Karoo Array Telescope: Lightning Protection Issues and RFI

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Abstract

A computational electromagnetic (CEM) code and a reduced scale model were used to characterize the design of the Karoo Array Telescope (MeerKAT), South Africa's demonstrator for the Square Kilometer Array (SKA). Different excitation techniques were used in the CEM code and are compared to actual scale model measurements in an anechoic chamber. With verified computational modeling, the optimized lightning down conductor layout and earth termination system interconnections were investigated, keeping cost and RFI in mind.

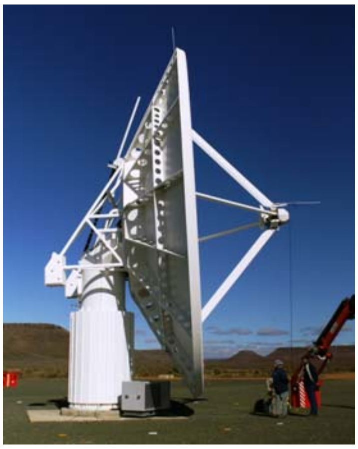
1. Introduction

The South African Square Kilometer Array (SKA) bid has led to an operational seven-dish prototype KAT-7, which is the pre-cursor to MeerKAT (Karoo Array Telescope). MeerKAT will consist of 64 offset-fed Gregorian telescopes of 15 m dish diameter. Even before foundations have been laid, the telescope is booked years in advance with international radio astronomy projects to pursue 10 Key Science Projects identified to be of great scientific importance [1]. South Africa's proposed core site has been proclaimed a radio quiet zone, with added benefit that the surrounding mountains provide some radio frequency interference (RFI) shielding.

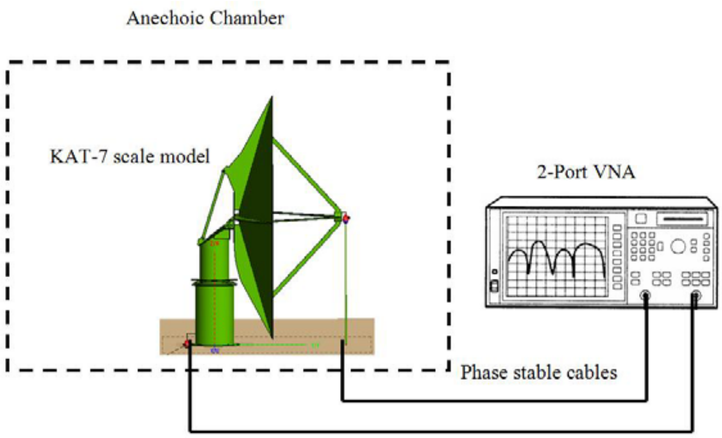
This paper presents our research on lightning protection issues which include the lightning down conductor (LDC), telescope bearings, and earthing. Through scale and computational modeling, we optimize the schemes with cost and RFI in mind.

2. KAT-7 Scale Model

The KAT-7 design in Fig. 1 (a) consists of a 15 m composite dish with centre-fed receiver structure mounted on a steel pedestal. To characterize the dish design in terms of RFI, a simplified 1/20th scale model was constructed. Minimally invasive S-parameter measurements of the scale model were made in an anechoic chamber, using a vector network analyzer (VNA). The measurement setup is shown in Fig. 1 (b). The results were compared to simulations done with a computational electromagnetic (CEM) code, FEKO, with good agreement. A verified computational model could then be used for further investigation into lightning current paths, earthing and RFI mitigation.



(a)



(b)

Fig. 1 (a) Photograph of KAT-7 dish in the Karoo. Here a signal was injected onto the lightning rod to simulate a direct lightning strike. Measurements were made on earth connections at the base of the pedestal. (b) Schematic setup for two-port S-parameter measurement in anechoic chamber.

