

A COMPACT, PRIME-FOCUS, DUAL-BAND COAXIAL HORN FOR THE GIANT METER-WAVE RADIO TELESCOPE (GMRT, INDIA)

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ABSTRACT

We describe the design of a compact, prime-focus, dual-band coaxial horn feed for the 45m-diameter GMRT antennas. The feed-system covers the 0.22 - 0.24 GHz and 0.55 - 0.9 GHz bands. A unique feature is the use of a stepped quad-ridge orthomode transducer (OMT) instead of the conventional but much longer tapered version to make a compact lightweight design. Good performance of the GMRT antennas with this feed system is predicted in both bands.

INTRODUCTION

One of the world's largest radio telescopes, the Giant Metre-wave Radio Telescope (GMRT), is located about 80 km north of Pune (India). It consists of 30 fully steerable prime-focus paraboloid reflectors of 45m diameter that are spread over distances of up to 25 km. The reflectors have a focal length of 18.54m and a half subtended angle of 62.5°. The GMRT is conducting research on galactic evolution and this required collecting radio emissions in the VHF/UHF band. A new feed-system was needed for the experiment and this resulted in the work reported here.

We designed a dual-band VHF/UHF prime-focus horn for the GMRT as part of an ongoing collaboration between CSIRO and the National Centre for Radio Astrophysics (NCRA) (India). The feed-system is required to cover the frequency bands of 0.22 - 0.24 GHz and 0.55 - 0.9 GHz. The scope of our work was to design the horn and the associated feed-system, and predict the performance of the GMRT antennas over these two frequency bands. CSIRO would provide the design and the CAD drawings while the manufacture and testing of the feed-system would be handled by the NCRA.

One of the main constraints in the design was compactness (strongly related to the weight) as the feed support mechanism on the antennas is limited in both strength and space available to fit a new feed-system. Volumetric constraints were such that the total feed-chain length should be less than about 1.2 metres and weigh less than 100 kg.

HORN PERFORMANCE

A TE₁₁ mode coaxial horn [1] was chosen as a feed because of the two distinct bands. Such a configuration leads to a very compact antenna, is relatively simple to fabricate and provides a convenient method of separating the two bands. The 0.55 - 0.9 GHz band signal is received through the inner waveguide while the 0.22 - 0.24 GHz band is received through the outer coaxial waveguide of the horn (see Fig. 1). Consequently, the output of the horn has two ports: a coaxial port for the lower frequency band and a circular waveguide port for the higher frequency band.

The horn was optimized to cover both bands effectively by providing a suitable illumination for the GMRT reflectors (-12 dB taper at 62.5°) and a good match in both frequency bands (return loss >15dB). Matching irises were used to provide a good match in the lower frequency band (see Fig. 1) and optimization was used to obtain the required performance. The computed radiation patterns of the resulting horn design are shown at the mid-band frequency of the 0.22 - 0.24 GHz band in Fig. 2 and the mid-band frequency of the 0.55 - 0.9 GHz band in Fig. 3.

SIGNAL EXTRACTION

In addition to the horn design, a means of extracting the signal is required in each frequency band whilst maintaining a good input match at the two horn ports.

The narrow 0.22 - 0.24 GHz band needs to be extracted from the coaxial waveguide. The fundamental mode in the coaxial section is of course the TEM mode but the dominant mode coupled by the horn is in fact the TE_{11} mode. Given that the feed is dual polarized, we need to output two orthogonal TE_{11} modes. If we simply used two orthogonal probes we would only couple the unwanted TEM mode. However, by using two pairs of opposing probes, which are then combined in anti-phase, we are able to couple the two orthogonal TE_{11} modes. To achieve this, each opposing pair of probes is combined using a 3dB-hybrid and two phased-matched cables as shown in Fig. 4. This technique has been shown to work well in the past and has been successfully used recently in a similar project [2].

