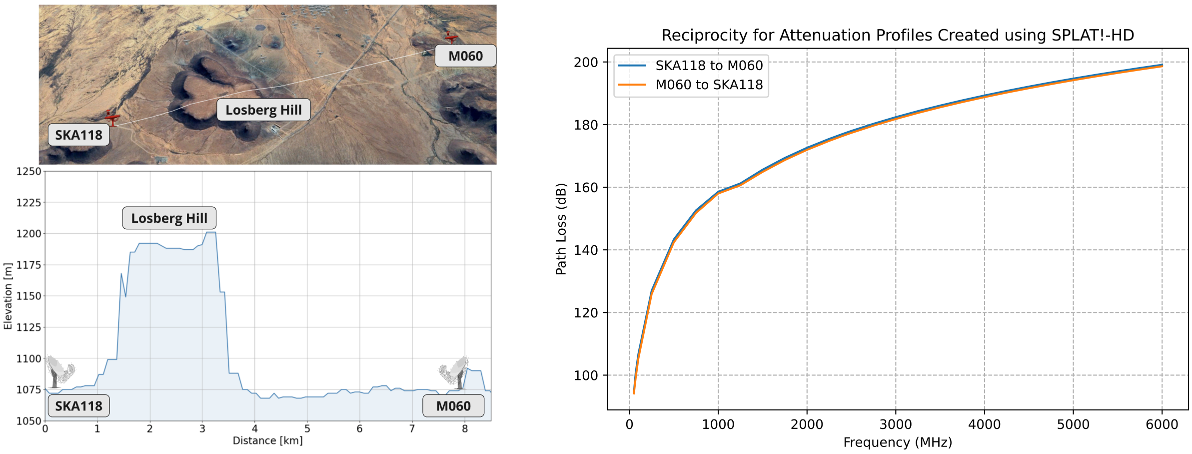
The proposed attenuation maps are based on the principle of RF propagation reciprocity. In electromagnetic (EM) applications the radiation and receiving patterns of antennas are identical, and these antennas can work equally well as a transmitter or a receiver. The reciprocity theorem as it applies to EM theory and antenna patterns are discussed through Maxwell's equations in [4]. Rather than running point-to-point predictions for every unique interference assessment case, i.e., transmitting devices to the nearest receiving telescope as in Figure 1 (a), the attenuation maps use the various radio telescopes as "transmitters" in the propagation modelling point-to-point calculations for a fixed, meshed grid area as in Figure 1 (b). This is a convenient and efficient computation for temporary interfering sources that can be located at multiple positions in proximity of the telescopes. An example of reciprocity in calculated path loss between two telescopes, SKA118 and M060, either side of Losberg Hill in the national park are shown show in Figure 2.



(a) (b)

Figure 1: (a) Interfering source as transmitter and radio telescopes as receivers; (b) Radio telescope as "transmitter" with path loss predicted in each grid point where possible interfering sources can be located.

The point-to-point predictions for each radio telescope are generated using the Longley-Rice irregular terrain model (ITM) in SPLAT-RF! [5] with Shuttle Radar Topography Mission (SRTM) 1-arc second resolution digital elevation map (DEM) data for a radius of 20 km around each telescope at a receiver height of 1.5 meters above ground. This leads to a data file, per emitter height, with path loss entries in decibels for every 30 meters in a grid with the telescope in question at the centre. This is done for every element in the array (i.e., 64 for MeerKAT or 197 for SKA-MID) and saved as individual attenuation maps. The individual receiver maps are integrated into a single map per frequency between 50 MHz and 25.5 GHz for a complete telescope array. The aggregation is done by taking the minimum attenuation available in a grid block between all the individual maps. The result is a 3D dataset that, as shown in Figure 3, is a function of longitude, latitude, and attenuation per frequency that can be interpolated per coordinates and frequency to determine the attenuation budget for that location in the grid. An example of an integrated attenuation map for the SKA-MID array at a frequency of 6 GHz is shown in Figure 4 (a).



(a) (b)

Figure 2: Reciprocity example between telescopes SKA118 and M060 either side of Losberg Hill in the MeerKAT National Park. (a) Elevation profile as a function of distance; (b) Calculated path loss between telescopes as a function of frequency.

