Design of a Prime-Focus Dual-Band Feed for the Giant Metre-wave Radio Telescope (GMRT, India): Final Report

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1. Introduction

We have designed a dual-band VHF/UHF prime focus horn for the 45m-diameter antennas of the Giant Metre-wave Radio Telescope (GMRT). The supply of the design is part of collaboration between CSIRO's Australia Telescope National Facility (ATNF) (Australia) and the National Centre for Radio Astrophysics (NCRA) (India). The GMRT is located about 80 km north of Pune (India) and consists of 30 fully steerable prime-focus parabolic reflectors of 45m diameter that are spread over distances of up to 25 km. The antennas have a focal length of 18.54m and a half subtended angle of 62.5°.

The dual-band feed system covers the frequency bands 0.22 to 0.24 GHz and 0.55 to 0.9 GHz. The scope of our work was to design the horn and the associated feed system, and calculate the theoretical performance of the GMRT antennas over these two frequency bands.

One of the main constraints in the design was compactness (strongly related to the weight) as the feed support is limited in both strength and length of the feed. We were asked to aim at designing the full length of the system to be around 1 to 1.2 metre, unfortunately, the final design is slightly longer.

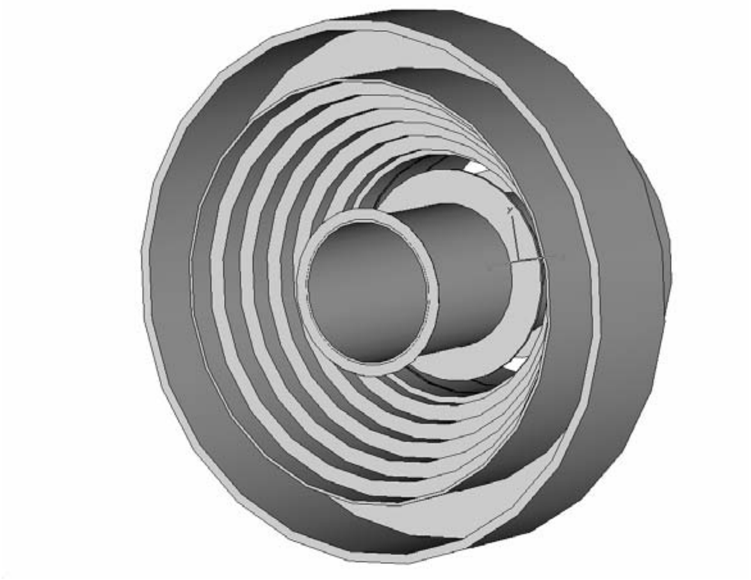
A coaxial horn arrangement was chosen because it leads to a very compact antenna. The 0.55 to 0.9 GHz band is received through the inner waveguide while the 0.22 to 0.24 GHz band is received through the outer coaxial waveguide of the horn (see Figure 1).

The preliminary design and performance of the horn were reported in [1] but have been updated and the revised design and performances are reported here. In this report, we will provide the geometry of the different components as well as some advice as to how the components should be manufactured. It was agreed, from the onset of this project, that CSIRO would only provide a design and that manufacture and testing would be handled by the NCRA. As an appendix to this report, we will supply a CD containing the relevant CAD drawings that will allow the NCRA engineers to produce the full set of engineering drawings necessary for manufacture.

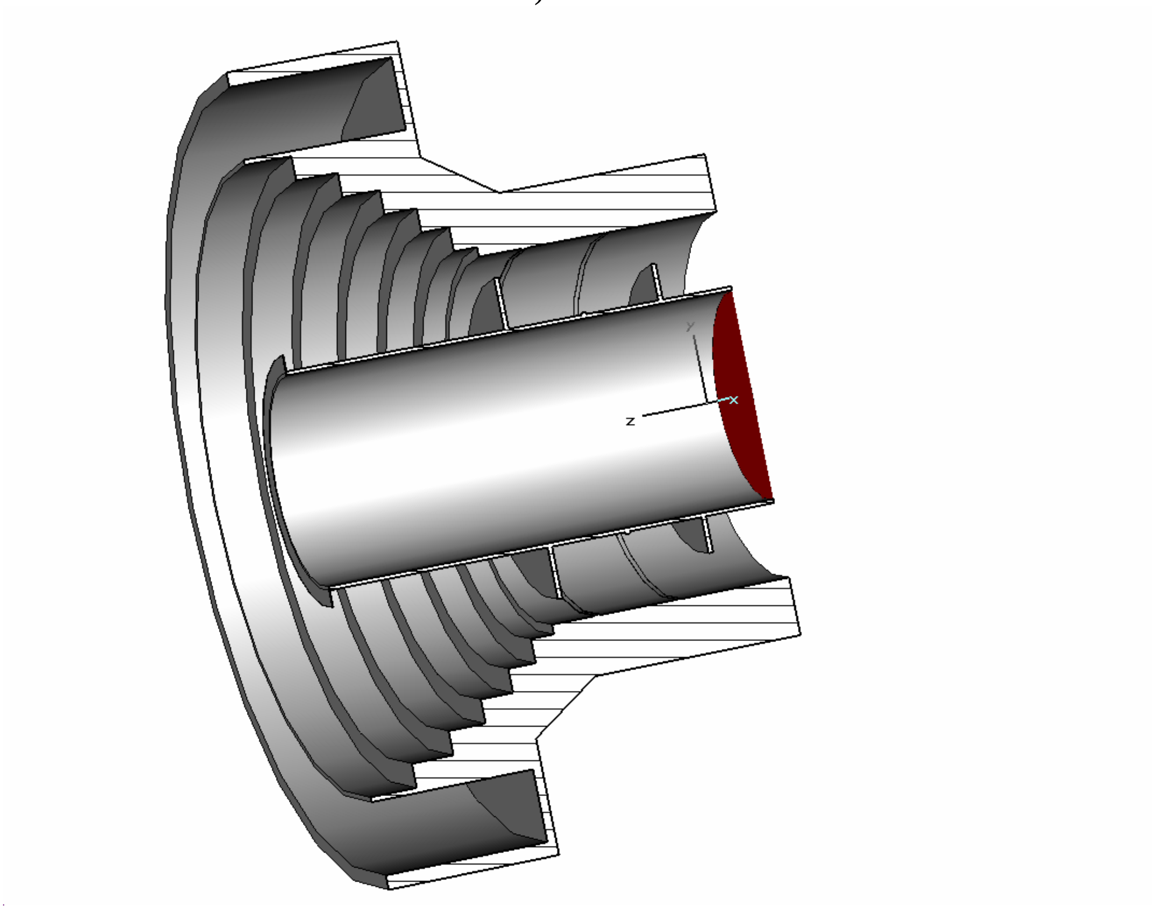
2. Horn Performance

As mentioned already, a coaxial horn arrangement was chosen because it leads to a very compact antenna. The 0.55 to 0.9 GHz band is received through the inner waveguide while the 0.22 to 0.24 GHz band is received through the outer coaxial waveguide of the horn (see Figure 1).

The horn was optimized to cover both bands effectively and provide a suitable illumination to the GMRT reflectors (-12 dB taper at 62.5°) and a good match in both frequency bands. Matching irises were required to provide a good match in the lower frequency band and this was achieved by optimization as may be seen in Figure 1 and Figure 2. The computed radiation patterns of the resulting horn design are shown in Figure 3 to Figure 7 for the 0.22-0.24 GHz band and in Figure 8 to Figure 15 for the 0.55-0.9 GHz band.



a)



b)

Figure 1: a) Full view and b) cut-away view of the dual-band coaxial horn showing the matching irises for the low-frequency band.

