Performance of a Quad-Ridged Feed in a Wideband Radio Telescope (EuCAP 2011)

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***Abstract*— A new quad-ridged, flared horn achieving nearly constant beamwidth and excellent return loss over a 6:1 frequency bandwidth is described. The system performance in two Radio Telescopes: 1) A 12-meter symmetric dual shaped reflector system intended for geodetic very long baseline interferometry and 2) A 15-meter offset dual shaped reflector intended for the SKA is presented showing it to be excellent wideband feed choice.**

I. Introduction

Almost all radio telescopes utilize antenna feeds with bandwidths less than an octave yet many of the observations could be greatly enhanced by wider bandwidth. This enhancement would allow more sensitive pulsar searches, measurements of spectral lines with large red shift, and determination of the spectral index of sources of broadband radiation. Advancements in low noise amplifiers have enabled decade bandwidth amplifiers with extremely low noise. There is thus a need for efficient wideband feeds for parabolic reflectors and this has been the focus of this work.

II. Quadruple-Ridged Flared Horn

Most wideband feeds under consideration for the Square Kilometre Array (SKA), the next generation radio telescope [1], are wideband log-periodic type feeds that consist of wire type elements for the radiating structure. Examples are the Log-periodic dipole antenna [2] used for the ATA, the QSC feed [3] and the Eleven feed [4]. Because of the thin wire connection they can be difficult to cool for a low noise application. Also, they tend to have very delicate and small feed connection area. One feed that can easily be cooled and is very robust is the open quad-ridged commercially available Lindgren feed [5]. This feed has been used on the wideband GAVRT system [6, 7] and the coolable feed amplifier system is pictured in Fig. 1. The disadvantage of this feed is that it is not as wideband as the other candidate feeds. Significant effort is underway to optimize a quad-ridged feed for wider bandwidth.

The horn design details can be found in [8] and [9]. The following is a brief summary of how we got there along with some of the key features of the design. The genesis of the design was the ETS-Lindgren 3164-05 commercially available horn that covers the 2 – 18 GHz band. It has a maximum return loss of 6 dB in band along with a 10 dB beamwidth that varies between 60 to 130 degrees. By placing the feed in a dewar, the RF performance was similar but there was a slightly smaller beamwidth variation but more ripples on the patterns and return loss. Also, since it was in a dewar the feed could be cooled. This feed was used for the GAVRT program [6, 7].

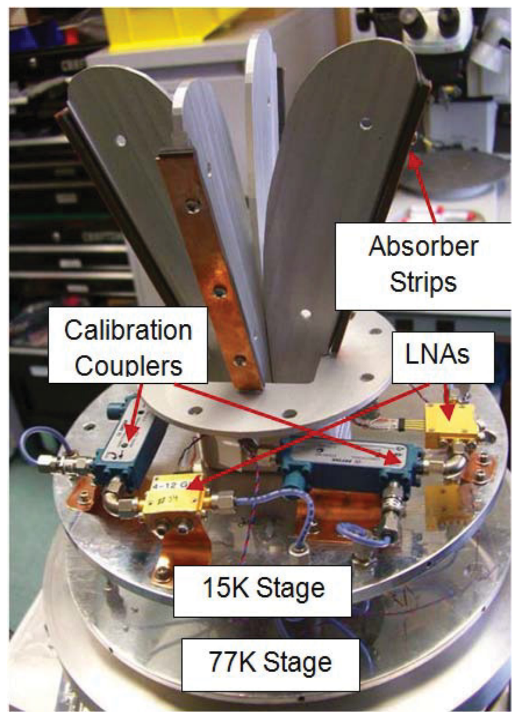

Fig. 1 Cryogenic wide band feed and LNA used in the GAVRT program.

The design approach for the improved horn combined ideas of ridged waveguides, profiled and aperture-matched horns [10] and through use of CST Microwave Studio® (MWS) EM simulation software, empirically determined the horn configuration yielding desired performance.

An example of a candidate quad-ridged feed is shown in Fig. 2. Key features of the design are: 1) Ridges - which provide for a lower cutoff of the dominant mode by as much as a factor of 4. Also the exponential profile presents a smooth impedance transition from 50 to 377 ohms. 2) Profiled sidewall – which manipulates the phase over the aperture to maintain constant beamwidth and minimizes EM interaction with the surrounding environment. 3) Aperture matching – which minimizes edge diffraction from aperture edges and introduces curvature to high frequency wave fronts, and 4) Mode suppressor – which attenuates higher order modes around the launch point.

