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A Wide-band Feed System for SKA Band 1 Covering Frequencies From 350 - 1050 MHz

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***Abstract*—We present the design of a wideband feed system for the Band 1 of the Square Kilometer Array (project). The Band 1 feed system uses a quad-ridged flared horn (QRFH) optimized for a offset Gregorian dual reflector dish to cover RF frequencies from 350 - 1050 MHz, and a cryogenic low noise amplifier (LNA). The feed horn is optimized to achieve best A_{eff}/T_{sys} over the entire band, by making trade-off between aperture efficiency and spill over noise contribution.**

The optimised feed horn shows above 70% efficiency over the entire 3:1 band, with return loss better than 10 dB. The cryostat following the feed has between 9 to 14 K noise, measured at the co-axial connector of the QRFH. The estimated on-sky sensitivity of the feed system is better than specified 4.2 m^2/K averaged over the entire frequency band.

***Index Terms*—QRFH, Wideband feed, SKA, cryogenic feed systems.**

I. INTRODUCTION

The Square Kilometer Array (SKA) is a new radio interferometer currently at the end of its design phase, the telescope aims to have total effective collecting area of one square kilometer, making it worlds biggest and most sensitive radio telescope at these frequencies. The project is an international effort to built world's largest radio telescope, involving 10 member countries. The telescope would cover frequencies from 50 MHz to 13.8 GHz, divided into SKA-low, SKA-survey, and SKA-mid [1]. The division is based on the technology that would be used in particular frequency bands. The SKA-low would use a low frequency aperture array operating from 50 - 350 MHz, the SKA-survey would use phased array feeds in a dual reflector system operating from 350 MHz to 4 GHz, and the SKA-mid would use five wide band single pixel feed systems to cover frequencies from 350 MHz to 13.8 GHz.

The work presented here concerns the development of feed system for the Band 1 of the SKA-mid. The Band 1 feed system is designed to cover RF frequencies from 350 - 1050 MHz. The SKA-mid Band 1 consists of a QRFH operating at room temperature, followed by a cryogenic LNA at 20 K ambient temperature.

II. BAND 1 SYSTEM OVERVIEW

The SKA Band 1 Feed Package uses a Quad-Ridged Flared Horn (QRFH) at ambient temperature and cryogenically cooled LNAs. The performance of the QRFH in the different optics designs considered for SKA are described in the optics analysis report [2]. The QRFH was selected after comparing cost and performance aspects with the Eleven Feed, the other feed considered as possible candidate for Band 1 [3].

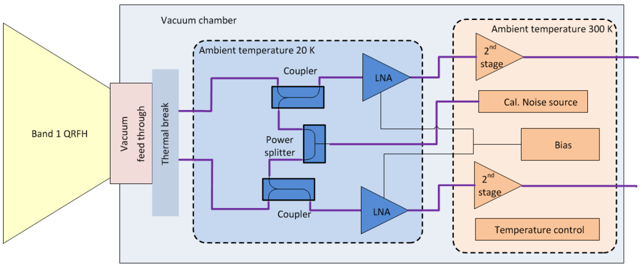

Fig. 1. Overview of Band 1 feed system.

Fig. 1 shows the design concept for the Band 1 feed system. The QRFH is placed at room temperature and attached mechanically to the front plate of the cryostat. The RF interface to the signal chain is provided by vacuum feed through connectors at the input of the cryostat. The heat transfer from 300 K to 20 K cold stage is minimised using stainless steel coaxial cables to transport the signal. These cables are anchored thermally at 20 K and 70 K. The RF signal for each of the two orthogonal polarisation then passes though a directional coupler where calibration noise signal is injected, followed by a cryogenic LNA and 2nd stage LNA. The cryogenic LNAs and direction coupler are attached to the 20 K cold stage of the cryostat. The 2nd stage LNAs, and calibration noise source are located at the 300 K stage.

