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Low Frequency Diffraction Effects when Shaping the Offset Gregorian Reflector System of the SKA

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***Abstract* - The offset Gregorian reflector system of the Square Kilometer Array (SKA) radio telescope is required to operate down to very low frequencies, where reflectors become (electrically) relatively small. Shaping the reflectors to control the aperture distribution can improve the electrical performance of the system. Since the system is expected to operate over more than a decade of bandwidth, the shaping is performed using standard Geometric Optics methods. This paper systematically investigates the effects that diffraction will have at low frequencies on the performance of several performance metrics for a wide range of shaped geometries. It is shown that the peak position of the primary design objective, the receiving sensitivity, is relatively insensitive to diffraction effects, making such wide band shaped reflectors a viable option for the SKA.**

***Index Terms* — Aperture efficiency, Reflector antennas, Radio astronomy.**

1. Introduction

An offset Gregorian reflector topology is the preferred choice for the antenna optics of the Square Kilometer Array (SKA) [1], thanks to the clean secondary beam it provides over a wide frequency band down to low frequencies given the relatively small size of the dishes. The dual reflector topology allows for the shaping of the dishes which provides an additional degree of freedom in the design optimization. For radio telescope applications an upper limit is normally placed on sidelobe level (SLL) while requiring maximum receiving sensitivity (ratio of effective area and system noise temperature). The problem of finding the reflector surfaces, given a desired mapping from the primary feed pattern to the secondary aperture distribution in the geometric optics (GO) limit, can be solved using the method described in [2].

Practically, the SKA system will operate at low frequencies where the GO limitation fails. This will cause the secondary pattern, and thus system performance, to vary over frequency – even if an ideal frequency independent feed can be devised and used on the system. This paper presents a detailed study of the effects of diffraction (brought about by reduced electrical size) of shaped offset Gregorian reflector systems. Performance metrics to be investigated include the aperture efficiency, receiving sensitivity, SLL, cross-polarization isolation (XPI) levels and secondary feed pattern symmetry.

2. Problem Description

The reflector systems evaluated here are limited to one of the SKA candidate systems described in [3]. In the interest of brevity, results are only reported for systems with a maximum main reflector chord of 18.2 m, a sub-reflector chord of 4 m, a sub-reflector subtended half-angle of $\theta_e = 58°$, and sub-reflector extension of 20°. The main reflector projected diameter is $D = 15$ m.

A simple Gaussian feed pattern with a 14 dB edge taper is used throughout, and the shaping is performed to produce, in the GO limit, an aperture distribution ($E(\rho)$ - with ρ the radial distance from the symmetry axis) of the form

$$|E(\rho)|^2 = \begin{cases} 1, & 0 \le \rho \le \sigma\rho_M \\ \exp\left[-b_\rho\left(\dfrac{\rho-\sigma\rho_M}{\rho_M(1-\sigma)}\right)^2\right], & \sigma\rho_M \le \rho \le \rho_M \end{cases}. \tag{1}$$

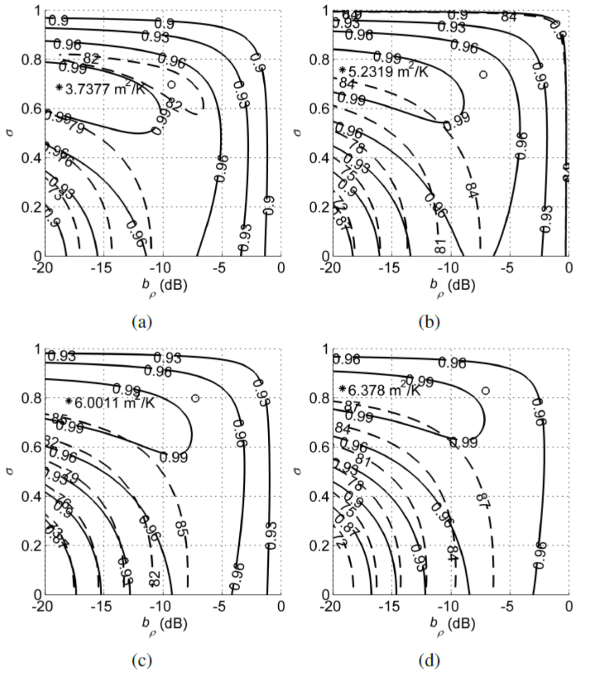
Here $\rho_M = D/2$ denotes the radius of the projected aperture, b_ρ is chosen for a prescribed edge value, and σ controls the extent of the central uniform power distribution in the aperture. The parameter space investigated here spans $0 \le \sigma \le 1$ and $0 \le b_\rho \le 20$ (dB).