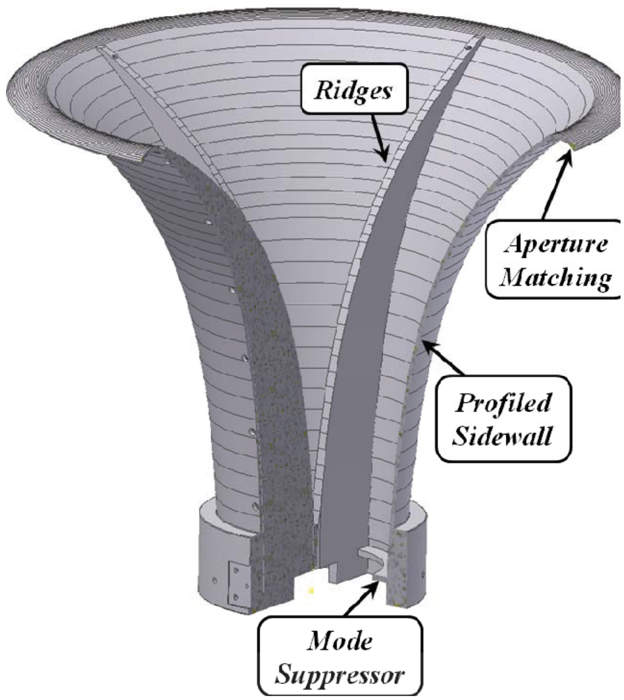

Fig. 2 A wideband quad-ridged feed

III. Predicted System Performance in a 12-meter VLBI type antenna

A version of the quad-ridged horn shown in Fig. 3 was designed and built to work with the 12-meter Patriot/Cobham antenna [11] pictured in Fig. 4. One potential application is to support geodetic very long baseline interferometry (VLBI) covering the 2 to 12 GHz frequency range. Edge angle to the subreflector is 50 degrees. Thus, the horn was designed with a target 10 dB beamwidth of approximately 85 degrees. Measured return loss is higher than 10 dB from 1.9 GHz all the way up to 19 GHz. Furthermore, it is better than 15 dB from 2.5 to 11 GHz which is 85% of the target frequency band. Horn radiation patterns were measured using a far-field pattern measurement setup on the roof of the electrical engineering building, Moore Laboratory, at Caltech. Both co- and cross-polarized radiation patterns were measured in three azimuthal planes, namely ϕ = 0, 45, and 90 degrees, for θ = [-180, 180] degrees (with one degree steps in the main beam) from 1 to 17 GHz with a frequency resolution of 40 MHz. The measured radiation patterns were used for the subsequent prediction of antenna performance.

Fig. 3 CIT Quad-ridge Flared Horn (QRFH)

Fig. 4 The 12-meter dual reflector antenna

One of the most common figures-of-merit (FoM) used in radio astronomy to asses feed performance on a telescope is given by FoM = Aeff/Tsys where Aeff and Tsys are, respectively, the effective aperture area and system noise temperature. A custom physical optics program, which takes into account shaping of both reflectors, was used to compute the aperture efficiency of the 12-meter Patriot antenna illuminated by the horn described here. The computed system aperture efficiency (not including dish rms, or strut and subreflector blockage) is plotted in Fig. 5. The predicted average aperture efficiency is over 69% over the entire band for both polarizations. Antenna temperature was calculated approximately for a zenith-pointing configuration using the method outlined in [12]. It is less than 10 Kelvin over 70% of the band and its average from 2 to 12 GHz is 10 Kelvin. Assuming a 15 Kelvin receiver noise temperature, this yields the FoM curves plotted in Fig. 5 which suggest that the system performance is better than 60% efficiency and 23 K T_{sys} (black dashed line) for much of the band.

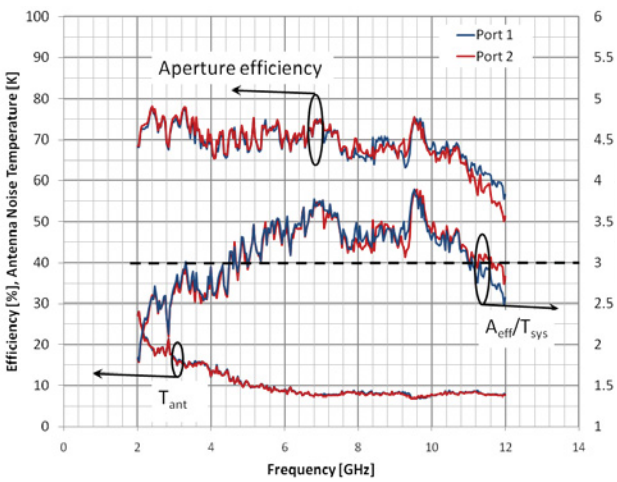

Fig 5 Aperture efficiency, antenna noise temperature and figure of merit calculation with this horn illuminating the 12-meter dual-reflector system.