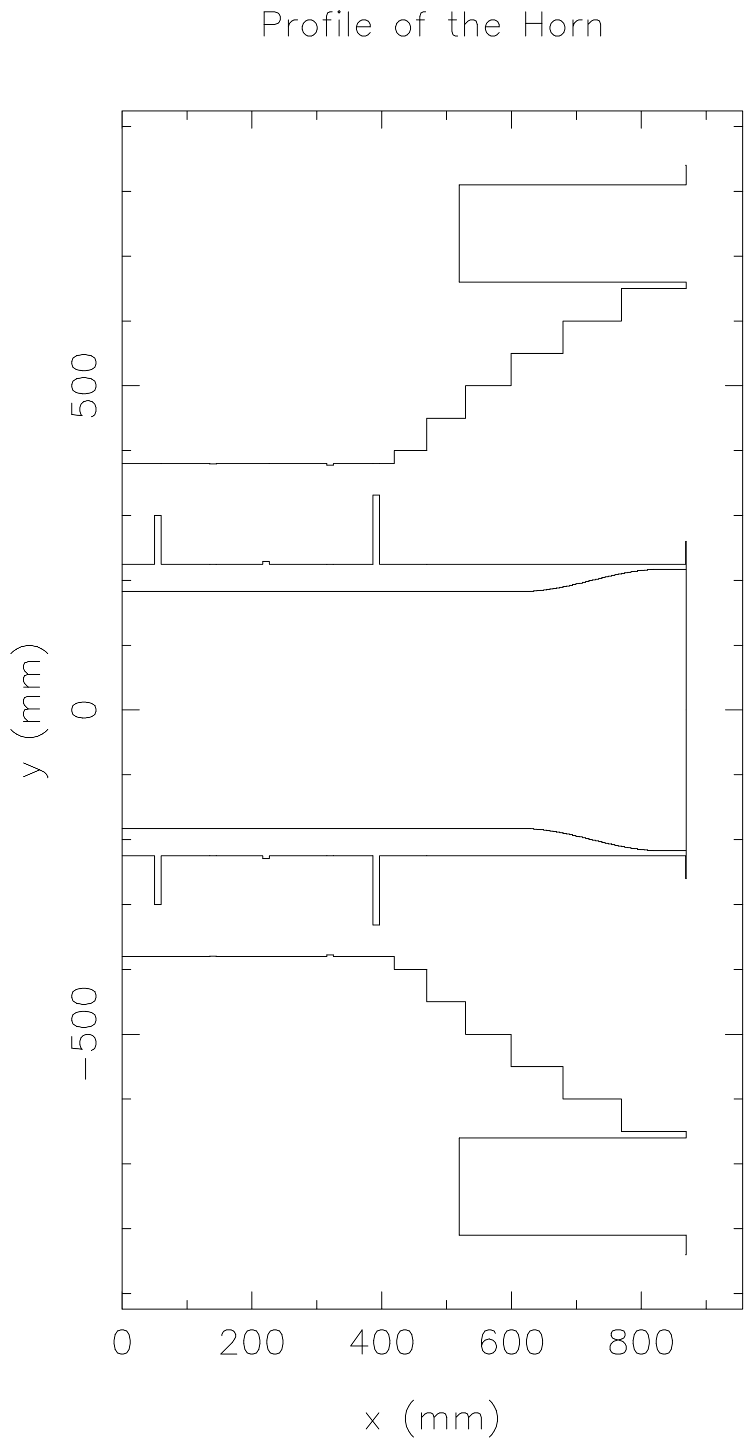


Figure 2: Detailed drawing of the horn.

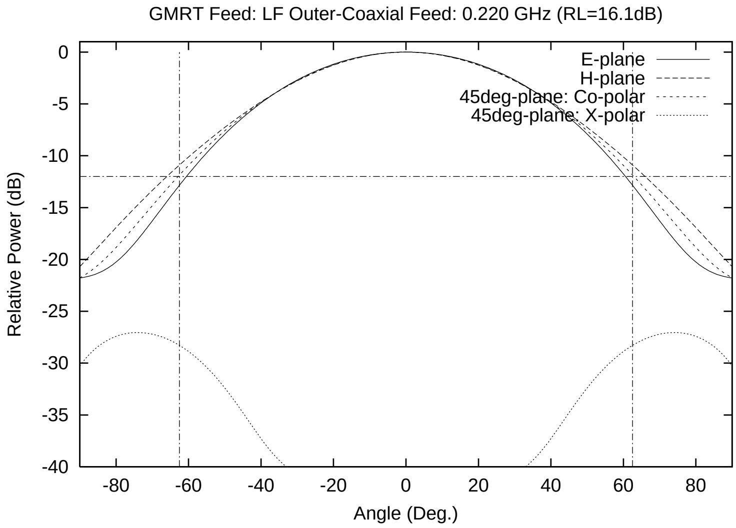


Figure 3: Radiation pattern of the horn at 0.220 GHz.

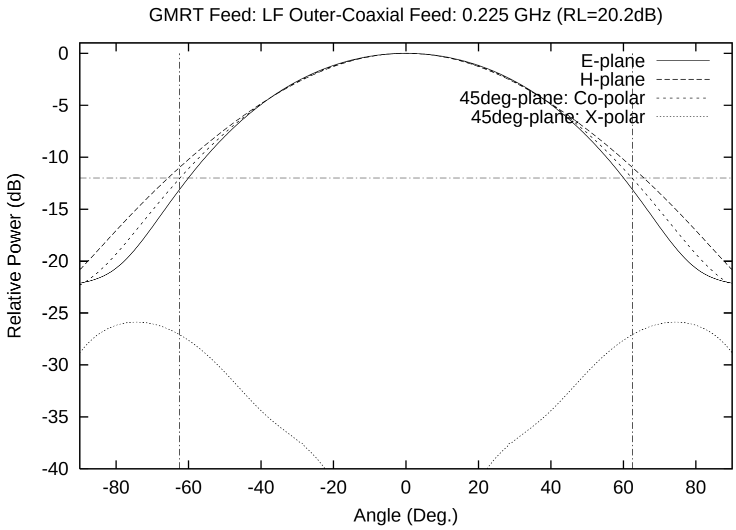


Figure 4: Radiation pattern of the horn at 0.225 GHz.

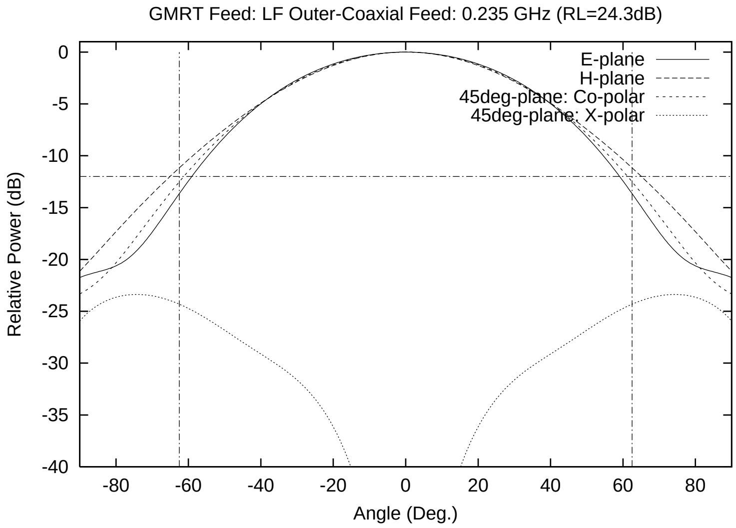


Figure 5: Radiation pattern of the horn at 0.230 GHz.