Primary performance metrics are the aperture efficiency and receiving sensitivity. The antenna noise temperature is calculated using the method in [4] and averaged over elevation angles between 0° and 75° from zenith (when tipping feed down). A receiver noise temperature of 15 K is assumed throughout. Secondary performance metrics are the first and second SLL, the XPI within the 3 dB normalized directivity contour, as well as the main beam symmetry. The latter is defined as the difference (in dB) between the maximum and minimum directivity levels of the main beam at the polar angle where the average normalized directivity is -3 dB.

3. Results

The main performance metrics are shown in Figs. 1 to 3 for four frequencies in the low band of the SKA dish system. Note that the aperture efficiency and receiving sensitivity exhibit broad and flat maxima, the position of which are not significantly varied over frequency. Absolute values are reduced with frequency due to increased diffraction losses as well as sky temperature. Low frequency performance degradation of the SLLs and XPI is more pronounced for dishes shaped to produce secondary patterns with low SLLs. The general contour shapes remain similar for all frequencies, with the XPI not a strong function of the shaping parameters. Main beam symmetry, however, is degraded more by diffraction effects for dishes shaped to produce high gain, with significant increases in absolute value as the frequency is decreased.

The implication is that, given a set of design goals in terms of SLL and receiving sensitivity, the optimum region in the mapping space is not a strong function of frequency. Therefore, if feeds can be manufactured to have similar radiation patterns over the full frequency band, diffraction effects from the dishes at low frequencies will not force a requirement for a radically different shaped reflector system [5]. However, in the lower band of the SKA (below 1 GHz) degraded performance of all the metrics is observed, implying one should not design for the same absolute inequality constraints over the full band.



(a) (b)

(c) (d)

Fig. 1. Percentage aperture efficiency (dashed lines, peak round marker) and normalized receiving sensitivity (solid lines, peak star marker) at 450 MHz in (a), 650 MHz in (b), 850 MHz in (c), and 1050 MHz in (d).

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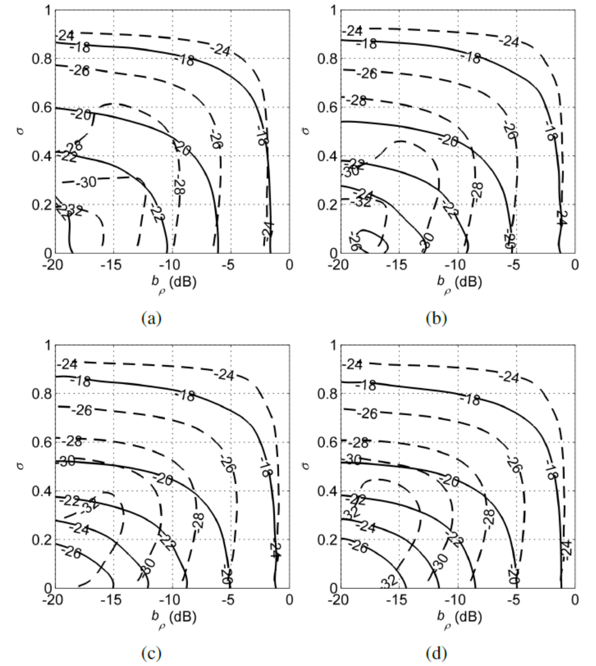
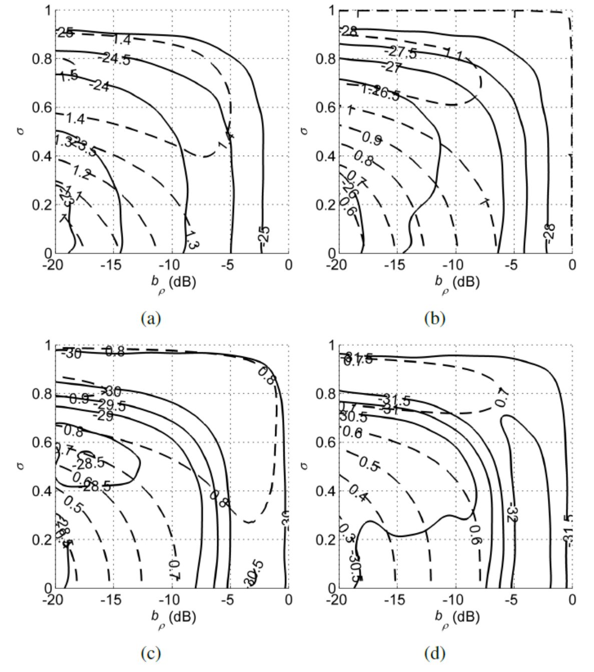


(a) (b)

(c) (d)

Fig. 2. SLL (dB) (first SLL solid lines, second SLL dashed lines) at 450 MHz in (a), 650 MHz in (b), 850 MHz in (c), and 1050 MHz in (d).



(a) (b)

(c) (d)

Fig. 3. Main beam symmetry (dashed lines) and cross polarization isolation (solid lines), in dB, at 450 MHz in (a), 650 MHz in (b), 850 MHz in (c), and 1050 MHz in (d).