III. CRYOSTAT DESIGN

Fig. 2 shows a cross section of the Band 1 cryostat, which uses a Gifford-McMahon (GM) cooler. The LNAs and the directional couplers are placed on thermally stabilized copper plate that is attached to the 20 K stage of the cryo-cooler using weak thermal links. A stainless steel (SS) co-axial cable is used between the vacuum feed through located at 300 K interface and the direction coupler at 20 K, to reduces the thermal heat flow. Since the SS co-axial cable is located before the first stage LNA, looses of the SS cable add significant noise to the overall system noise, therefore length of this cable is carefully optimized to reduce the added noise contribution but at the same time providing enough thermal isolation between the two temperature stages.

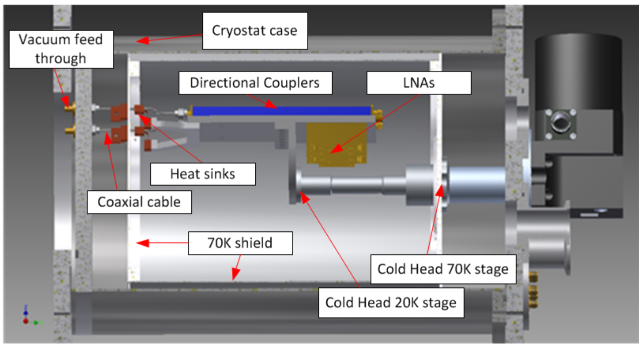

Fig. 2. Overview of Band 1 cryostat.

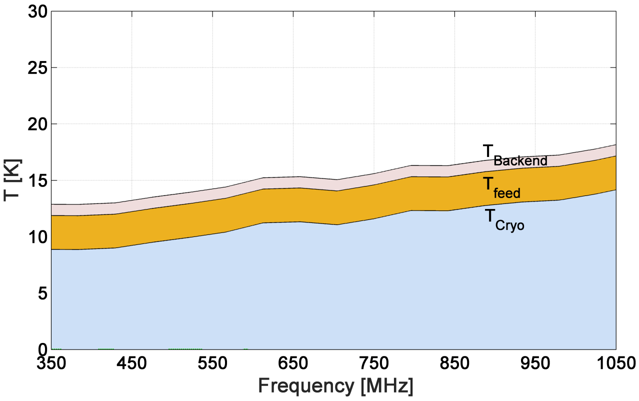

Fig. 3. Measured noise temperature of the receiver at the input of the horn.

Fig. 3 shows the expected noise temperature at the input of the feed horn, where T_{Cryo} is the noise temperature measured at the input of the cryostat which includes the cryogenic LNA, direction coupler and all the losses up to the 300 K interface of the cryostat. T_{feed} represents the estimated noise contribution from the feed at room temperature, and $T_{Backend}$ is the noise contribution from all the subsequent components after the first cold LNA.

IV. FEED DESIGN

The QRFH for the Band 1 of the SKA-mid has been designed to maximise the overall sensitivity of the telescope, by making trade off between the aperture efficiency and spill over noise contribution over the entire band while keeping the feed input reflection coefficient in the acceptable range. Fig. 4 shows the Band 1 QRFH, both the ridge profile, and outer horn profile is defined using spline function. In our simulations we observed that a spline profile horn provide better efficiency compared to exponentially tapered QRFH over 3:1 band width. For wider bandwidths however, exponentially profile [4] might still provide better efficiency.

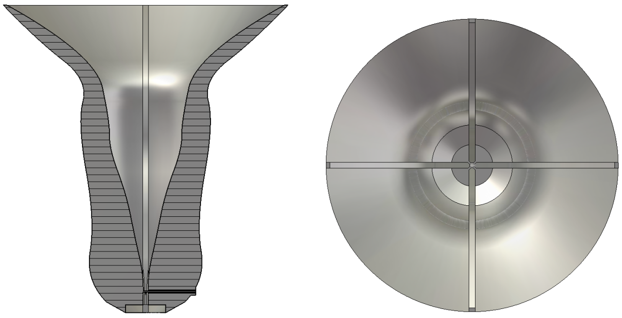

Fig. 4. SKA-mid Band 1 QRFH using spline profile for the flare and ridges.