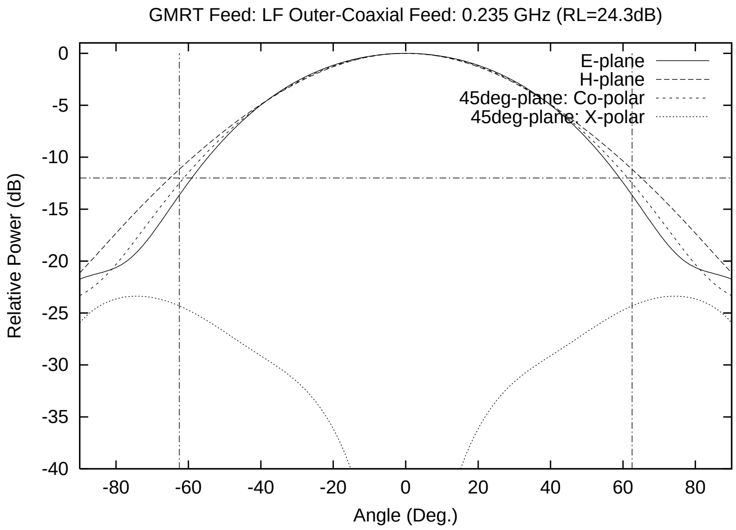


Figure 6: Radiation pattern of the horn at 0.235 GHz.

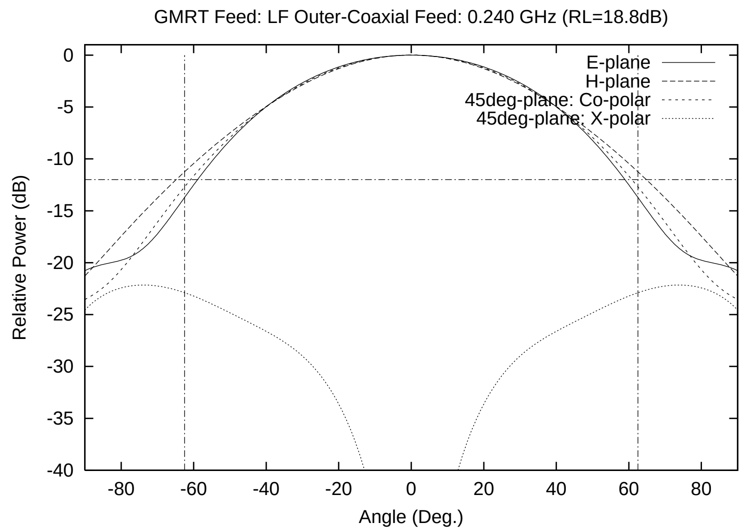


Figure 7: Radiation pattern of the horn at 0.240 GHz.

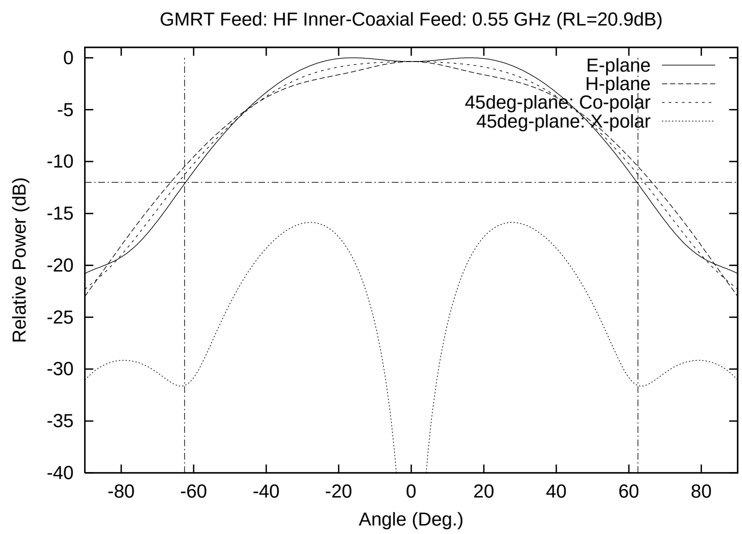


Figure 8: Radiation pattern of the horn at 0.550 GHz.

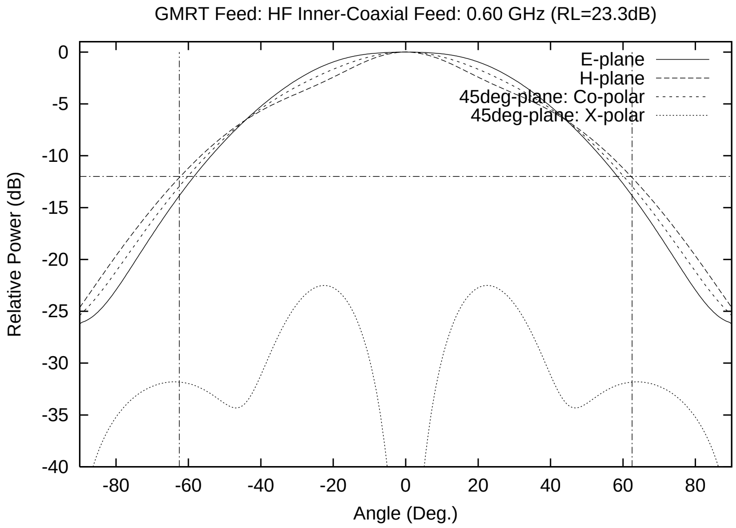


Figure 9: Radiation pattern of the horn at 0.600 GHz.

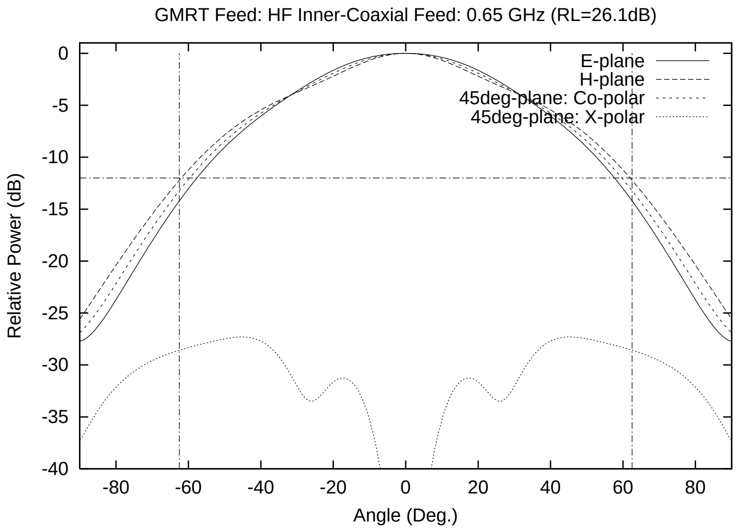


Figure 10: Radiation pattern of the horn at 0.650 GHz.

