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Design of an Asymmetrical Quadruple-ridge Flared Horn Feed: a Solution to Eliminate Polarization Discrepancy in the Offset Reflecting Systems

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***Abstract*—Quadruple-ridge Flared Horns (QRFHs) have been showing qualified performance as the feed antennas for the reflecting systems in the Square Kilometre Array (SKA). However, due to the offset optics of the SKA reflecting system, identical illuminations from dual polarizations of the feed would result in different system performance. This difference would become more severe towards high frequencies and may cause the worse polarization unqualified for the desired specification.**

In this paper, an asymmetrical QRFH feed working over SKA Band B (covering frequencies 4.6–24 GHz) is proposed and optimized to tackle this problem. The asymmetrical Band-B feed is composed of two different and orthogonal pairs of both ridges and sidewall quad-pieces, so as to provide orthogonal polarizations but different illuminations. Simulated results show that, by this asymmetrical design different illuminations can be provided for two polarizations, and the polarization discrepancy has been eliminated over most of the bandwidth. Benefitting from the elimination, both polarizations of the Band-B feed have now achieved the SKA specification in terms of aperture efficiency.

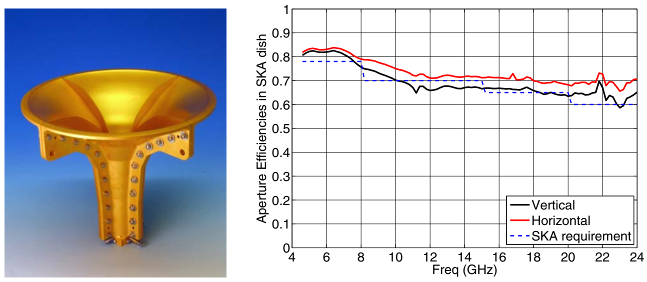
***Index Terms*—quadruple-ridge flared horn, polarization discrepancy, offset reflector antenna.**

I. Introduction

The Square Kilometre Array (SKA) is an international interferometric array which in its final stage will provide a combined collecting area of one square kilometres. This telescope would be divided into SKA-low, SKA-survey and SKA-mid, utilizing different receiving technologies to cover frequencies from 50 MHz to 13.8 GHz. For SKA-mid, 15 m offset-Gregorian dual-reflector antennas would be used and five wide band single pixel feeds are required to cover the particular frequency bands. As a member of the SKA organization, Sweden (represented by Onsala Space Observatory and Chalmers University of Technology) participates in two of its design consortia, i.e. the Band-1 (350–1050 MHz) [1], [2] and Band-B (4.6–24 GHz) [3], [4] wide band feed systems.

Quadruple-ridge Flared Horns (QRFHs) have been showing qualified performance as the feed antennas for SKA-mid dish systems and were adopted in the developments of both Band-1 and Band-B feeds. By utilizing the spline-defined profiles, both Band-1 and Band-B feeds managed to provide a satisfactory aperture efficiency in the SKA dual-reflector antenna. However, during the design of Band-B feed, it was found that its two polarizations suffered from a discrepancy between their aperture efficiencies in the SKA offset dish (see Fig. 1(b)), despite that radiation patterns from the two polarizations of the feed are almost identical (please refer to Fig. 11 (a) and (b) in [3]). Compared with the horizontal polarization, the vertical one is obviously degraded by about 5% at mid- and high-band, and thus falls below the SKA requirement for a portion of the bandwidth. This polarization discrepancy is mainly caused by the asymmetrical shapes of both the main and sub-reflectors and would be more serious towards higher frequencies. This is why the discrepancy can not be observed very clearly on Band-1 feed (Fig. 7 in [1]) and at lower-band (4.6–8 GHz) of Band-B feed. However, for the symmetrical Band-B feed we didn't take this effect into account during optimization.

The work presented in this paper concerns an asymmetrically designed QRFH feed, with the purpose of making the vertical polarization also qualified for the SKA requirement over Band B. None-rotationally symmetrical QRFHs have been investigated in [6], with the aperture shapes being circular, pyrimidal, and diagonal. They manage to provide different beamwidths for different scenarios, but none of them is able to provide different illuminations for different polarizations, which has been achieved by the asymmetrical design presented here. After optimization the polarization discrepancy has been eliminated for most of the bandwidth.



(a) (b)

Fig. 1. (a) The manufactured symmetrical Band-B feed and (b) its predicted aperture efficiencies $\epsilon_{\mathrm{ap\_SKA}}$ in the SKA dish, based on simulated radiation patterns, with the blue-dashed line representing the SKA requirement.

