Towards Electromagnetic Characterization of MeerKAT Telescope

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Abstract

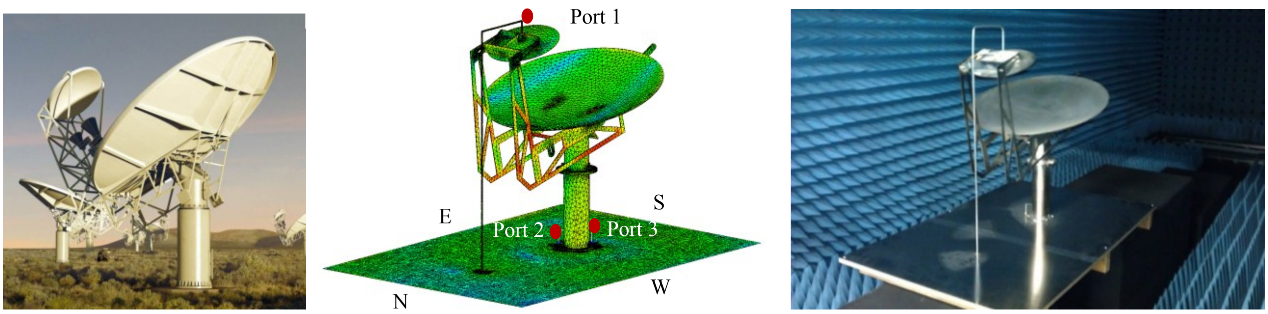
As part of South Africa's Square Kilometre Array (SKA) programme, the Karoo Array Telescopes (KAT) KAT-7 and MeerKAT have been developed. Lightning protection and radio frequency interference (RFI) mitigation form essential parts in the design of the KAT systems. Electromagnetic (EM) characterization of single dish structures has been done using computational electromagnetic (CEM) and reduced scale modeling. This paper describes progress on EM and RFI characterization of the MeerKAT design, with specific focus on lightning-induced RFI, lightning surge protection, and earthing.

1. Introduction

The South African SKA project office (SKA Africa) has finalized the MeerKAT telescope design and 64 foundations have been cast for the 15 m offset-Gregorian dish antennas. This telescope will form part of the international SKA Phase 1, which will comprise a planned 254 dishes in the Northern Cape region of South Africa, and 96 in Western Australia [1]. The EMRIN research group from Stellenbosch University has been actively involved in the RFI mitigation strategies for KAT-7 [2]; the experience gained has been invaluable for inputs to the MeerKAT design. With construction of the first two dishes later this year, extensive testing is planned to verify the design, including earthing, lightning surge protection and lightning-induced RFI mitigation measures. CEM and reduced-scale modeling have already been used successfully on similar KAT-7 aspects [3-5].

2. MeerKAT Characterization Methodology

A simplified 1/20th scale model of the initial MeerKAT dish design was constructed together with an exact CEM model in the commercial Method-of-Moments (MoM) based code FEKO [6]. Verification of this model is done with scattering parameter measurements in an anechoic chamber on the physical model. The simplified scale design was created by the SKA Africa project office using the initial MeerKAT structure shown as an artist's impression in Fig. 1 (a). The scaled design was imported from the mechanical design software into FEKO, seen in Fig. 1 (b). The physical model parts were laser-cut to ensure geometric dimensional accuracy, and sub-assemblies welded together. These were tin-plated and bolted together. The model was then mounted on a 1.2 m by 0.85 m ground plane and three measurement ports were added. The main port uses a sub-miniature-A (SMA) connector below the ground plane to a semi-rigid cable in front of the dish, with the centre conductor connected to the sub-reflector of the dish in a stowed position. This attempts to simulate a lightning strike on the dish at its highest point when stowed.



(a) (b) (c)

Figure 1 (a) Artist's impression of the initial MeerKAT offset-Gregorian dish design [1]. (b) Simplified scale model in FEKO on a finite ground plane, with injection port 1 at the top and two pick-up ports 2 and 3 at ground level (indicated in red). Current density results are shown with a plane wave from the western side simulating an indirect lightning strike. (c) Photograph of the physical simplified scale model in the anechoic chamber.

