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Electromagnetic analysis and preliminary commissioning results of the shaped dual-reflector 32-m Ghana radio telescope

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Abstract. This paper presents results from the electromagnetic analysis of the African VLBI Network shaped Ghana radio telescope at the operating frequencies of 5 and 6.7 GHz. The geometry implemented in commercial electromagnetic software provides insight into the effects of the slanted beam-waveguide, shaped reflector illumination and mechanical tolerances, which are known to be more stringent compared to a perfect paraboloid. It is shown that the theoretical maximum gain and aperture efficiency at 5 GHz are 63.80 dBi and 85.45%, respectively. The corresponding values at 6.7 GHz are 66.47 dBi and 88.00%, respectively. Comparisons to sidelobe maps produced from astronomical observations are also discussed, showing possible misalignment in the structure when utilised outside its originally intended purpose.

1. Introduction

The African Very Long Baseline Interferometry (VLBI) Network (AVN) is a Square Kilometre Array South Africa (SKA SA) initiative funded by the African Renaissance Fund (ARF). This project aims to create science opportunities in participating countries and enable partaking in SKA pathfinder development by amongst others, converting large antennas into radio astronomy telescopes. The early electromagnetic analysis of a 32-m telecommunications dish in Kutunse, Ghana, the first conversion effort of the project, is described in [1]. The effort is expanded upon here, with analysis and characterisation of the effects of the shaped profiles at 5 and 6.7 GHz. Additionally, the simulated antenna patterns are compared with results from the 'first light' science observations.

2. Overview of antenna optics

The Ghana antenna consists of a Cassegrain shaped dual-reflector system with four mirrors in a 12.68° slanted beam-waveguide (BWG). A full discription of the antenna optics is provided in [1] with the theory on shaping synthesis of dual-reflector antennas detailed in [2]. The primary reflector has an f/d of 0.32 and the Cassegrain system an equivalent focal length of 107.68 m. The shaped sub-reflector has a foci length and half-subtended angle of approximately 9.44 m and 8.50°, respectively. The maximum difference between the best-fit parabolic profile and the shaped primary mirror and the best-fit hyperbolic profile and the shaped sub-reflector is 35 mm and 155 mm, respectively.

3. Performance results

This section introduces results obtained by solving the electromagnetic problem with the physical optics method in GRASP (General Reflector Antenna Software Package) [3]. The system is excited with a Gaussian feedhorn with a -22 dB taper, as specified in antenna documentation [4], where the large taper minimizes the spillover in the BWG. Fig. 1 shows the 6.7 GHz co-polar radiation patterns for the E-plane and H-plane of the shaped antenna, where Table 1 shows comparison between the performance of the shaped and equivalent unshaped case. The cross-polarisation, sidelobe level (SLL) and beam near horizon values are given relative to the maximum gain at zenith. The shaped design has the effect of narrowing the mainbeam for the given reflector size(s), which can be seen in a gain increase of approximately 0.7 dB and reduction in total spillover. However, the spillover in the BWG is a major contributor of an increase in system noise as the shroud surrounding the mirrors are seen by the antenna at ground temperature (here assumed as 290 K). Consequently, it was found that the BWG would add approximately 5.5 K noise at 6.7 GHz, which in radio astronomy terms is not insignificant. Also, a disadvantage in the shaped design when used for radio astronomy is the significant increase in SLL. Furthermore, because of the asymmetry between the curved BWG mirrors, the far field rotates by 25.3° in azimuth (twice the degree of the slant rotation) which results in less prominent nulls near the mainbeam as well as significant depolarisation which is the major impact of the BWG.

Table 1. Ghana antenna performance values comparison between shaped and unshaped system.

Configuration	Unshaped		Shaped	
Parameter	5 GHz	6.7 GHz	5 GHz	6.7 GHz
Maximum Gain (dBi)	63.09	65.80	63.80	66.47
Maximum Cross-polarisation (dB)	−36.98	−37.92	−36.74	−37.77
Half-power Beamwidth (HPBW)(°)	0.13	0.10	0.11	0.09
SLL (dB)	−22.63	−22.90	−15.21	−15.15
Beam Near Horizon (dB)	−59.11	−53.52	−48.09	−53.68
Spillover (dB)	0.55	0.45	0.19	0.14
Aperture Efficiency (%)	72.56	75.42	85.45	88.00

4. Antenna efficiency

The shaped profiles performs its purpose in that it delivers a high gain, high aperture efficient reflector antenna. This is accomplished by the inverse taper of the illumination distribution on the main reflector as shown in Fig. 2, where higher power towards the unblocked part of the reflector is visible. The asymmetrical illumination caused by the slant in the BWG is also noticeable. The Ghana antenna has an illumination efficiency of approximately 92% at 6.7 GHz, which is the product of the taper efficiency (94%) and the phase efficiency (97%). The aperture field phase (represented as a surface deviation plot and assuming no surface roughness) is shown in Fig. 3 and is not particularly flat in the region where the illumination map shows its highest power. It seems the middle area of the dish is out by 0.5 mm compared to the outer part which has higher amplitude values. It is clear that the shaping utilises less the center part of the dish as one would expect to see with a conventional parabolic profile.