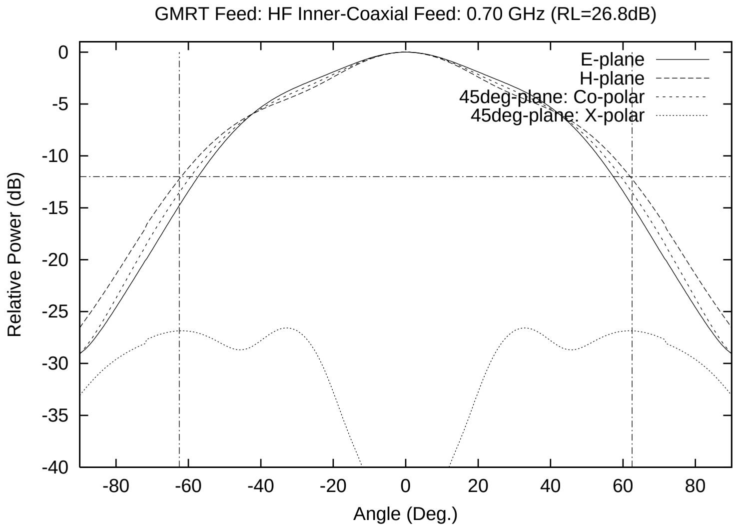


Figure 11: Radiation pattern of the horn at 0.700 GHz.

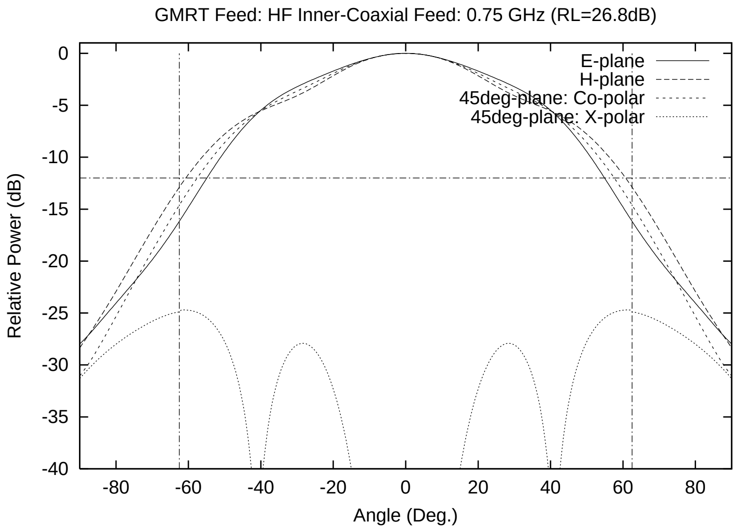


Figure 12: Radiation pattern of the horn at 0.750 GHz.

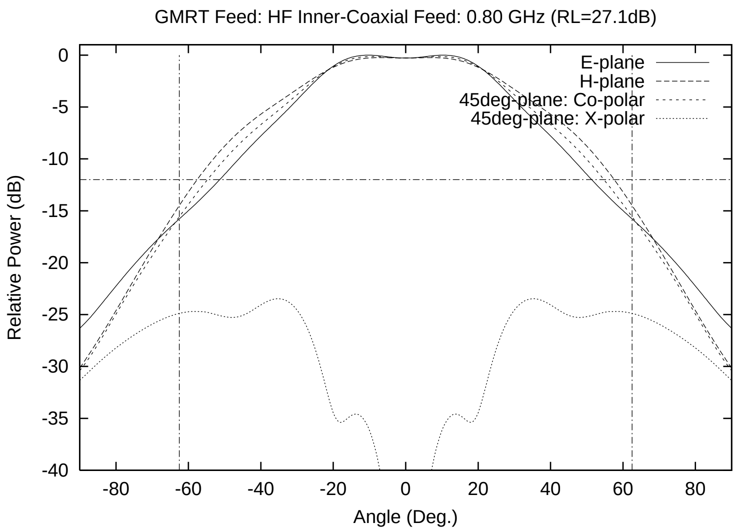


Figure 13: Radiation pattern of the horn at 0.800 GHz.

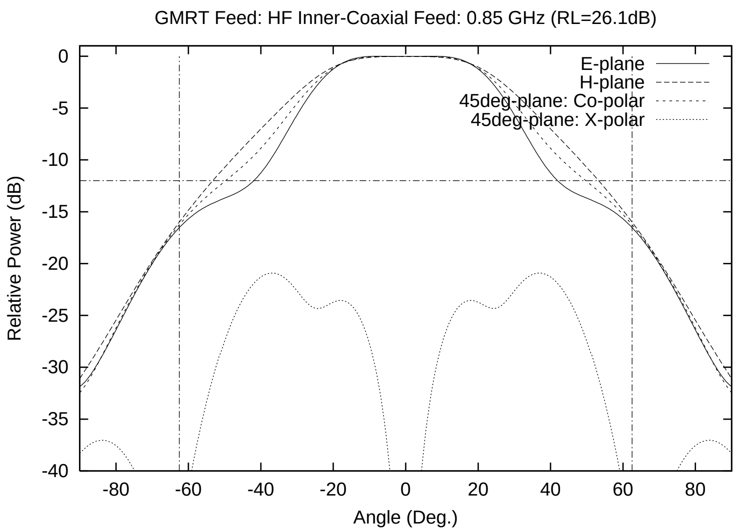


Figure 14: Radiation pattern of the horn at 0.850 GHz.

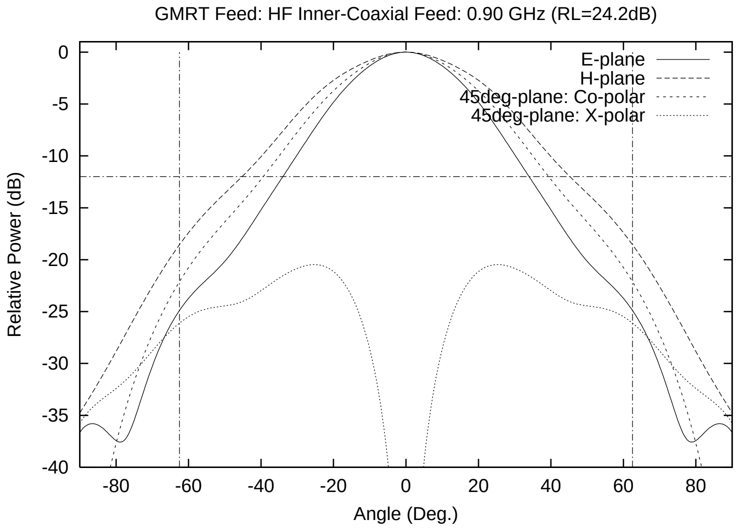


Figure 15: Radiation pattern of the horn at 0.900 GHz.

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 ports.

The 0.22-0.24 GHz band is extracted from the coaxial waveguide using four orthogonal probes and requires a pair of 3dB hybrids and four phased matched cables to combine the ports combiner network (see Figure 16). This technique has been shown to work well in the past and has been successfully used recently in a similar project [2]. The actual probe dimensions and their positions are shown in Figure 17.