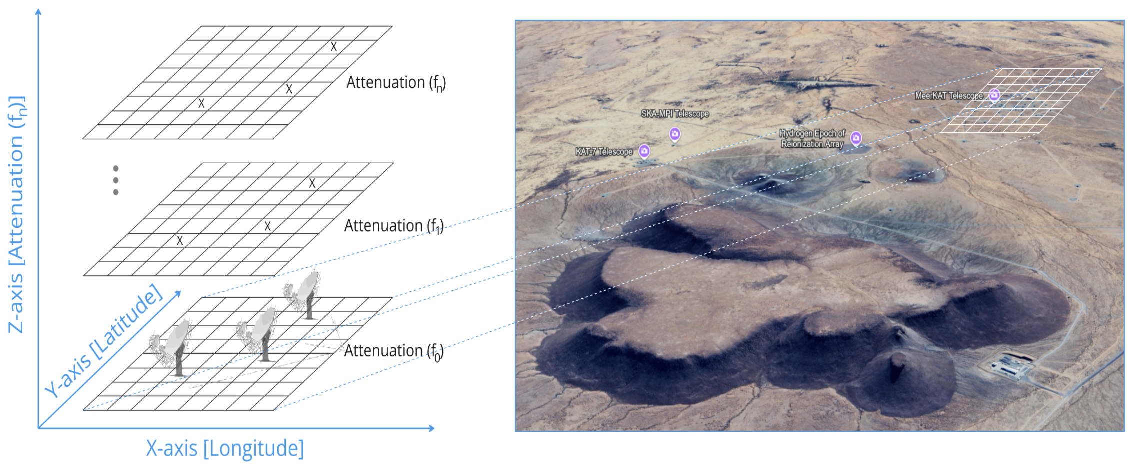
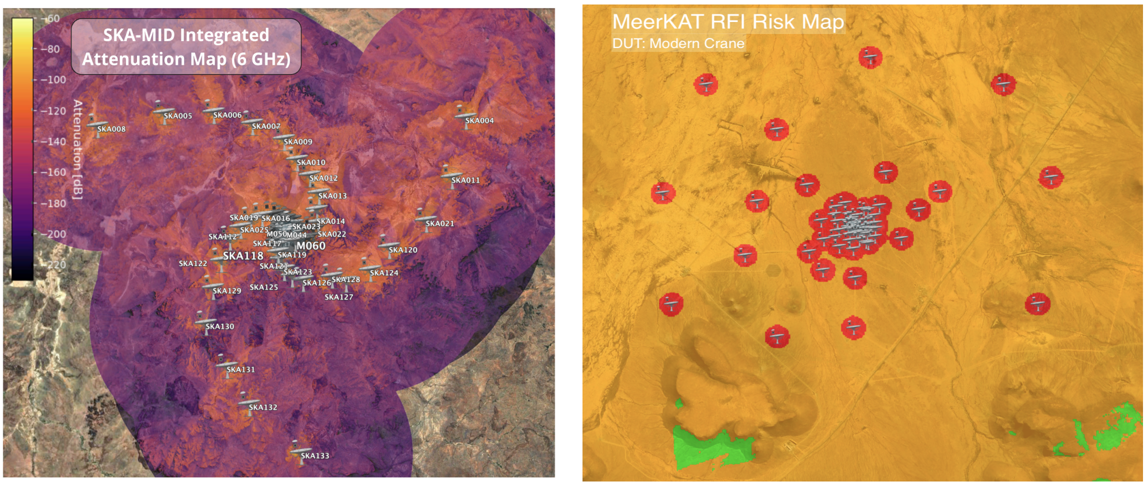


Figure 3: Schematic of 3D dataset as a function of longitude, latitude, and attenuation per frequency.

5. RFI Risk Assessment

Risk assessment tools were developed by both SARAO and the SKA Observatory to reduce analysis time in determining where, and to what extent, devices might interfere with the operational telescopes. The input is an effective isotropic radiated power (EIRP) measurement file, or commercial/military EMC standards radiated compliance limits, and the output is a KMZ file that can be used in a GIS application. These tools use the pre-generated RF attenuation maps to quickly interpolate the path loss profiles, given the intended location of use, and produce RFI risk maps. The attenuation profile calculated is a list of attenuations applicable for various frequencies for that location. The RFI risk map in Figure 4 (b) shows where an example temporary device will likely cause interference levels higher than the telescope protection thresholds (shown as yellow),



(a) (b)

Figure 4: (a) SKA-MID integrated attenuation map at a frequency of 6 GHz; (b) Zoomed in MeerKAT RFI risk map for a modern crane.

as well as where it might exceed the radio telescope digital saturation levels (shown as red). A more detailed propagation analysis can be considered for medium and high risk locations.

6. Conclusions

This paper highlights the use of integrated RF attenuation maps to streamline interference impact assessments of large, complex telescope sites. The attenuation maps are based on the principle of RF propagation reciprocity. The maps are pre-generated by considering the radio telescopes as "transmitters" in the propagation modelling whilst determining point-to-point path loss calculations for a meshed grid surrounding the telescope receivers.

References

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