5. Mechanical tolerances

The Ghana antenna was originally optimised for a single elevation of approximately 64° when observing a geostationary satellite, which raises uncertainties when utilising the structure to

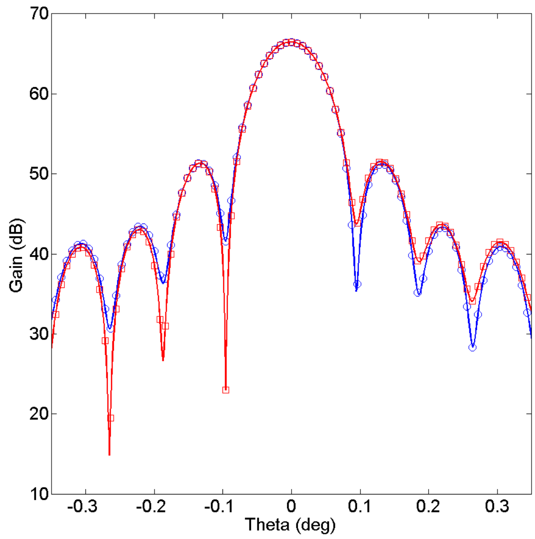

Figure 1. E-plane (blue circles) and H-plane (red squares) patterns of the Ghana shaped antenna.

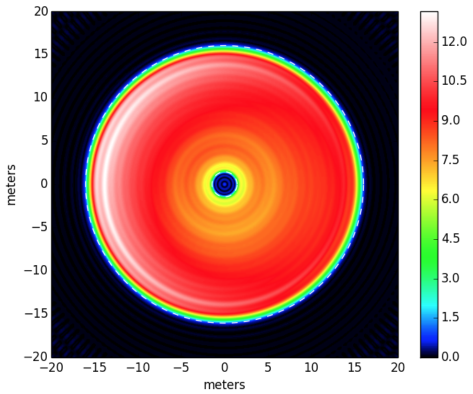

Figure 2. Aperture field distribution plot of the Ghana shaped antenna at 6.7 GHz.

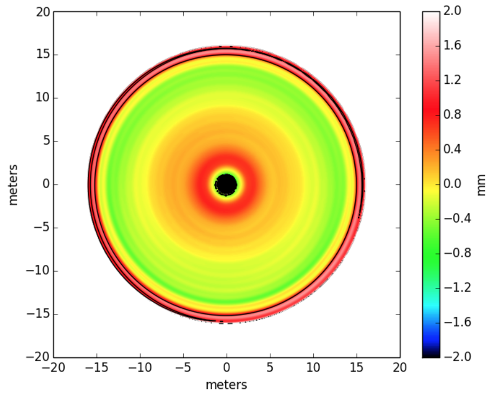

Figure 3. Surface deviation plot of the Ghana shaped antenna at 6.7 GHz.

observe at many different elevations. Especially, displacement of the sub-reflector in the primary focus position will have the greatest effect on the performance of the antenna. GRASP simulations confirms this with displacement of the sub-reflector attributing 94% of gain loss when considering the average contribution of all six mirrors for four different displacement values.

6. Comparison to commissioning results

An useful step towards realising the actual alignment condition of the antenna, is to perform observations of several strong astronomical sources. This is done in an attempt to develop sidelobe maps of the mainbeam at the higher operating frequency of 6.7 GHz, which can be used as a diagnostic for possible misalignment of the sub-reflector. An example of the results are shown in Fig. 4 where observations of Cygnus A (a radio galaxy) and Taurus A (Crab Nebula supernova remnant) are compared to simulations of on-axis displacement of the sub-reflector. Taurus A is the stronger but more extended source, resulting in a broadening of the mainbeam and filled in nulls. Cygnus A in comparison, is weaker but more compact. These observations indicate that the sidelobes are reasonably symmetrical but higher than indicated by the simulations, which can likely be attributed to a focusing error.

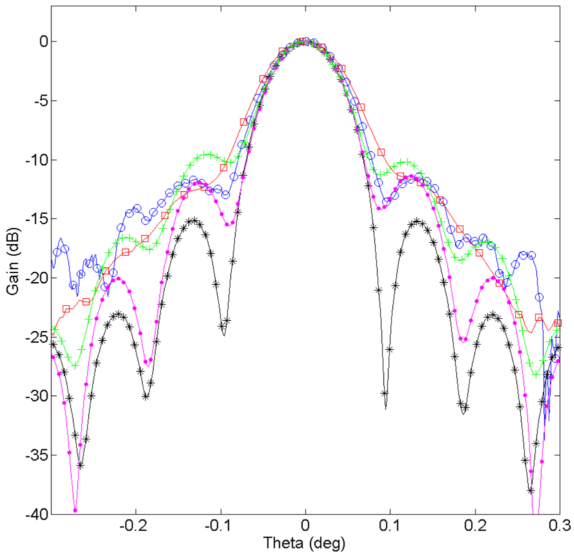

Figure 4. Beam pattern simulations for the Ghana dish in comparison with Cygnus A (blue circles) and Taurus A (red squares) observations. The GRASP patterns shown are those without any sub-reflector offsets (black asterisks) and offsets of plus (green pluses) and minus (magenta dots) 2.25 cm in the up-and-down zenith direction.

7. Conclusion

This paper gives a compact overview of the performance of a shaped dual-reflector antenna and its effects in performance when utilised for radio astronomy purposes. As very little is known about the real aperture efficiency of the Ghana antenna, future work includes physical measurement of the primary and sub-reflector to determine their roughness using the microwave holography technique. This will also determine misalignments in the structure which can be corrected to ensure optimal performance.

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