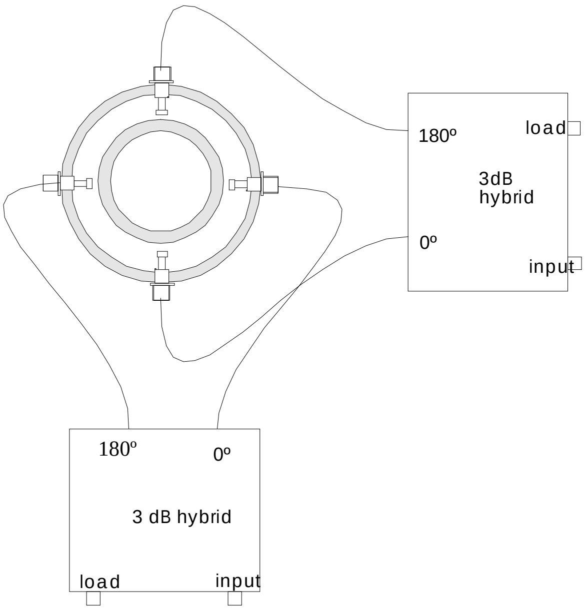


Figure 16: Coaxial junction and coaxial network

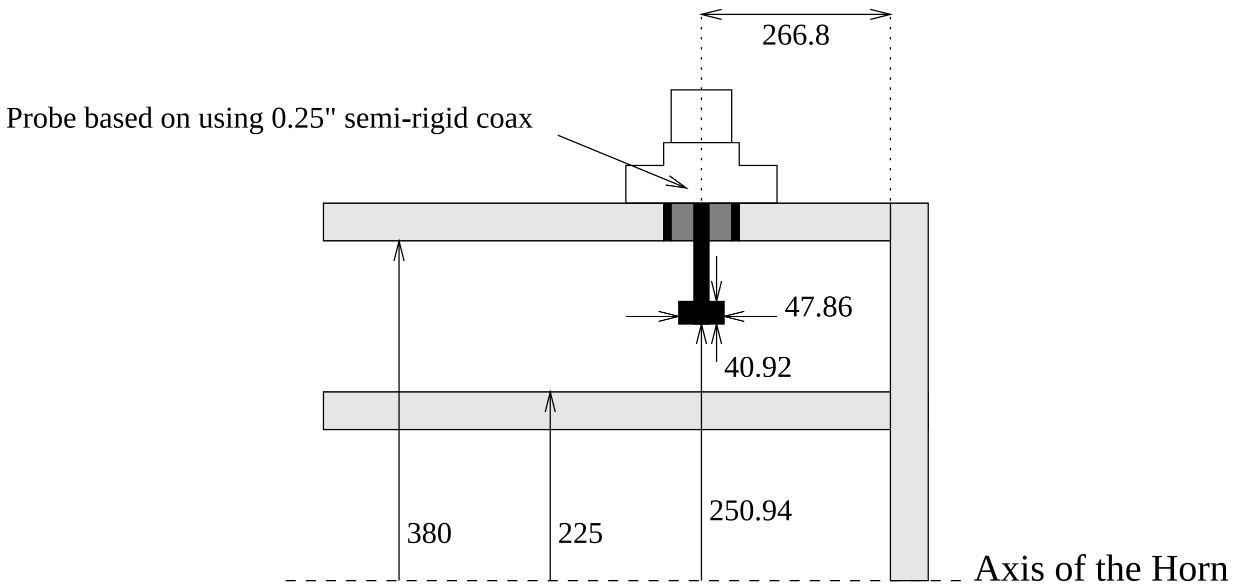


Figure 17: Location and probe dimensions for 0.22-0.24GHz section (dimensions in mm).

The spacing between the probe and the first matching iris of the coaxial part of the horn should be made as long as physically possible within the length constraints. It would be better to try to keep that distance around 200mm or so if possible. Some experiment might be necessary.

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 almost 65%, a wideband transition such as a quad-ridged orthomode transducer (OMT) was considered. However, the conventional design of quad-ridged OMTs uses a very effective but also very long (in terms of wavelength) taper from the input to the output probes. It was estimated that scaling an existing design would lead to a feed-system 3 to 4 m long, which is unacceptable for this application.

We decided to try to reduce the length of the transition using a stepped transformer [3] instead of the conventional smooth profile of the OMT fins. A significant effort was then directed towards optimising such a short OMT to cover the required band. Preliminary results show 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 Figure 18. It includes the two necessary coaxial connections which use the standard UT250 (0.25 inches) coaxial semi-rigid cables. Note that what is shown in this figure is the void, 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 to the back of the quad-ridged OMT. The theoretical return-loss of both probes is plotted in Figure 19 where it can be seen that a nominal -15 dB reflection coefficient is achieved.

Further 3-D models of the quad-ridged OMT are shown in Figure 20 and Figure 21. The dimensions of the quad-ridged OMT are given in Figure 22, Figure 23 and Table 1.

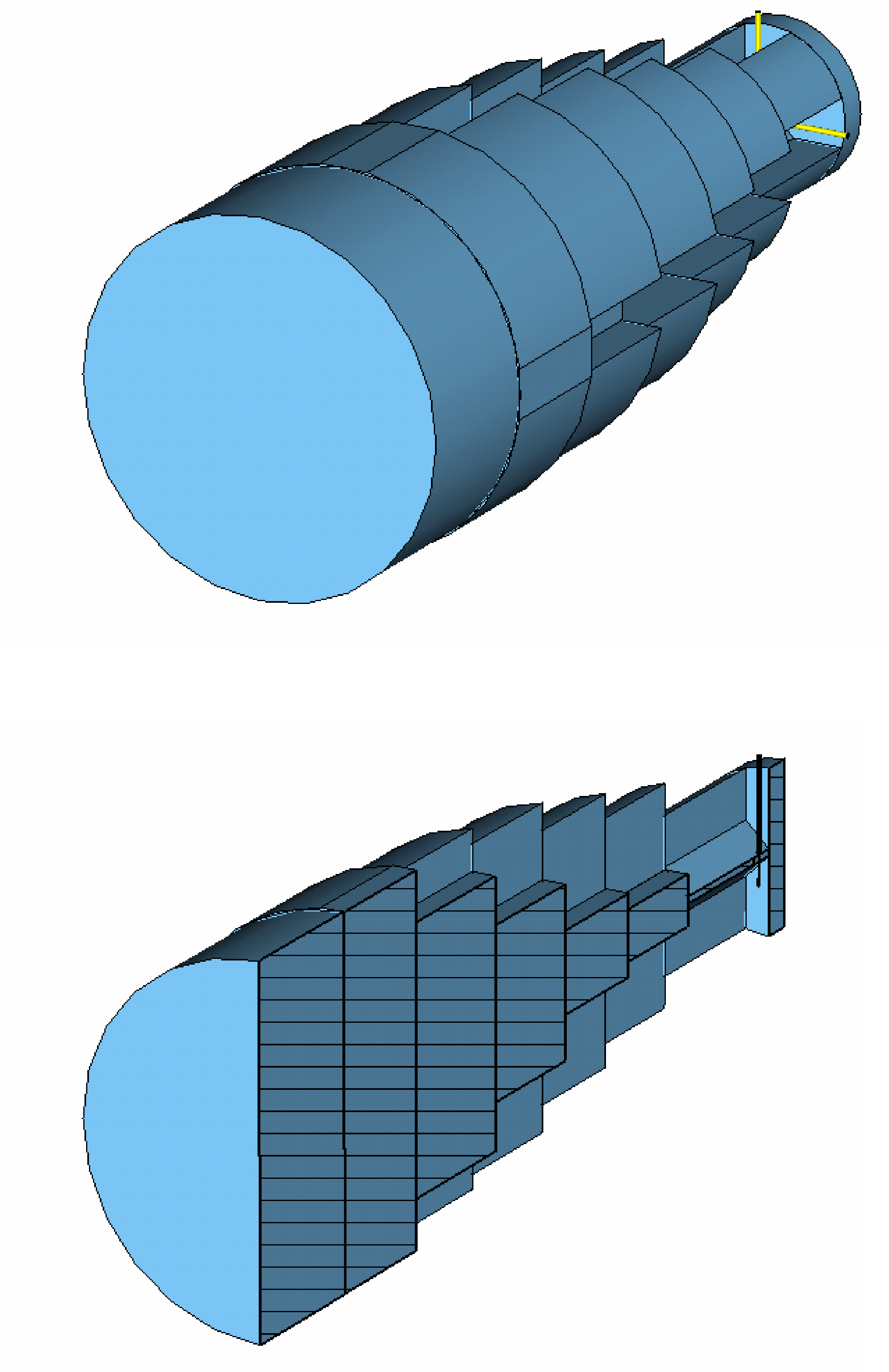


Figure 18: Geometry of the OMT. Note that what is displayed here is the void i.e. metal surrounds the geometry shown.

