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## Enhancing SKA Band 1 Polarimetry by Using Two Different Feed Rotations

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### Abstract

We investigate the possibility of enhancing the polarimetric performance of the Square Kilometre Array (SKA) telescope's band 1 by mounting the feeds with two different rotations relative the dish. One rotation aligns the two polarizations along the horizontal and vertical directions and the other rotation is 45 degrees to the horizontal, vertical directions. Taken together, this configuration amounts to introducing a simple and cheap type of polarization diversity. We find that such a configuration can improve polarimetry. This is important since the offset gregorian dish design employed for SKA1-mid tends to produce beam-shapes that are not rotationally symmetric, and thus polarimetry tends to vary azimuthally.

### 1. Introduction

The SKA project aims to design and construct the world's largest and most sensitive radio telescope array in its frequency range. The mid-frequency range will be covered during phase 1 of SKA by the so called SKA1-mid. It is to be built in South Africa and will consist of around 130 dishes mounted with various dual-polarized antenna feeds covering frequency bands between 350-13800 MHz. Band 1 covers the 350-1050 MHz frequency range and is a dual-polarized quad-ridge flared horn (QRFH) feed designed by Onsala Space Observatory, Chalmers University [1]. As its operating band is approximately 3:1, and thus greater than an octave, it can be seen as a wide-band antenna. As such maintaining desired properties as constant throughout the band is challenging. Another challenge is that as the lowest band of SKA1-mid, band 1 must deal with constraints of having wavelengths comparable to the size of the feed, that is of the order of 1 meter.

One area of concern is that of polarimetry performance. The main SKA polarimetry requirement is that the so-called *Intrinsic Cross-polarization Ratio* (IXR), which will be detailed in the next section, should not be below 15 dB within the field-of-view (see ref. [2,3]). The current

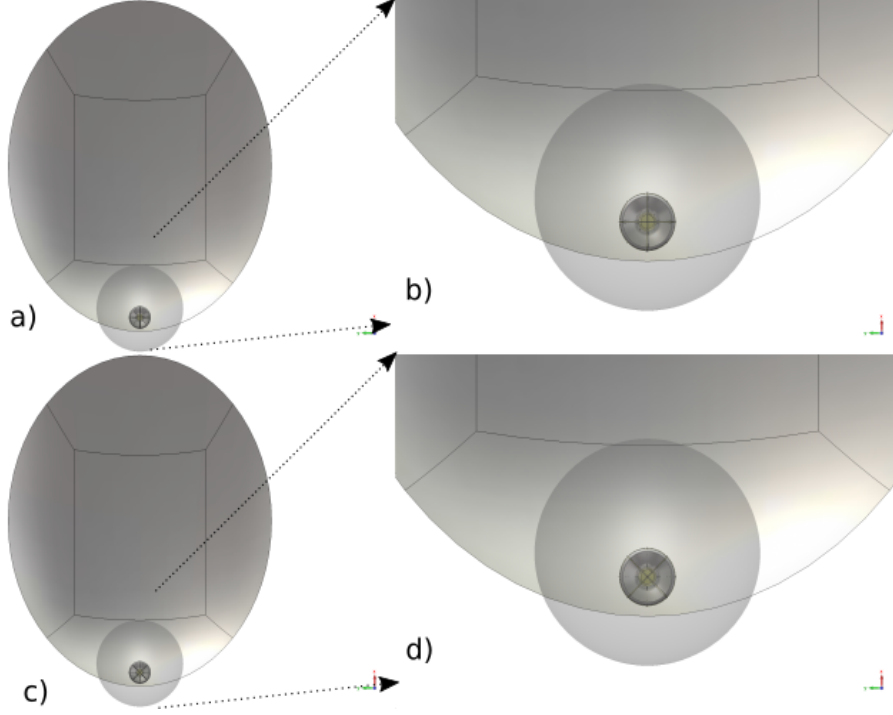
band 1 design fulfills this requirement. The IXR, however still varies in particular at the edges of the FoV as we will show, so there is room for improvement. Here we will investigate how polarization diversity (see ref. [4,3]) based on simple rotation of the feeds can improve the polarimetry.

### 2. Experiment

To test the possibility of using simple, feed rotation based polarization diversity, we used the nominal design of the SKA band 1 feed mounted in the SKA dish and compared it with the same configuration but with the feed rotated 45 degrees, see Figure 1. We refer to the former, nominal configuration as the rotation 0 configuration and the latter one as the rotation 45 configuration.