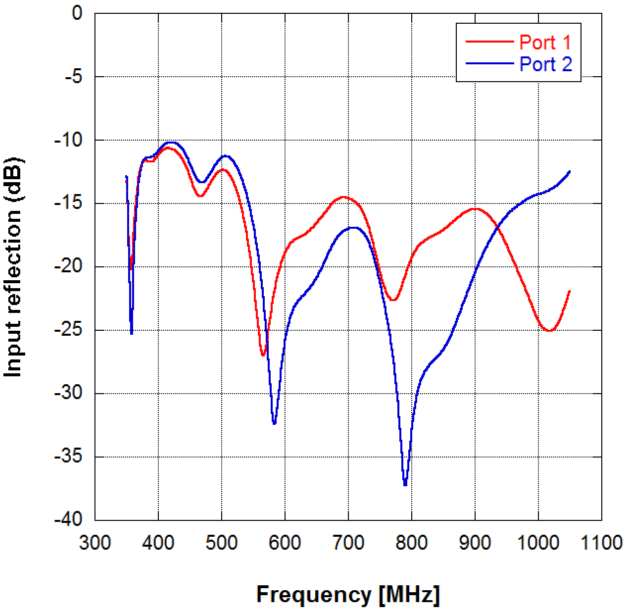

Fig. 5. Simulated reflection at the co-axil input line of the QRFH.

Fig. 5 shows the CST [5] simulation results of reflection coefficient of the QRFH for both the ports. For both the ports the input reflection is better than $-10\ dB$. The slight degradation in the input matching at the low end of the frequency band is believed to be associated with the ridge and horn profile, and not with feeding section. By modifying the ridge and horn profile input reflection can be improved, but we observe reduction in the overall efficiency. However, we believe that further optimisation of the feed could improve the input matching without substantially affecting the efficiency.

V. ANALYSIS OF THE SYSTEM SENSITIVITY

In order to accurately estimate the overall system sensitivity, one needs to accurately estimate the spill over noise contribution after the reflector system. The estimation of the overall on-sky sensitivity and optimisation of QRFH is done using a GRASP system simulator [6], where the CST far field patters are analysed in the SKA dish geometry in GRASP [7]. Fig. 6 shows the dish geometry used in the feed optimisation. SKA dish is a offset Gregorian geometry, the projected diameter of the primary reflector is 15 m, and the diameter secondary reflector is has 5 m, with extension on the bottom side to minimise the ground noise pickup in the feed spill over.

The simulated aperture efficiency of the QRFH in the SKA dual reflector geometry is shown in Fig. 7. For both the polarisations the aperture efficiency is better than 75% over

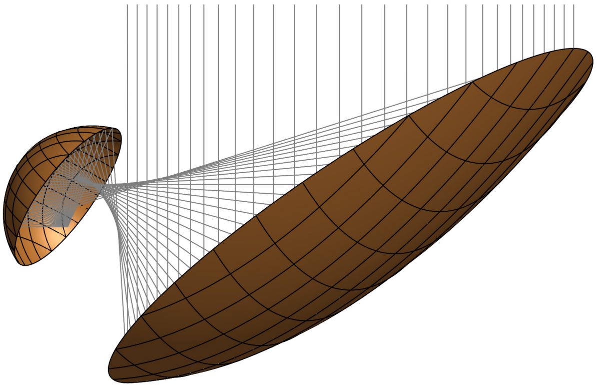

Fig. 6. Offset Gregorian dish geometry for the SKA.