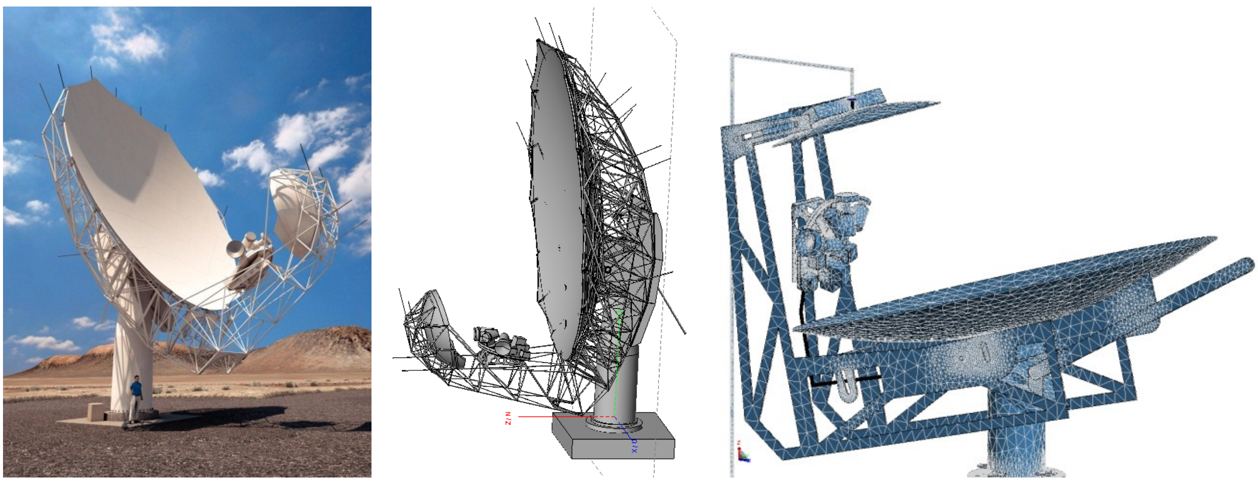
Two small loops connected at the bottom of the dish are connected to the centre conductor of two separate SMA connectors below the ground plane. These ports allow scattering parameter (S-parameter) measurements to be made for verification of the FEKO model. Fig. 1 (c) shows a photograph of the complete model as measured in the anechoic chamber.

A similar model verification methodology used for KAT-7 was adopted for MeerKAT. Direct lightning strikes could be modeled in both FEKO and the scale model as a direct injection of current onto the dish structure through port 1. In the FEKO model shown in Fig. 1 (b), the ports indicated in red are used to calculate three-port S-parameters in the simulation. All the ports are modeled as being 50 ohm. Due to complexity of the computational model, the MoM discretization resulted in 63,264 triangles in free space. The resulting matrix of unknowns required in excess of 150 GB of random access memory (RAM) to solve. The simulation was submitted to the Centre for High Performance Computing (CHPC) in Cape Town, South Africa. Ten nodes with a total of 300 GB of memory were used. The calculation for each frequency point takes approximately an hour; consequently, an upper frequency limit of 1.5 GHz was chosen.

The S-parameter measurements in the anechoic chamber were taken from 50 MHz to 4 GHz. Although the chamber absorption is optimal between 2 GHz and 18 GHz, the system ports are closely coupled, yielding good measurements even at the lower frequencies. A two-port vector network analyzer (VNA) was calibrated and used for three consecutive full two-port measurements (ports 1 - 2, 1 - 3 and 2 - 3). For each measurement, the unused port was terminated in 50 ohm for comparison to the FEKO simulation.

An indirect lightning strike is modeled as an EM plane wave from four different directions of the dish in FEKO. The four directions are indicated on Fig. 1 (b) as North, West, South and East. The three ports are now modeled as 50 ohm loads, with induced currents calculated on each as the simulation output. The plane wave is normalized to 1 V/m, allowing a direct calculation of antenna factor to be made for each port; this is done using the port voltage as the current multiplied by the impedance. A measurement of each port's antenna factor can then be directly compared to the simulation. To measure the simulated EM plane wave on the physical scale model, gain substitution measurements were made on all ports, with the dish oriented in three of the four different directions, facing a known antenna in the anechoic chamber. For each of the nine measurements made, the far-field gain for that port and orientation could be calculated and converted to antenna factor. The measured antenna factor magnitude results are compared to the FEKO simulated results in the following section.

After the initial modeling, changes were made to the final design of the MeerKAT antenna. The dish was initially planned to be constructed of composite material, but this was changed to metal plates for manufacturing accuracy and local content across Africa purposes. A concomitant change to the backing structure led to the design shown as an artist's impression in Fig. 2 (a). This design has been imported into FEKO (Fig. 2 (b)), but still requires simplification. Early simulations, using imported, scaled sub-assemblies of the design, have already been initiated. An example is shown where the receiver indexer (RI) of the antenna is imported in Fig 2 (c).



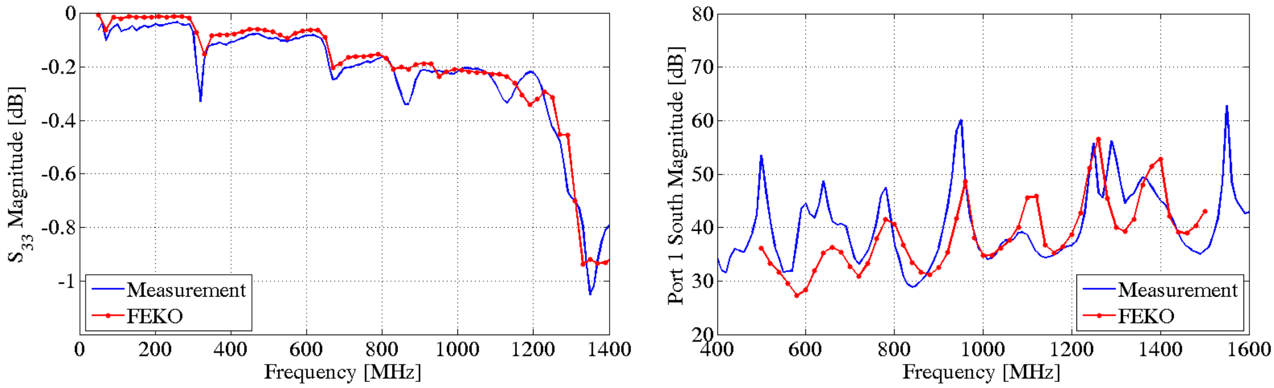
(a) (b) (c)