The extraction of the wider-band 0.55 - 0.9 GHz signal from the inner waveguide is more difficult and requires special attention. As the bandwidth is significant (65%), a wideband transition such as a quad-ridged orthomode transducer is the usual solution [1]. However, the conventional design of quad-ridged OMTs uses a very effective but also very long (in terms of wavelengths) taper from the input to the output probes. It is estimated that scaling an existing design would lead to a feed-system that is 3 to 4 m long, which is unacceptable for this application.

The conventional tapered quad ridged OMT has more bandwidth than required so in this case we were able to reduced the length of the quad-ridged transition by using a stepped transformer in ridged waveguide [3] instead of the conventional smooth \sin^2 profile for the OMT fins [1]. A significant effort was then directed towards optimizing such a short OMT to cover the required band. Preliminary results showed that a feed-system of around 1.2m long is achievable with return-loss of around 15 dB, which is usually considered acceptable for radio astronomy applications.

A 3-D model of the OMT alone is shown in Fig. 5. It includes the two orthogonal linear coaxial connections, which use the standard UT250 (0.25 inch) coaxial semi-rigid cables. Note that what is shown in Fig. 5 is the vacuum, where metal surrounds the displayed shapes. One can also see the coaxial probes used to extract the two linearly-polarized signals. These two probes are usually called “front” and “rear” probes, corresponding to their physical proximity at the back of the quad-ridged OMT. The theoretical return loss of both probes is plotted in Fig. 6, where it can be seen that a nominal -15 dB reflection coefficient is achieved. A cross-section view of the complete feed-system is shown in Fig. 7.

PERFORMANCE OF THE ANTENNA

The theoretical radiation pattern of the antenna equipped with the dual-band feed-system was simulated in order to estimate the gain and the associated antenna efficiency. The phase-centre of the feed-system is nominally located 50 mm inside the horn when measured from the aperture and the feed was adjusted for optimum performance. The results are summarized in Table 1 where it is shown that good performance is obtained in terms of antenna efficiency in both bands.

CONCLUSIONS AND ACKNOWLEDGEMENTS

We have described the design of a dual-band feed-system for the 45m-diameter reflectors of the GMRT radio telescope. The feed consists of a coaxial horn with optimized matching irises to reduce the aperture mismatch in the outer coaxial waveguide. The signals in the lower frequency band are extracted from the outer waveguide by means of four orthogonal probes and a combiner network. A new stepped quad-ridged transition is used to extract the higher frequency band from the inner waveguide. A nominal edge illumination of -12 dB is achieved in both bands while the predicted worst-case return loss is about 15 dB at the edges of the bands. Although, the final design is slightly longer than the 1.2m ideal specification, it is still suitable for the intended application.

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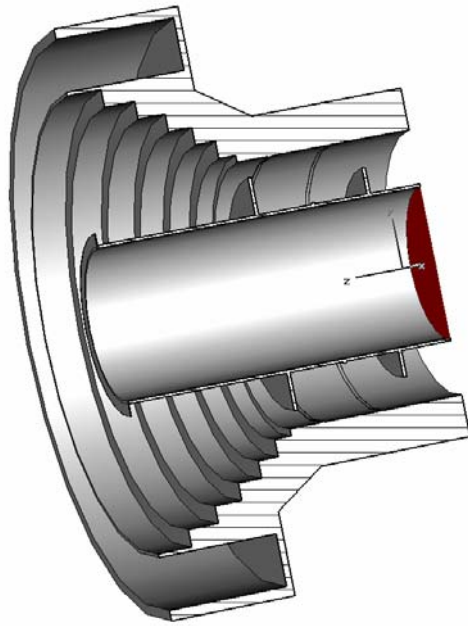


Figure 1: Cut-away view of the dual-band coaxial horn showing the matching irises for the low-frequency band.