II. The Asymmetrical Structure

The reason for the discrepancy shown in Fig. 1(b) lies in the identical beam patterns provided by the QRFH feed for the two polarizations, which in the SKA offset optics would result in different edge taper levels for different polarizations, and therefore fail to match the SKA offset-Gregorian reflecting system. Definitions of the two polarizations in the SKA dish are shown in Fig. 2, the vertical polarization is defined to correspond to the long axis of the main reflector (represented by point 'A' in Fig. 2), while the short axis (represented by point 'B') is corresponding to the horizontal polarization.

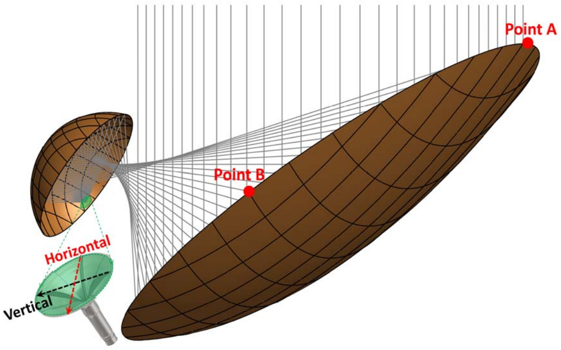


Fig. 2. Illustration of the dish with feed location, directions of both polarizations are also indicated.

The edge taper levels at points 'A' and 'B' on the main reflector were examined for both polarizations, as shown in Fig. 3. The results were derived from the simulated secondary farfield patterns which were created by the feed together with the sub-reflector. Along the long axis, the edge taper levels range between -10 dB to -3 dB, and the vertical polarization possesses a slightly higher edge taper level than the horizontal in general. While along the short axis, the horizontal polarization exhibits a much higher edge taper level than the vertical. To eliminate the discrepancy, different illuminations for two polarizations are needed.

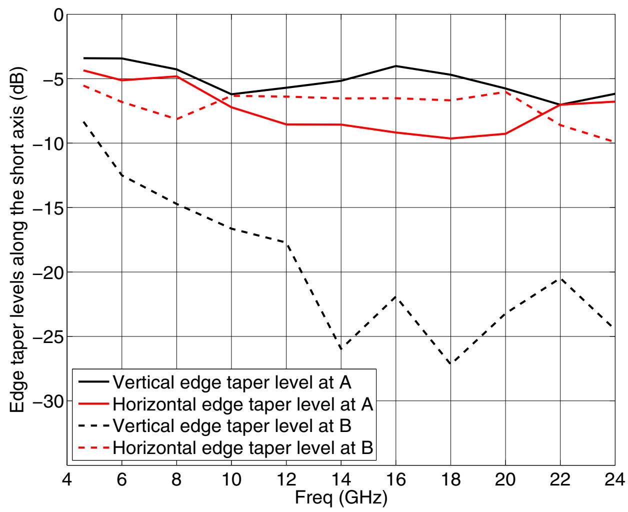


Fig. 3. Edge taper levels along the long axis (point 'A') and short axis (point 'B') of the main reflector, for both polarizations. The frequency step is 2 GHz.

It was also found that for QRFHs, the electrical field of vertical polarization mainly concentrates between the two corresponding vertical ridges and a limited portion of the adjacent sidewall, vice versa for the horizontal polarization, see Fig. 4. Moreover, the change of vertical ridge profile would to some extent result in different beamwidth for vertical polarization, but it shows very limited influence on the horizontal patterns.

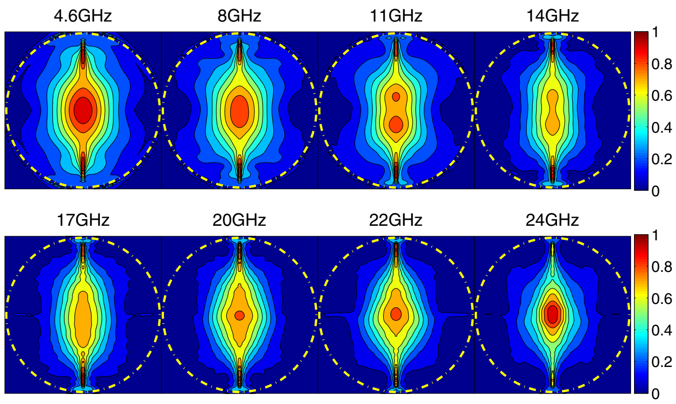


Fig. 4. Normalized electrical field distribution of the vertical polarization at the aperture plane of the Band-B feed, at 4.6 GHz, 8 GHz, 11 GHz, 14 GHz, 17 GHz, 20 GHz, 22 GHz and 24 GHz respectively, with the yellow dash-dotted circle representing the feed aperture.