Figure 2 (a) Artist's impression of the final design of the MeerKAT antenna [1]. (b) Final design of the MeerKAT antenna as imported to scale into FEKO. (c) Receiver indexer sub-assembly included in the initial FEKO model.

3. Scale Model Verification Results

Two of the model verification results are shown in Fig.3, where measurements are compared to simulations. Measurements were done from 50 MHz to 2 GHz, whereas simulations were limited to 1.5 GHz. Fig. 3 (a) gives the port 3 reflection coefficient (S_{33}) comparison and Fig. 3 (b) shows the port 1 antenna factor with the plane wave from the south of the dish. The S_{33} result shows close agreement to within 0.15 dB across the band, as may be expected for a port feed of this kind. The comparison of AF magnitude shows that the measurement and FEKO results at non-resonant points are aligning reasonably. The chamber was designed for maximum absorption from 2 GHz to 18 GHz, which is not optimal for the frequencies concerned. Measurements will be repeated at a larger national anechoic facility which can be used from 300 MHz; this will reduce measurement uncertainties, allowing the CEM model to be refined. Time gating will also be used in due course. At present, however, the results are at the correct level and show agreement trends. We had a similar experience when we were in the process of refining our KAT-7 model.

The verification of the initial design model, together with the previous KAT-7 findings, ratify the use of the computational model for EM characterization of MeerKAT. With a simplified full scale model according to the final design of MeerKAT, verified by on-site measurements, detailed investigations on RFI current paths will be possible. This has particular bearing on the receiver regions which need to be optimized in terms of cabling and shielding.



(a) (b)

Figure 3 (a) S-parameter magnitude comparison of the port 3 reflection coefficient. (b) Antenna factor magnitude comparison of port 1 with a plane wave from the south of the model.

4. Future Work

The changes to the final design of MeerKAT only involved the layout of the substructure and the material of the dish. The size and positioning of the reflector and sub-reflector, as well as the pedestal structure design, remained the same. This implied that the initial FEKO model can be used unchanged for early investigations into induced currents. The RI of the antenna is one of the critical areas which forms the rationale for this research. The RI design has been imported as a sub-assembly into the FEKO model as illustrated in Fig. 2 (c). The final full-scale MeerKAT design is now in a FEKO modeling environment as well, with the pedestal and dish partially simplified. Further simplification is planned of the backing structure, which would keep the model within memory and run-time limits on the CHPC.

The first two MeerKAT antennas will be installed during 2014 which will allow testing of the design from civil, mechanical, electrical and electronic engineering standpoints. Further EM measurements are planned to consolidate the full scale FEKO modeling and to scrutinize RFI mitigation measures. Similar tests in the frequency domain (FD) have been valuable for KAT-7 [7]. However, to investigate an appropriate frequency range, individual frequency measurements are time-consuming. Time domain (TD) techniques are planned where a wideband impulse radiating antenna will illuminate the dish with a plane wave. Measurements can then be made on cabling systems inside and outside the dish, using a real-time transient analyzer dubbed RATTY [8]. This will be used together with wideband current probes to characterize the EM shielding properties of the dish. The measurements will be compared with FEKO modeling of the full scale imported dish. The verified model can then be used for detailed EM investigations.

Conventional surge protection is defined in [9]. However, with the offset-Gregorian dish layout, the placement of the RI equipment makes definitions of lightning protection zones (LPZs) challenging. The MeerKAT design already includes rigorous shielding and RFI mitigation techniques to ensure safety of equipment and integrity of receiver systems. This enables LPZs to be extended from within the pedestal to the RI. Simulation will assist in calculating the level of EM fields and induced currents for typical lightning strikes, to verify the shielding effectiveness measures for surge protection. The influence that the earth termination system resistance to ground has on the surge protection level can be investigated as well.

5. Conclusion

The verification methodology of a computational model of the MeerKAT design using a reduced-scale model has been described. The result comparison of simulated direct and indirect lightning strikes was shown. The verification of a computational model allows investigations into lightning surge protection, lightning induced RFI mitigation and earthing for MeerKAT. With a final design changed from the initial design, future work includes TD metrology of the full-scale structures, to verify a full-scale FEKO model. Progress on this work will be communicated at the conference.

6. Acknowledgments

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