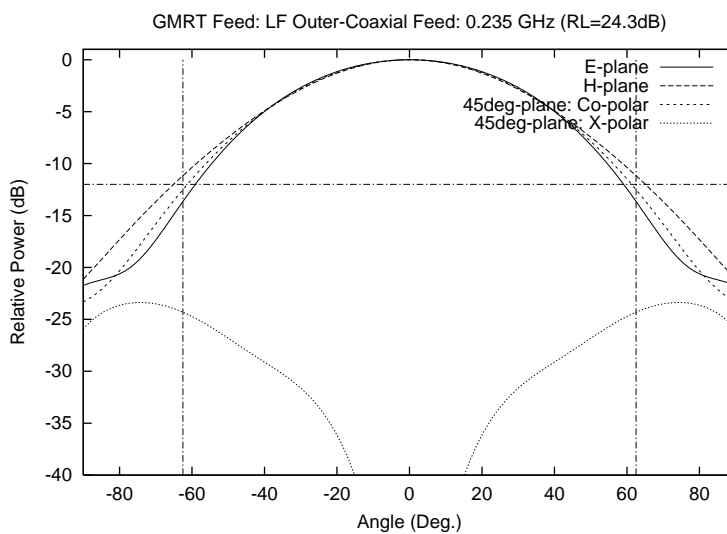


Figure 2: Computed radiation pattern of the coaxial horn at 0.230 GHz.

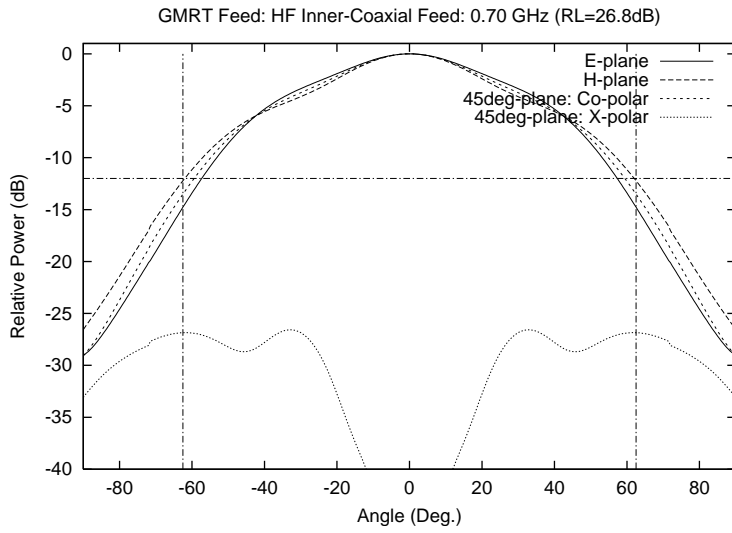


Figure 3: Computed radiation pattern of the horn at 0.700 GHz.

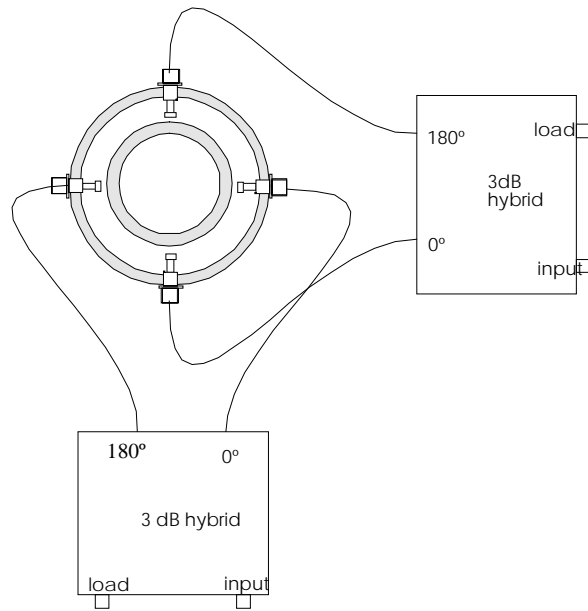


Figure 4: Coaxial junction and coaxial network for low frequency band.

