Electromagnetic Gap Leakage Analysis for the SKA Mid-Frequency Dish

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***Abstract*—This paper presents electromagnetic analysis as performed on the Square Kilometre Array (SKA) mid-frequency dish in order to estimate the ground leakage caused by gaps in the main reflector. The effects of the ground leakage are shown in terms of conventional performance parameters such as gain and aperture efficiency, as well as the percentage of feed power hitting the ground behind the main reflector. Analysis were performed for SKA Band 1 and 2 with a combined frequency range of 0.4 − 1.8 GHz. It is shown that the gaps in the main reflector reduce the gain between 0.23 and 0.05 dB and could increase the noise temperature by approximately 14 K when pointed at zenith. The transmission percentage of the incident power hitting the ground is below 0.2% across the combined bands.**

I. Introduction

The Square Kilometre Array (SKA) [1] mid-frequency dishes are scheduled to be constructed in the Karoo region in South Africa within the next decade. Important figures of merit of radio telescopes are gain and system noise temperature, which directly effects the sensitivity of the telescope. An unwanted contributor of noise temperature is exposure of feed power to the ground beneath or surrounding the antenna, which includes leakage through small panel gaps in the main reflector. The amount of leakage can be obtained, for example, by physical measurements in the field or by an heuristic model where each gap is seen as a slot radiator. However, it is advantageous to have an analytical electromagnetic (EM) model of the gain loss and feed-to-ground power. This paper uses powerful electromagnetic software to simulate the decrease in aperture efficiency and percentage of incident power hitting the ground and produces an estimate of the increase in system noise temperature.

II. Antenna Model and Gain Analysis

The SKA dish is a 15-m shaped offset Gregorian system with a 5.16 m sub-reflector as described in [2] and shown in Fig. 1. The main reflector is composed of 66 triangular panels with 3 mm gaps. The physical area of the sum of the gaps is thus approximately 0.3% of the total physical area of the main reflector. Initial performance for the mechanical design is described in [3].

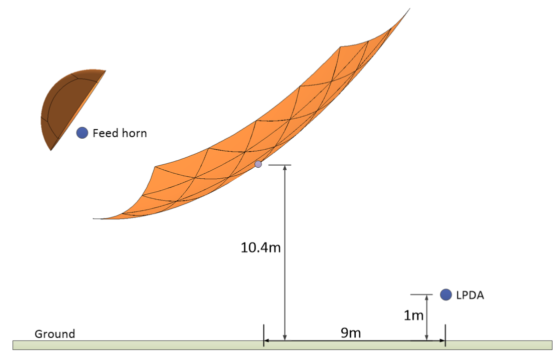

Fig. 1. Simulation setup including main and sub-reflector and feed horn at secondary focus. The LPDA antenna is introduced to illustrate the measurement setup as described in Section III (ground included for illustrative purposes).

The effect of panel gaps in the main reflector can be observed by the decrease of maximum gain and increase in gain behind the reflector. This can be seen in Fig. 2 which shows the far field patterns at 1 GHz for the SKA dish with and without panel gaps. Simulations were performed in the electromagnetic software FEKO [4] by solving the problem with the full-wave Multilevel Fast Multipole Method (MLFMM).

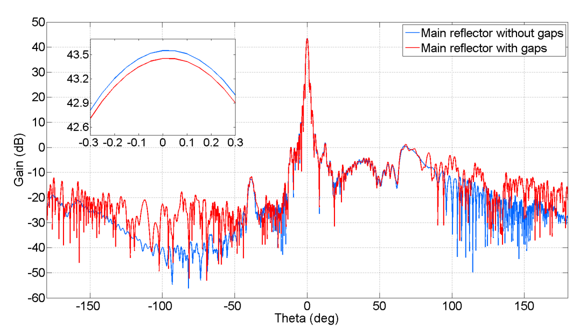

Fig. 2. Far field patterns at 1 GHz (Band 2) for the SKA dish with and without main reflector panel gaps.