Based on this, asymmetrical structure is deliberately designed so as to provide different patterns for the two polarizations, as is shown in Fig. 5. The main body of the feed consists of two different and orthogonal pairs of both ridges and sidewall quad-pieces, which means different ridge and sidewall profiles are chosen for different polarizations. The sidewall of the feed horn is no longer rotationally symmetrical and each polarization is mainly bounded by the two diagonals. The horizontal polarization is mainly defined between ϕ=45° to ϕ=135° and ϕ=225° to ϕ=315°, and the vertical polarization between ϕ=135° to ϕ=225° and ϕ=315° to ϕ=45°.

Fig. 6 is the cross-section view of the two sets of profiles, for both ridges and sidewall. As it is the flared part that is mainly influencing the pattern performance, the two sets of profiles

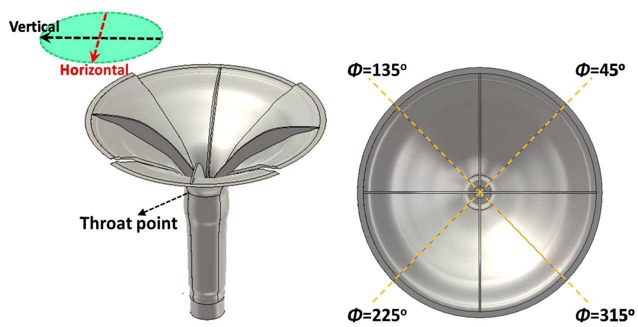


Fig. 5. Electrical model of the asymmetrically designed Band-B feed in CST.

begin to differentiate from the "throat point" (l=107.5 mm). From here the feed opens up, and the difference between the profiles becomes larger towards the feed aperture, while behind this point the profiles are kept identical. Considering that our only purpose is to change the beamwidth, the two sets of profiles were correlated by a scaling factor F_{scale}, which means only one set of the spline-points plus F_{scale} have to be considered in the optimization.

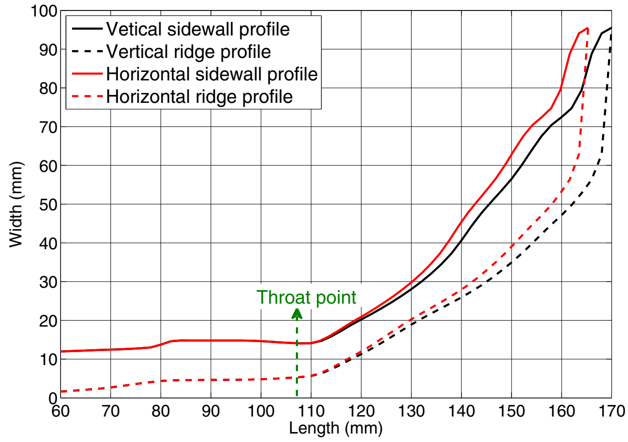


Fig. 6. The cross-section view of the two sets of profiles, for both ridges and sidewall.

III. Optimization and Results

The optimization was carried out using the System Assembly and Modeling (SAM) feature in CST [5], the goal function was defined as to maximize the aperture efficiencies of both polarizations and meanwhile minimize the difference between them. To reduce the complexity, only the spline-points between the throat point and the aperture plane (i.e. 107.5–170 mm) plus F_{scale} were involved in the optimization. There are 25 parameters in total for the optimization.

The polarization discrepancy was optimized to a minimum when $F_{scale} = 0.925$, and the corresponding aperture efficiencies in the SKA dish $\epsilon_{\text{ap\_SKA}}$ of the two polarizations are shown in Fig. 7. The polarization discrepancy has been significantly reduced for most of the bandwidth, $\epsilon_{\text{ap\_SKA}}$ of both polarizations are almost identical at low-band and mid-band, but towards high-band (20–24 GHz) their difference becomes larger. The results show that in order to eliminate the polarization discrepancy, different illuminations have to be provided by the feed and in this way we can compensate for the offset geometry of the SKA dish.

In Fig. 8, the 10 dB beamwidth in E-, D- and H-planes exhibit similar trends for both polarizations, but slight difference between them can be still observed, so as to provide different illuminations. The peak of the relative cross-polar level (XPI) in D-plane becomes worse than that of the symmetrical case for both polarizations, they are better than -8 dB here while in the symmetrical case they are better than -11 dB. Moreover, the horizontal XPI is slightly worse than vertical XPI across the bandwidth.