IV. Predicted System Performance in a SKA Reflector Design

Another version of the QRFH was designed to work in the Design Verification Antenna (DVA), the US design concept for the Square Kilometre Array (SKA) program [13]. The 15-meter offset dual shaped Gregorian antenna is pictured in Fig. 6.

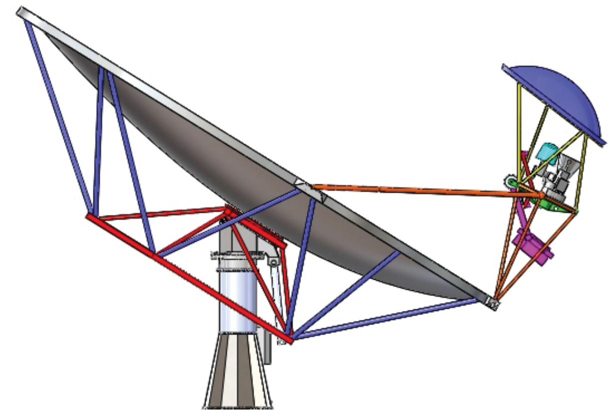

Fig. 6 Drawing of Antenna showing Feed Indexer

The design frequencies are 1.4 to 10 GHz and the subreflector opening angle is 55 degrees. As before, the key design parameter is Aeff/Tsys.

Shown in Fig. 7 is the efficiency of the QRFH compared to the efficiency of the GAVRT Lindgren feed scaled to cover the 1.4 to 10 GHz frequency range. The QRFH uses computed primary patterns and the GAVRT feed the measured primary feed data. The efficiency improvement over the commercially available Lindgren feed is quite apparent.

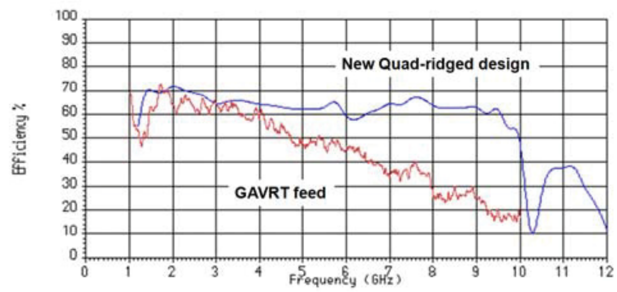

Fig 7 Efficiency of GAVRT and QRFH

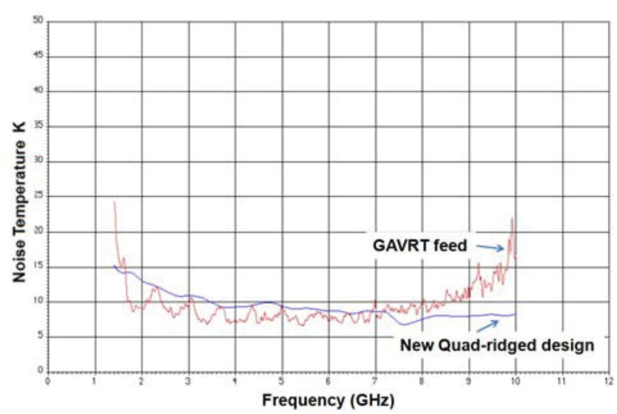

Fig 8 Antenna Noise Temperature of GAVRT and QRFH

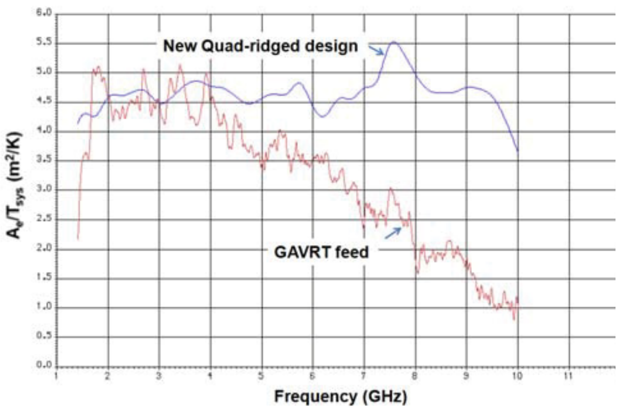

Fig. 9 Aeff/Tsys for the 15-meter SKA antenna

Figure 7 compares the antenna noise temperature. Again the extended frequency coverage range is displayed. The real improvement can be seen in Fig. 9 where the Aeff/Tsys for the SKA antenna is shown.

V. CONCLUSIONS

The QRFH is a unique feed that accommodate different optics and input impedance requirements. The performance in two Radio Telescopes is presented showing the QRFH to be an excellent wideband feed choice. For the fabricated feed, the predicted system performance is >60% aperture efficiency and <25K antenna noise temperature from 2 to 12 GHz.

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