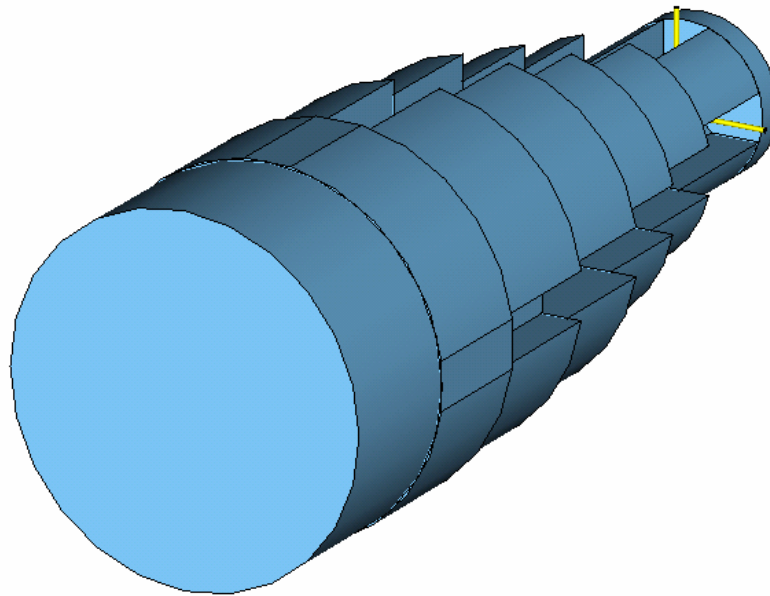


Figure 5: View of the OMT alone (note that what is displayed here is the void i.e. metal surrounds the geometry shown.).

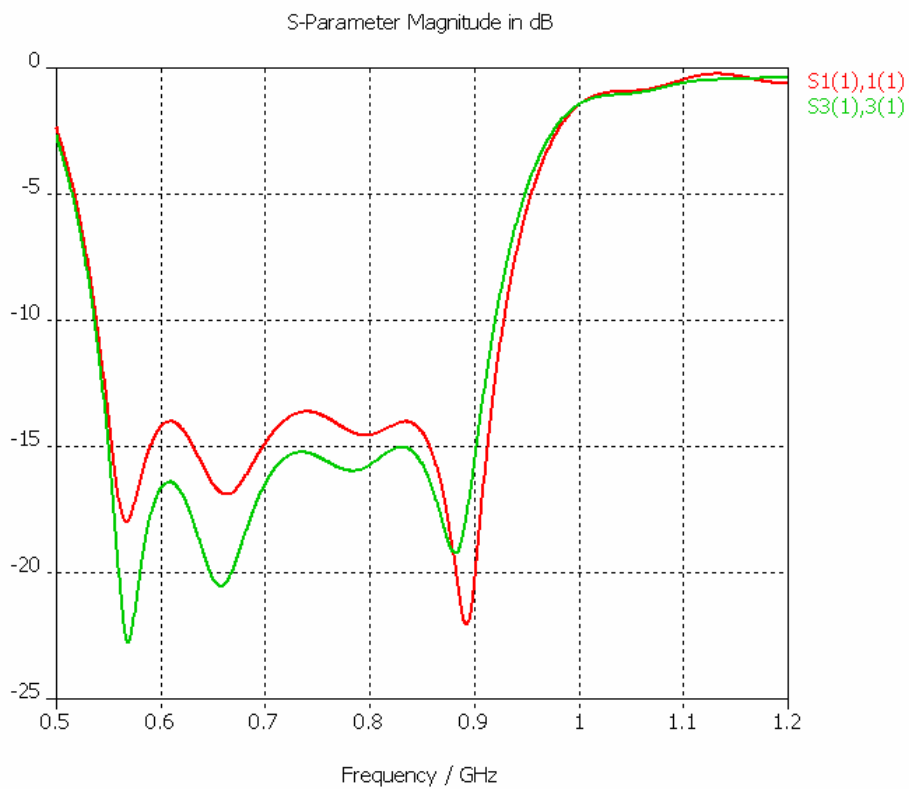


Figure 6: Return loss of front-probe (red) and rear-probe (green) of the high-frequency band OMT. (S11: Rear-probe, S33: Front-probe).

Table 1: Computed performance of the GMRT antenna with the new dual-band horn.