One can see from Figure 1 that the rotation 45 configuration is interesting since it is more symmetric than the nominal rotation 0 configuration. In the latter case the vertical  $x$  component is in the symmetry plane of the dish while the horizontal  $y$  component is orthogonal to it. In contrast, in the rotation 45 configuration, both  $x$  and  $y$  are 45 degrees to the symmetry plane. Thus the rotation 45 configuration may be expected to have a mirror symmetric pattern with respect to the symmetry plane of the dish.

We used the EM simulation software CST to produce the far-field pattern of the QRFH which in turn was used in the physical optics/physical theory of diffraction (PO/PTD) solver in GRASP to compute the final far-field pattern of the QRFH when mounted on the dish. The results were then analyzed by computing the IXR in three cases: rotation 0, rotation 45, and the combined rotation 0 and rotation 45.



**Figure 1:** Overview of the two feed configurations showing the main reflector, the secondary reflector and the QRFH feed placement. b) & d) are zoom-ins of a) & c) respectively. As can be seen in b) & d), the only difference in the configurations is the rotation of the feed. The alignment of the linear feed probes are the same as the ridges seen as a cross at the center of the feed. a) & b) show the rotation 0 alignment while c) & d) show the rotation 45 alignment. The coordinate system is  $x$  pointing straight up while  $y$  is pointing to the left.

The combination of the two rotations was made in the sense of a beam-formed combination, which we detail now. As the feeds are dual-polarized one obtains a pair of far-field patterns that together define a Jones matrix pattern,  $\mathbf{J}$ , which is a function of direction and frequency. Denoting the rotation 0 Jones matrix  $\mathbf{J}_0$ , and the rotation 45 Jones matrix  $\mathbf{J}_{45}$ , the combined Jones matrix is

$$\mathbf{J}_{comb} = \begin{pmatrix} \mathbf{J}_0 \\ \mathbf{J}_{45} \end{pmatrix} \quad (1),$$

thus the combined Jones is the 4x2 matrix of the two Jones matrices stacked vertically.

The polarimetric performance of these various configurations is assessed using the Jones intrinsic cross-polarization ratio (IXR<sub>J</sub>) that is defined in terms of the two singular values of the Jones matrices,  $\sigma_{max}, \sigma_{min}$ , as

$$IXR_J = \left( \frac{\sigma_{max} + \sigma_{min}}{\sigma_{max} - \sigma_{min}} \right)^2 \quad (2)$$

The IXR was introduced in ref. [5], and its generalization to arrays of dual-pol antennas in ref. [3].

### 3. Results

The SKA1-mid dish is an offset gregorian design. As such the horizontal and vertical planes are not symmetric to each other as they would be in an ordinary prime focus dish. Thus we expect that the horizontally and vertically aligned polarizations will not be symmetric to each other either, while the feed rotated 45 degrees to the horizontal and vertical planes will be more similar to each other. This is indeed the case. However, none of the alignments produce body-of-rotation type radiation patterns, as can be seen in Figure 2 and 3.

When we combined the rotation 0 and rotation 45 configurations we get a generally improved polarimetric performance across the beam as can be seen in Figures 4 and 5, where the ratio of the combined feeds are compared to rotation 0 and rotation 45 configurations respectively. As a final comparison, we superimpose the contour lines of IXR=30 dB for all three configurations in Figure 6. The curve of the combined configuration is more symmetric around the pointing direction than the other two. Figure 6 also tabulates the areas of the curves in square degrees and the combined configuration has the largest area. This indicates that the combined configuration has good polarimetry over a large field-of-view.

## 5. Discussion

In this paper we have shown that polarimetry can be improved for the SKA1-mid band 1 by using two different feed alignments. In practice this could be employed by mounting the feeds on some of the  $\sim 130$  dishes with a 45 degree rotation while the others retain the nominal horizontal-vertical alignment. The exact number of rotated feeds need not be half, for instance even one rotated feed may not improve the overall polarimetry, but may provide a useful source of comparison for polarimetric calibration and testing.

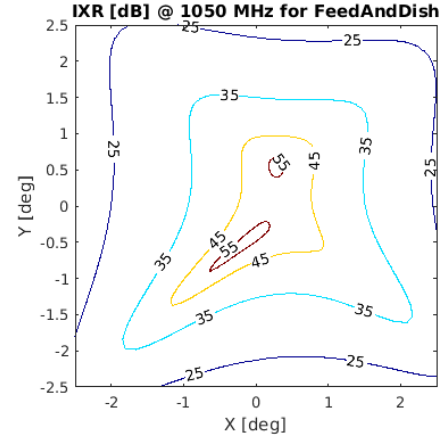
Of course one would have to process the rotated feeds slightly differently. This could be done by introducing an adding and subtracting step either at the front-end in analog or digitally, or one could derotate in post-processing.

The downside of rotated feeds is mainly the additional complexity of mounting, keeping track, and processing a polarimetrically heterogeneous array of feeds.