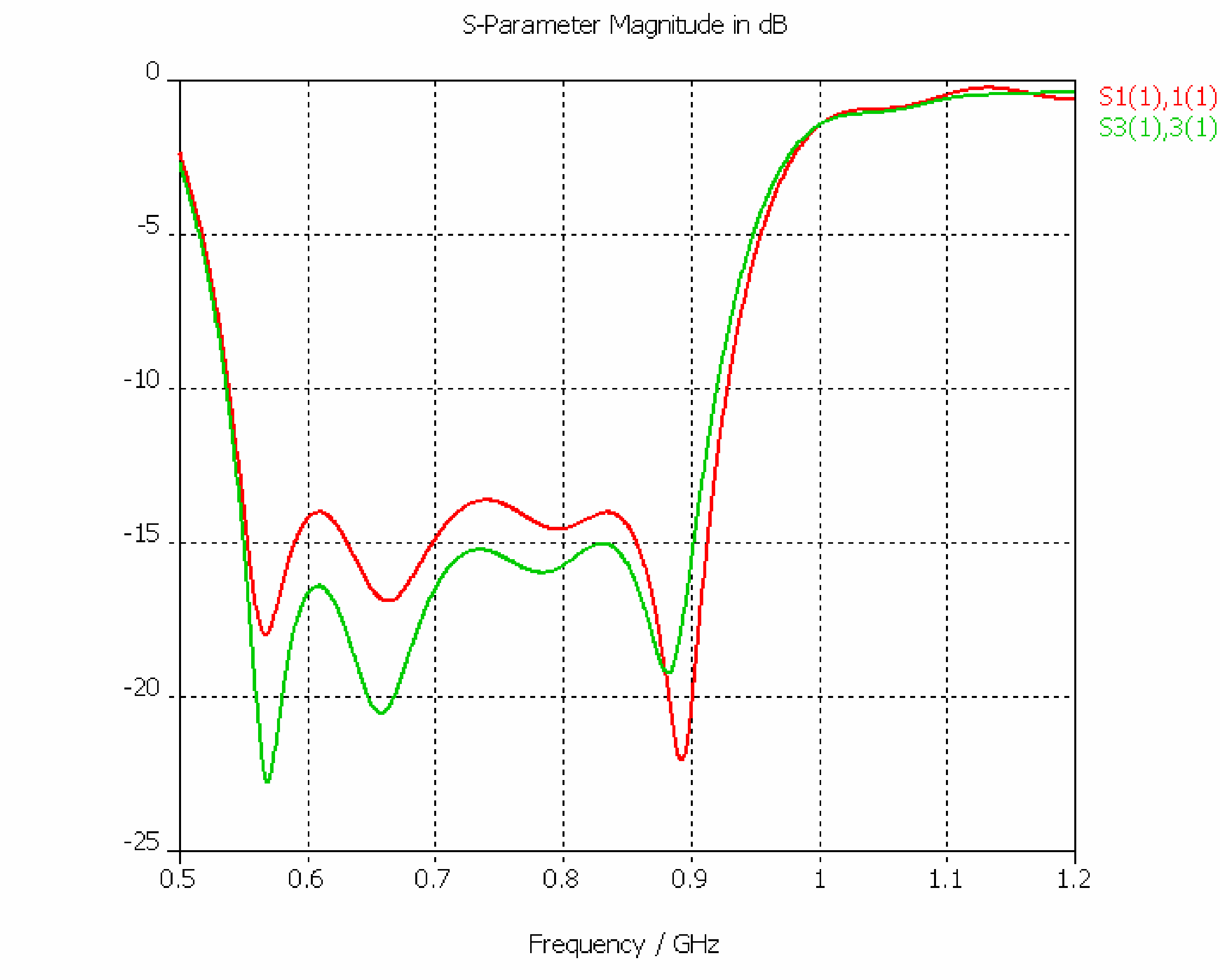
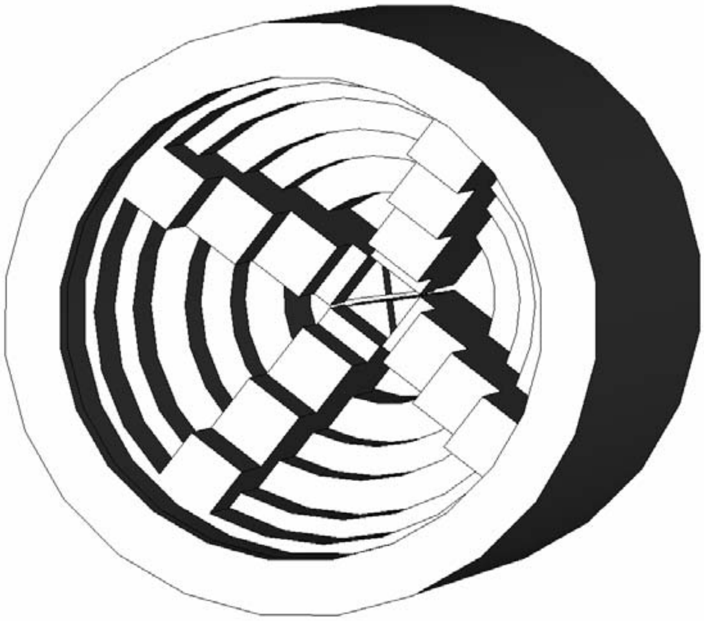
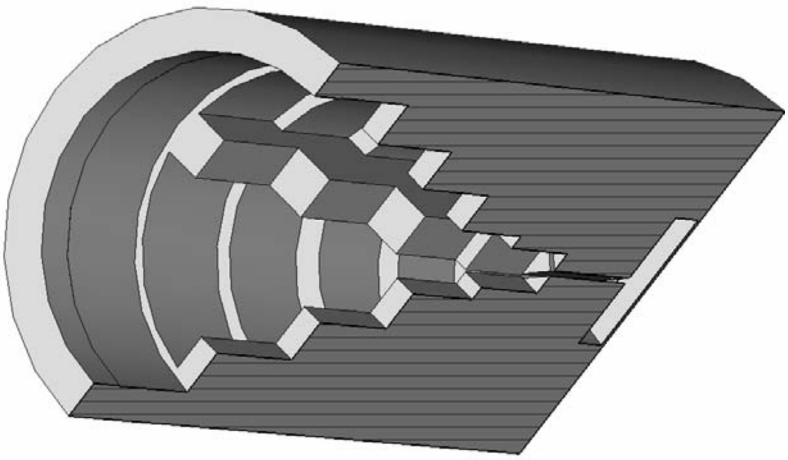


Figure 19: Return loss of front-probe (red) and rear-probe (green) of the 0.55 to 0.9 GHz OMT. (S11: Rear-probe, S33: Front-probe).



a)



b)

Figure 20: a) full view and b) cut-out view of the OMT.