Fig. 3 shows the maximum gain loss over frequency due to gaps in the main reflector for Band 1 (0.35 – 1.05 GHz) and 2 (0.95 – 1.76 GHz). The maximum antenna gain decreases between approximately 0.14 and 0.23 dB for Band 1 and 0.05 and 0.11 dB for Band 2 due to the gaps. Assuming the worst case scenario where the reflector is pointed at zenith and sees the largest portion of ground (87% of the angular region), an increase in system noise temperature of up to 14.3 K can be expected in Band 1. However, the reflector will see less ground and more sky as the reflector tilts resulting in a smaller increase in noise temperature. At a more appropriate elevation angle of 60°, where the angular region on the ground is only 51%, the increase in noise temperature is 8.5 K at most in Band 1 and 3.2 K on average over Band 2. The SKA organisation requires that less than 2 K noise temperature is added from transmission through the panel gaps.

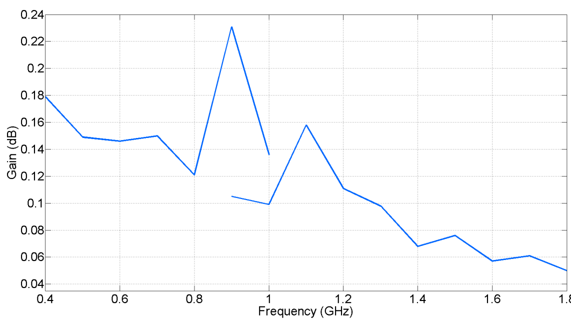

Fig. 3. Gain loss over frequency due to gaps in the main reflector.

III. Alternative Measurement Setup

An alternative method to measuring the leakage through panel gaps in the main reflector is by placing a transmitting antenna on the ground beneath the reflector and calculating the ratio of power received at the secondary focus. The measurement setup is shown in Fig. 1 and can be described as follows: a log-periodic dipole array (LPDA) antenna is placed 9 m behind the main reflector (represented with a height of 1 m from the ground) with an active port. The LPDA is oriented with its mainbeam towards the main reflector. The SKA Band 1 and Band 2 feed horns are used independently at the secondary focus. This ensures two ports in the EM simulation and allows for calculation of S-parameters.

The LPDA is designed and optimised in FEKO and has 17 dipole elements. The length of the shortest and longest elements are 0.08 and 0.472 m, respectively. The LPDA operates over a frequency range of 0.4 – 1.8 GHz.

It is useful to get an estimate of the expected upper and lower limits of S21 for the LPDA and the feed horn(s). The upper limit is where the LPDA and horn(s) are placed face-to-face and only free space loss of the signal power (no main or sub-reflector) is present. This produced an S21 of between approximately -33.8 and -40.6 dB for Band 1 (2.04 and 0.93% transmission) and -39.1 and -50.6 dB (1.1 and 0.3% transmission) for Band 2. The lower limit is the setup described in Fig. 1 with the main reflector replaced by a flat plate 30% larger than the main reflector. This case produced an S21 of between approximately -69.9 and -78.3 dB for Band 1 (0.032 and 0.012% transmission) and -85.9 and -87.4 dB (0.0051 and 0.004% transmission) for Band 2.

The S21 value is represented as a transmission percentage as shown in Fig. 4 for Band 1 and 2. The transmission percentage unexpectedly varies from one frequency to the next, but follows a downward trend when viewed across an entire band. This illustrates the behaviour of constructive and destructive effects due to both diffraction around the edge of the reflector and transmission through the panel gaps. This behaviour is related to a specific spatial position of the LPDA and changing its position will likely result in different transmission curves. The coupling is also very low and therefore susceptible to second-order effects.

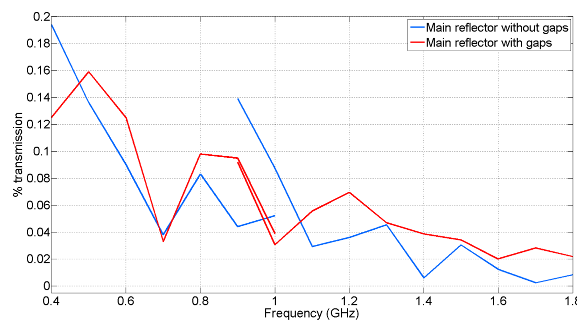

Fig. 4. Percentage transmission for SKA Band 1 and 2 of the main reflector with gaps compared to a solid reflector without gaps.

IV. Conclusion

Future work includes implementing improvements to the FEKO model for example incorporating the mechanical support structures and calculating the mutual coupling between antennas caused by gap leakage at different elevations. The eventual aim would be to compare all EM results to a future measurement campaign in the field.

Acknowledgment

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