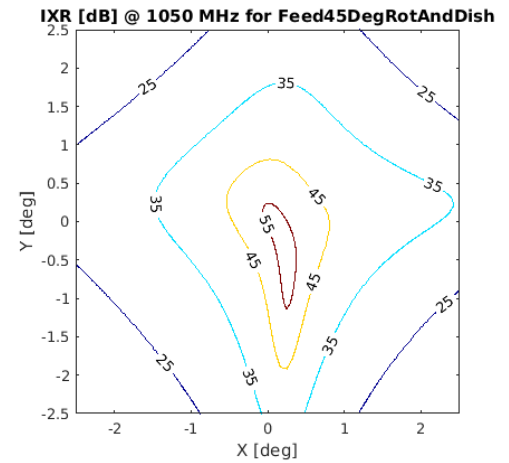
Naturally other rotations could be used besides the 45 degree rotation discussed here. We expect that if one were to introduce more feed rotations in the array, the polarimetric performance patterns would become more rotationally symmetric around the pointing direction, which is desirable for most observations.

## 7. References

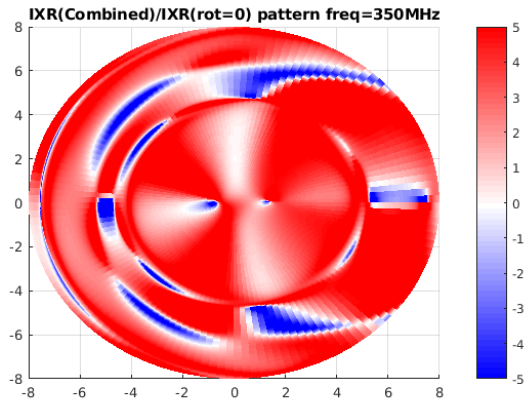
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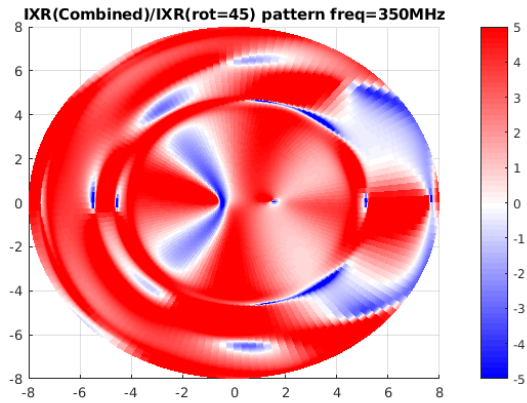
**Figure 2:** Contour map of IXR pattern of band 1 feed with rotation 0 at 1050 MHz. Contour lines are marked in units of dB. Note that the orientation of  $x, y$  are flipped here with respect to Figure 1.



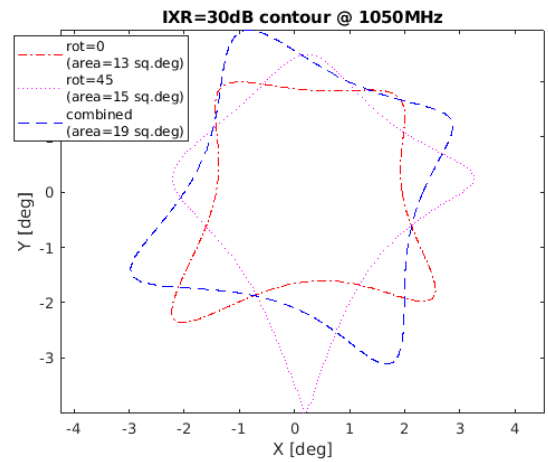
**Figure 3:** Contour map of IXR pattern of band 1 feed with rotation 45 at 1050 MHz. Contour lines are marked in units of dB. Note that the orientation of  $x, y$  are flipped here with respect to Figure 1.



**Figure 4:** IXR(combined)/IXR(rot=0) in dB. The mostly positive dB regions indicates that the IXR of the combined configuration is generally better than the rotation 0 configuration alone. Note that the orientation of  $x,y$  are flipped here with respect to Figure 1.



**Figure 5:** IXR(Combined)/IXR(rot=45) in dB. The mostly positive dB regions indicates that the IXR of the combined configuration is generally better than the rotation 45 configuration alone. Note that the orientation of  $x,y$  are flipped here with respect to Figure 1.



**Figure 6:** Superposition of the IXR=30 dB contours for the case of rotation 0, rotation 45 and the combination of the two, at the frequency 1050 MHz. The legend tabulates the area of these curves. The combined configuration has the largest area. Note that the orientation of  $x,y$  are flipped here with respect to Figure 1.