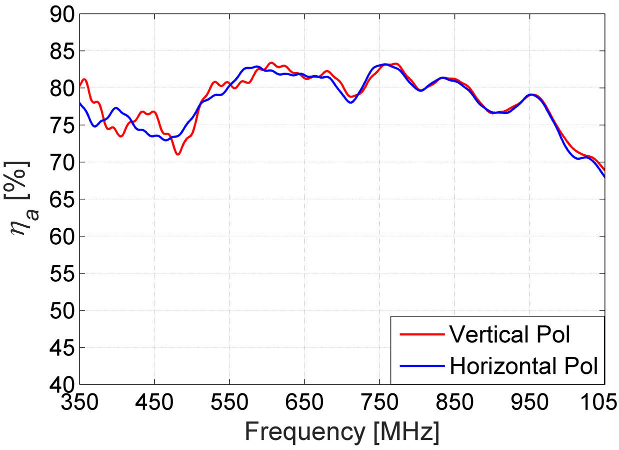

Fig. 7. Simulated aperture efficiency of the QRFH in the SKA dual reflector geometry.

most of the frequency band, and better than 70% over the entire band.

Fig. 8 shows the simulated system sensitivity of the feed in the SKA dish geometry, using the receiver noise estimation described in previous section, and the analysis from GRASP and system simulator. The sensitivity is calculated when the dish is looking at zenith, for other elevation angles the over all sensitivity changes as function of elevation angle.

VI. CONCLUSION

The current design of the Band 1 QRFH using a spline profile to define the ridges and horn, provides 75% efficiency in the offset Gregorian dual reflector SKA dish, with input reflection better than $-10\,dB$ over the entire frequency band. The overall Band 1 system with QRFH placed at room temperature and the cryogenic LNAs shows very promising results and estimated performance meets the sensitivity requirement of $4.2\,m^2/K$ averaged over the entire frequency band.

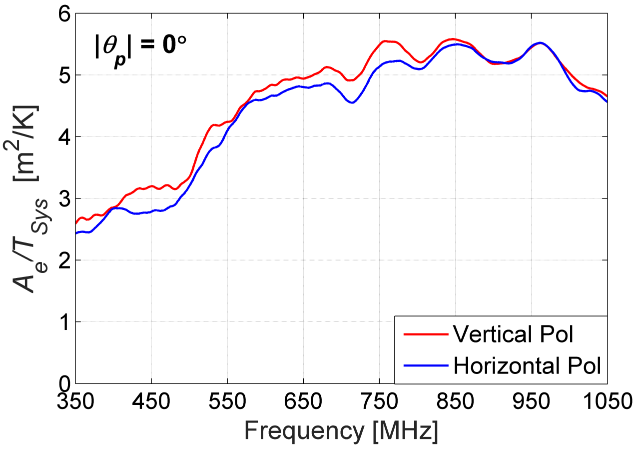

Fig. 8. Simulated dish sensitivity (A_{eff}/T_{sys}) of the QRFH in the SKA dish geometry.

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REFERENCES

[1] P. Dewdney, "SKA1 system baseline design," pp. 1–98, March 2013 [Online]. Available: https://www.skatelescope.org/wp-content/uploads/2014/11/SKA-TEL-SKO-0000002-AG-BD-DD-Rev01-SKA1_System_Baseline_Design.pdf.

[2] R. Lehmensiek, "SKA optics options: SPF EM analyses," SKA organisation, Internal project document, Dec 2014.

[3] B. Billade, "Band 1 feed selection document, performance and cost study," SKA organisation, Internal project document, Oct 2014.

[4] A. Akgiray, S. Weinreb, W. Imbriale, and C. Beaudoin, "Circular quadruple-ridged flared horn achieving near-constant beamwidth over multioctave bandwidth: Design and measurements," *Antennas and Propagation, IEEE Transactions on*, vol. 61, no. 3, pp. 1099–1108, March 2013.

[5] CST, "CST MICROWAVE STUDIO," http://www.cst.com/Content/Products/MWS/Overview.aspx.

[6] M. Ivashina, O. Iupikov, R. Maaskant, W. van Cappellen, and T. Oosterloo, "An optimal beamforming strategy for wide-field surveys with phased-array-fed reflector antennas," *Antennas and Propagation, IEEE Transactions on*, vol. 59, no. 6, pp. 1864–1875, June 2011.

[7] TICRA, "GRASP," http://www.ticra.com/products/software/grasp.