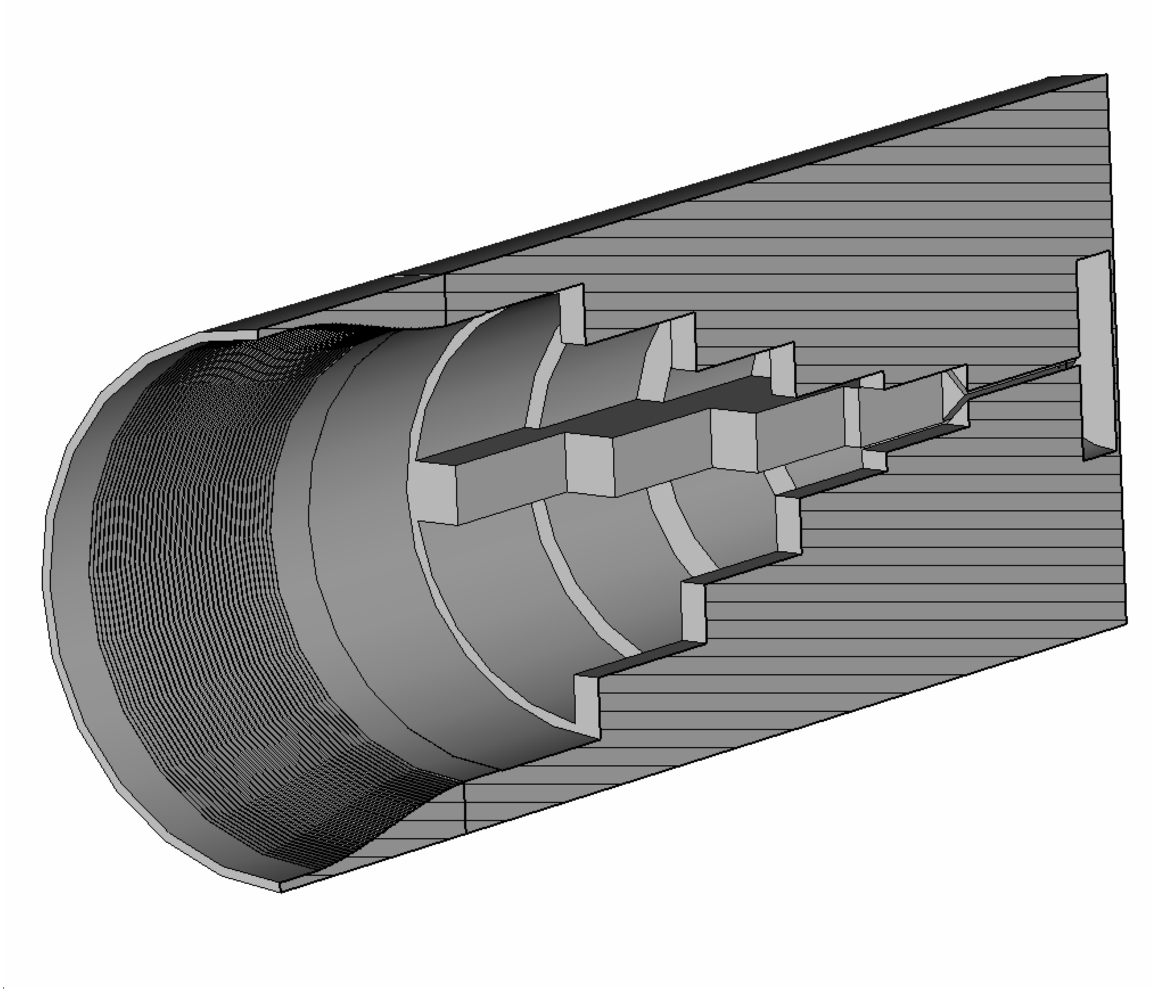
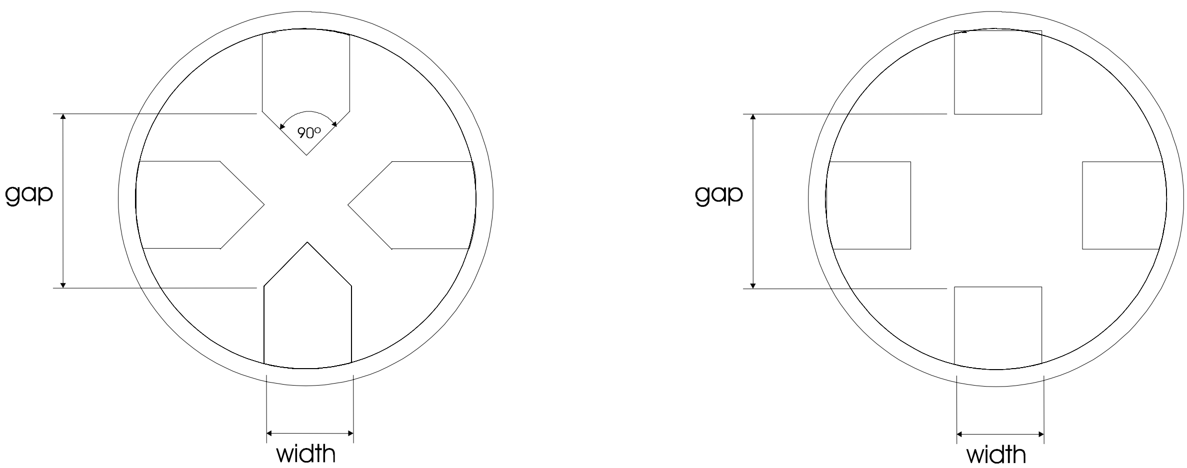


Figure 21: Cut-out view of the 0.22-0.24 GHz horn with OMT.



(a) (b)

Figure 22: Quad-ridged OMT cross-sections:

(a) Pointed ridge section (section 7 in Figure 23),

(b) Standard ridged guide.