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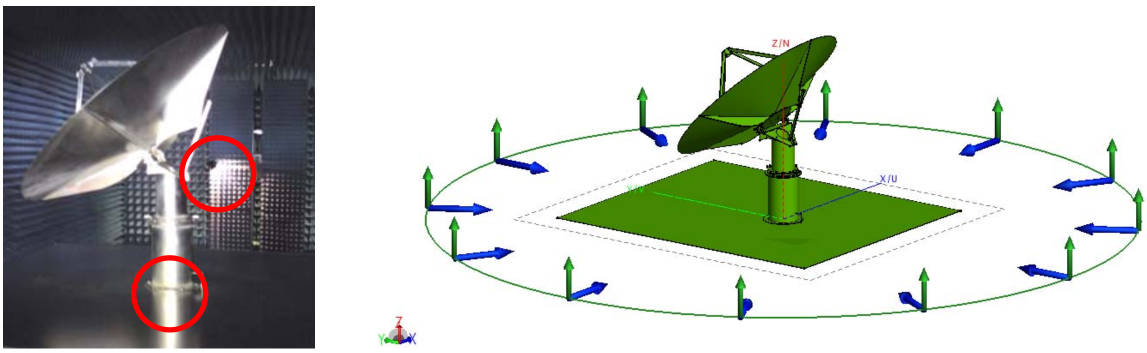
3. Excitation Methods

Two different excitation methods were used to simulate direct and indirect lightning strikes, namely a direct current injection, and a plane wave illumination. For the current injection technique, a semi-rigid cable was connected through a metallic ground plane, with the centre conductor terminated on the scale model dish lightning rod (see Fig. 1(a)). A measurement port is formed by a small loop at the base of the pedestal, allowing a two-port S-parameter measurement in an anechoic chamber with the VNA.

When lightning strikes an installed dish antenna, there is no return path as in the simulated direct strike on the model. This prompted further investigation into the proposed representation. We found that the current injection forms several closed loops which influence the measurement [2]. However, International Telecommunications Union (ITU) recommendations state that the method is valid when the injection is separated by a distance of more than three times the object under test base diameter away from the object [3]. The method used was within this limit. In section 5 we show how a symmetrically spaced injection was used to model lightning currents into the dish foundation earth termination system.

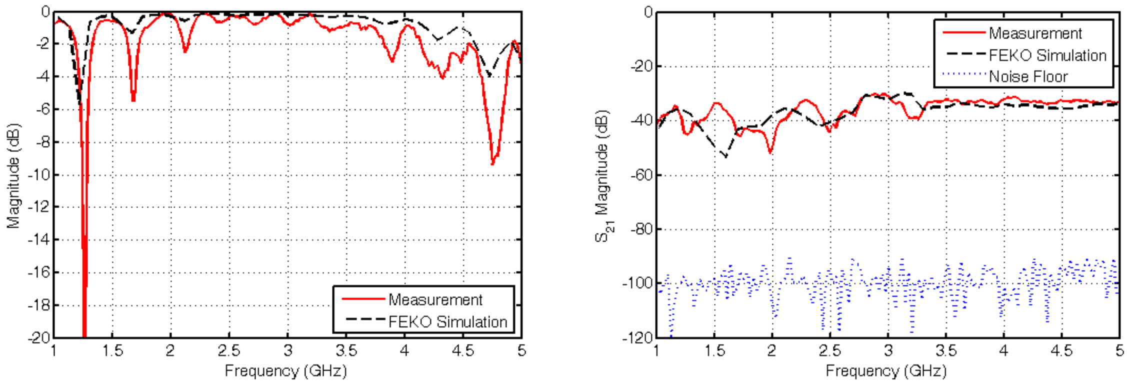
To simulate an indirect lightning strike, a plane wave was used in both computation and measurement. Fig. 2 (a) shows the measurement in the anechoic chamber, where the excitation is driven though the measurement port of the scale model, and the radiation is measured using a log-periodic dipole antenna (LPDA). The S_{21} parameter is reciprocal to the S_{12} parameter, which relates to a plane wave illuminating the dish. The model is rotated in azimuth through different positions, as well as changing the orientation of the dish. This is replicated in FEKO by plane waves from different directions, and adjustments of the dish orientation corresponding to the measurement.