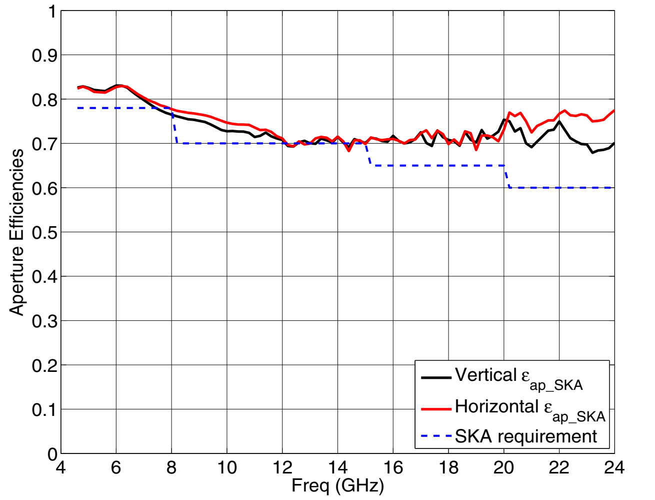


Fig. 7. The aperture efficiencies of both polarizations in the SKA dish when $F_{scale} = 0.925$, with a blue line representing the SKA requirement.

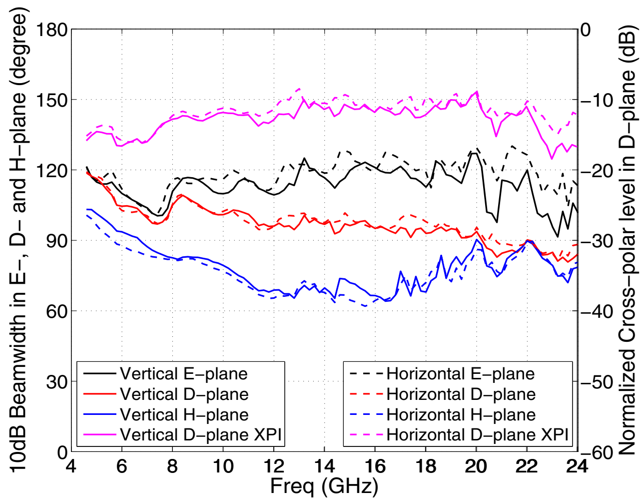


Fig. 8. The nominal 10 dB beamwidth in E-, D- and H-planes of both polarizations, as well as the peak of the relative cross-polar level (XPI) in D-plane. Solid curves for horizontal and dashed for vertical.

The asymmetrical design has also an influence on the reflection coefficients due to the discontinuous boundary between two polarizations. This makes the vertical reflection coefficient (S11) better but the horizontal reflection coefficient (S22) slightly worse than that of the symmetrical case, see Fig. 9. The vertical S11 is below -15 dB for most of the bandwidth while the horizontal S22 exhibits an obvious degradation of about 2 dB near its cut-off frequency. We believe this can be improved by making a more gradual change on the horn sidewall between the two polarizations. Port isolation is better than -31 dB over the bandwidth.

IV. Conclusion

In this paper, we propose and investigate an asymmetrically designed QRFH feed, which has successfully eliminated its polarization-dependent discrepancy in aperture efficiency in

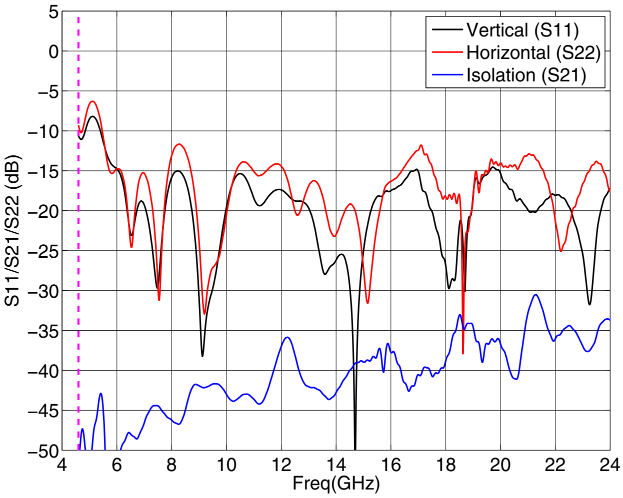


Fig. 9. The simulated S-paramters of the asymmetrical Band-B feed.

the SKA offset reflecting systems for most parts of Band B, covering 4.6–24 GHz. The ridge and sidewall profiles of the feed were deliberately designed to be different, so as to provide different illuminations for different polarizations, which results in similar aperture efficiencies for the two polarizations in the SKA dish. The polarization discrepancy still exists over 20–24 GHz, which we believe could be further reduced by introducing more spline-points around the "throat point" which mainly influences the radiation patterns at higher frequencies. In Fig. 7, strong resonances could be observed towards mid- and high-band, this could be solved by also taking the spline-points that are behind the "throat point" into the optimization.

However, due to the discontinuous boundary between the two polarizations, return loss of the horizontal polarization would be degraded by about 2 dB around the cut-off frequency. To develop the ideas in this paper further, a new QRFH with elliptically-shaped aperture is being investigated within our research group, with the aim to provide better performance for offset reflector antennas.

Acknowledgment

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