Frequency (GHz)	Gain (dBi)	Efficiency (%)
0.22	38.6	67.8
0.23	39.0	68.1
0.24	39.1	64.0
0.55	46.7	70.1
0.60	47.6	72.5
0.65	48.3	72.5
0.70	49.0	73.5
0.75	49.5	71.8
0.80	49.7	65.6
0.85	49.7	59.0
0.90	49.5	49.9

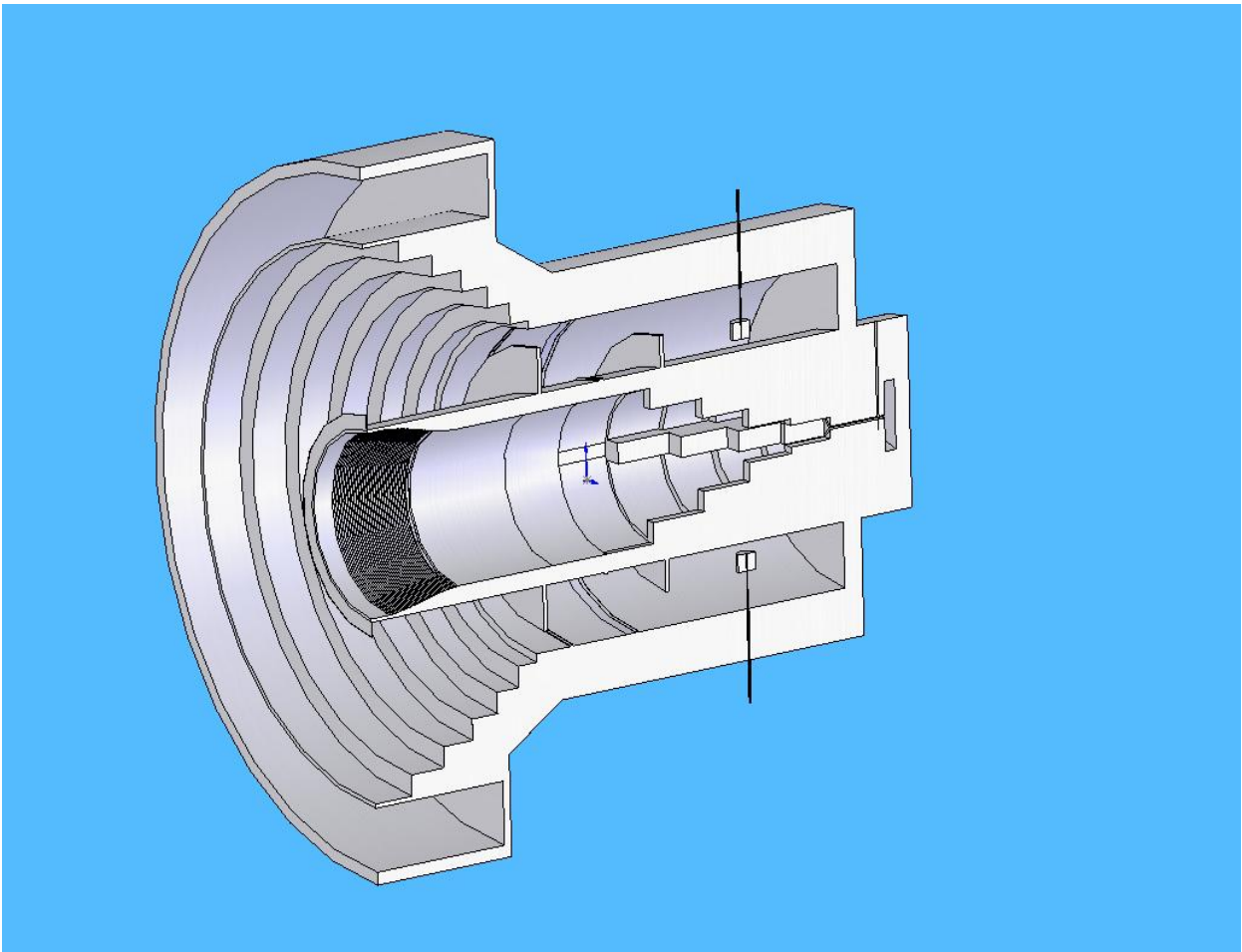


Figure 7: Cut-away view of the complete dual-band feed-system.