Two of the measurement results are shown in Fig. 3 (a) and (b). The first result shows the agreement between the measured and simulated S_{11} for the current injection method. Fig. 3 (b) shows the comparison of results for a plane wave from the side, and the dish pointing directly upwards. Having verified the computational model by measurement for different scenarios to this level, we used the computational model for further investigation into RFI mitigation, lightning protection and earthing.



(a) (b)

Fig. 2 (a) Photograph of scale model plane wave measurement in anechoic chamber. Red circles show the measurement port on the dish pedestal and the LPDA at the chamber far end. (b) FEKO model with plane wave excitation from 12 different directions. Green arrows show electric field excitation and blue arrows show wave propagation direction.



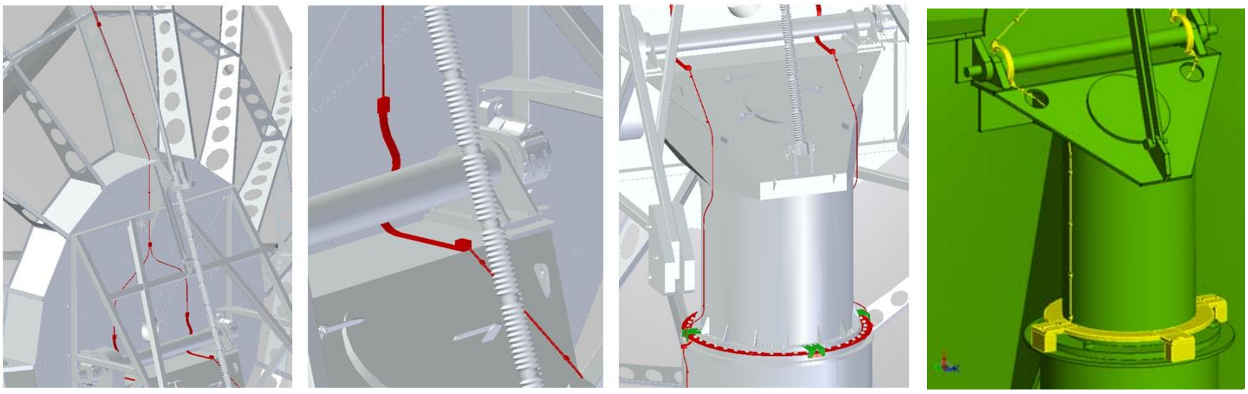
(a) (b)

Fig. 3 (a) Comparison between S_{11} measurement and FEKO simulation of injection port at scale model dish feed. (b) Comparison between plane wave measurement and simulation of scale model. The dish faces upwards with the plane wave from the side.

4. LDC Optimization

The IEC standards for lightning protection [4] allow that all steel parts of a structure can be used as part of the LDC system. Even steel reinforcing in concrete may be used, if properly bonded to the LDC. The only constraint is that the lightning current path needs to be continuous and have a resistance to earth of less than 10 Ω [4]. However, at the dish elevation bearings (Fig. 4 (a) and (b)) and azimuth bearings (Fig. 4 (c) and (d)), the connections between the structure and bearings were painted for corrosion protection, causing discontinuities in the current path. Here additional lightning down conductors were needed.

Through FEKO Method of Moments simulations the number of conductors and their connections over the bearings could be optimized in terms of cost. The connections over the azimuth bearing were optimized for RFI mitigation as well [4], due to capacitive coupling from the stainless steel plate connection to the four copper shoes, shown in Fig. 4 (d). It was shown that four conductor connections instead of two would minimize the RFI towards the interior of the pedestal by up to 12 dB in electric field levels, as well as current density levels [2, 5].



(a) (b) (c) (d)

Fig. 4 (a) LDC design at back of dish, with down conductors splitting in two across elevation bearing. (b) Elevation bearing down conductors connected to flexible strap which could either go beneath (as shown) or over bearing axle. (c) Down conductors connected to stainless steel circular plate which connects the top part of the pedestal to the bottom part of the pedestal via four spring loaded copper shoes. (d) Simplified design for FEKO simulation.

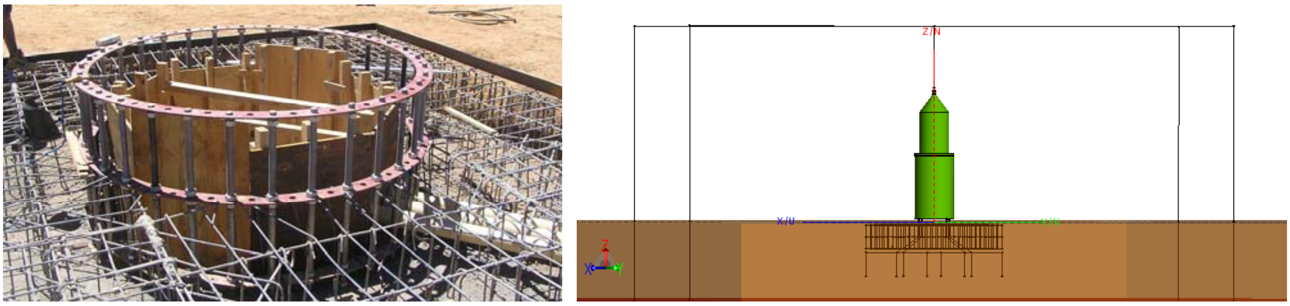
5. Earth Termination

The earth termination of the lightning protection system was also considered using the FEKO model. The standards required that when the steel reinforcing in the foundation is used as part of the earth termination system for lightning protection, it needs to be bonded, but preferably welded together. However, due to extreme wind stresses on the dish structure, the reinforcing in the foundation is quite extensive (see Fig. 5 (a)). Welding all the elements on the first foundation took three days. Other foundations were then bonded using only binding wire and the last was left unconnected.

These connected and unconnected scenarios were modeled in FEKO, at a frequency corresponding to 50 MHz, which is the highest probable frequency component of lightning from [5, 6]. A simplified pedestal excluding the dish was used above a Sommerfeld ground plane, with the foundation and earthing below. The current injection was modeled using four symmetrical conductors connected to a perfect ground plane beneath the Sommerfeld soil layer (Fig. 5 (b)). The foundation was modeled with wires which were either connected or unconnected (but in close proximity to each other).

The simulation results showed that the interconnection methods did not make much difference at the higher 50 MHz frequency, but that the connections of the pedestal structure and the steel foundation rings to the earthing ring and rods were important. The difference between being connected or unconnected to the earthing was up to 17 dB in the level of current that could be dissipated into the soil [6].

Measurements of resistance to earth were made on all the foundations, showing that the addition of the steel reinforcing to the earthing system lowered the resistance to earth, but the interconnection using binding wire was just as good as the welding connection. This eliminated the need for welding, which would save time and cost on future foundations for MeerKAT.



(a) (b)

Fig. 5 (a) Pedestal foundation steel reinforcing while concrete is being poured. All steel elements were either welded, bonded with binding wire or left unconnected for the different dishes of KAT-7. (b) Four symmetrical wires connected to bottom ground plane forms current injection path onto simplified pedestal model in FEKO. Soil and concrete were modeled as a Sommerfeld ground plane, with the steel reinforcing connected to the earth system imbedded in the layer.

6. Conclusion

A verified computational scale model was used for investigations into current paths for lightning protection and RFI mitigation of the South African demonstrator project KAT-7. Two different excitation techniques were used to consider direct and indirect lighting strikes. The simulations assisted in optimizing the LDC system by considering the number of conductors and connections over the bearings of the dish. The optimized bonding improved RFI mitigation at the bearing interface. Saving was also achieved by investigating the steel reinforcing interconnections to the earthing system. The use of binding wires instead of welding saves on time and cost, which will have a significant impact on construction cost for MeerKAT's 64 dishes.

7. Acknowledgments

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