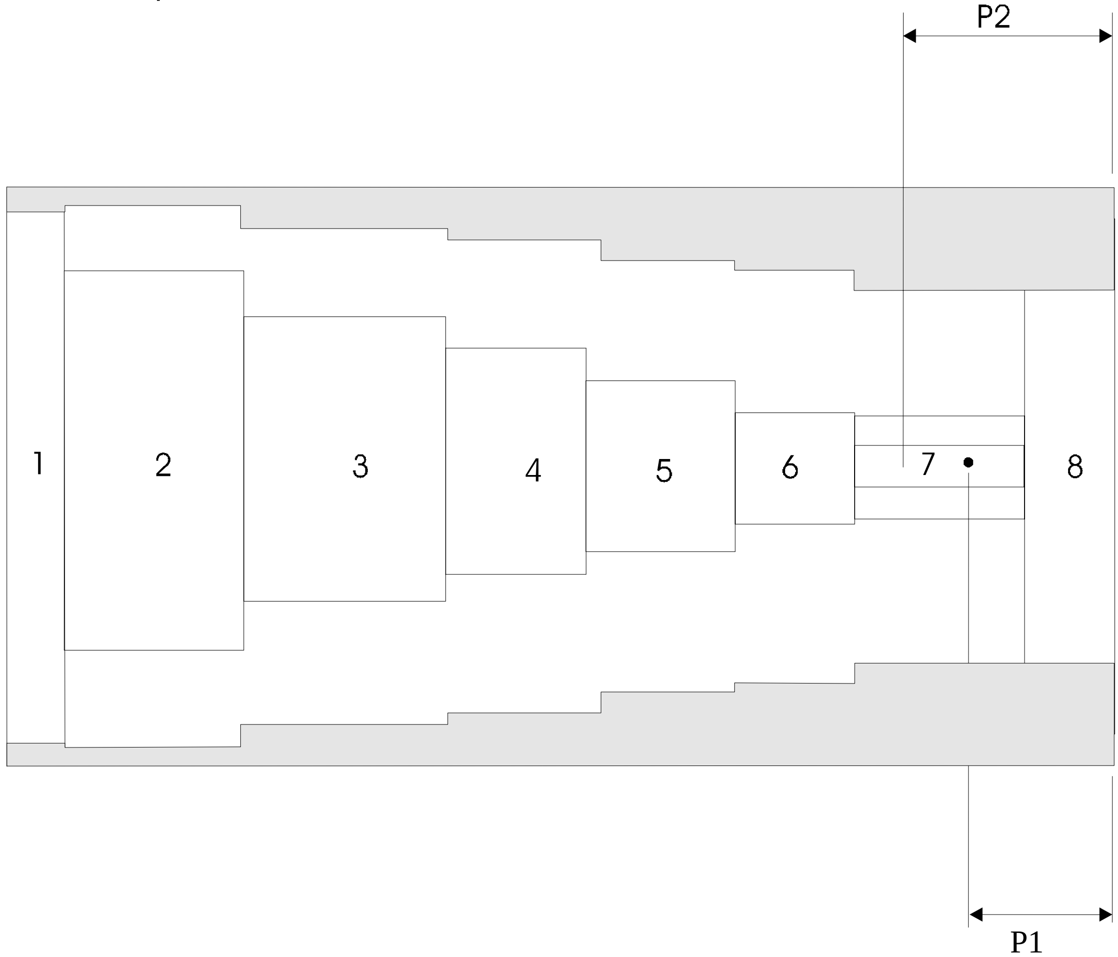


Figure 23: Quad ridged OMT length.

Table 1: Quad-ridged OMT dimensions.

Section No	type	Length (mm)	Radius (mm)	Ridge gap (mm)	Ridge width (mm)
1	Circular waveguide	>20	183.000	n/a	n/a
2	Standard ridged waveguide	128.608	183.928	182.325	48.436
3		141.644	175.380	132.560	48.436
4		126.294	161.121	85.219	48.436
5		115.220	134.887	40.662	48.436
6		108.205	111.990	25.443	48.436
7	Pointed ridged waveguide	150	81.993	27.646	48.436
8	Circular waveguide	29.254	81.993	n/a	n/a
P1	Position probe 1	47.400	n/a	n/a	n/a
P2	Position probe 2	57.254	n/a	n/a	n/a

4. Performance of the Antenna

The radiation pattern of the antenna was simulated in order to estimate the gain and the associated efficiency [1]. The phase-centre of the feed system is assumed to be 50 mm inside the horn when measured from the aperture (i.e., the focus of the GMRT antenna has to be located 50mm inside the horn along the axis of the horn). The results are summarized in Table 2.

Table 2: 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**

5. Mechanical Design

The feed system consists basically of three main components:

- A coaxial feed horn Figure 2 and Appendix A.
- A quad-ridged orthomode transducer to extract the 0.55 – 0.9 GHz frequency band.
- A four-probe feed system to extract the 0.22 – 0.24 GHz frequency band.

To achieve an acceptable length the Quadridged OMT must fit within the outer coaxial section as shown in Figure 24.

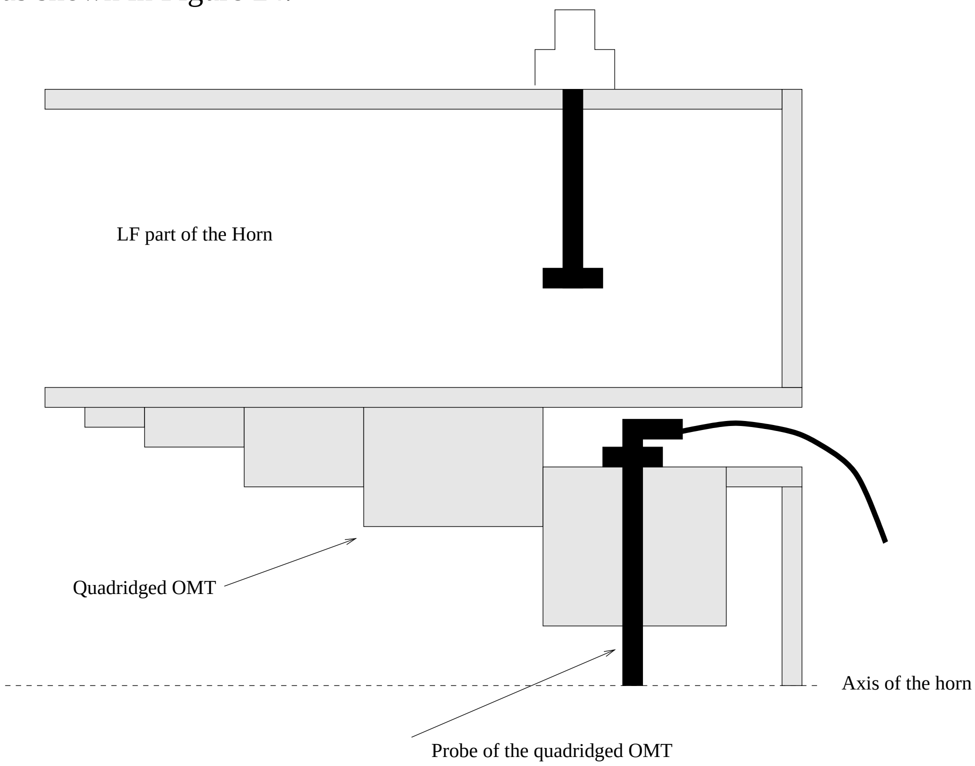


Figure 24: Layout of the 0.55-0.9 GHz quadridged OMT section showing the position of the coupling probes in the inner and outer sections

6. Conclusions

We have described the design of a dual-band feed for the 45m reflectors in the GMRT radio telescope. The feed consists of a coaxial horn with optimised 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 stepped quad-ridged transition is used to extract the higher frequency band from the inner waveguide. A nominal edge illumination of –12dB is achieved in both bands and the worst-case return loss is about 15 dB at the edges of the bands.

A disk containing a .sat file of the feed system is supplied with this report (see Appendix B).

References

[1] Granet C., Bird T.S., Davis I.M., "Design of a prime-focus dual-band feed for the Giant Metre-wave Radio Telescope (GMRT, India): Progress report No 1", CSIRO ICT Centre, PO box 76, Epping 1710 NSW, Australia. Report ICT 05/052, 21 Feb. 2005.

[2] C. Granet, H.Z. Zhang, A.R. Forsyth, G.R. Graves, P. Doherty, K.J. Greene, G.L. James, P. Sykes, T.S. Bird, M.W. Sinclair, G. Moorey, R.N. Manchester, "Design, manufacture and test of a dual-band feed system for the Parkes radio telescope", Accepted: To be published by the IEEE Antennas & Propagation Magazine, April 2005.

[3] S. Hopfer, "The design of ridged waveguides", IEEE Transactions on Microwave Theory and Techniques, Vol. 3, Issue 5, Oct. 1955, pp. 20-29

Appendix A: Geometry of the coaxial horn

The points necessary to draw the geometry of the coaxial feed horns are printed here for reference, but a file called GMRT_coaxial_horn.dwg is supplied in the accompanying CD.

```
To draw the outer part:
    0.000  380.000
   50.000  380.000
   50.000  380.000
   60.000  380.000
   60.000  380.000
  134.970  380.000
  134.970  379.480
  144.970  379.480
  144.970  380.000
  216.880  380.000
  216.880  380.000
  226.880  380.000
  226.880  380.000
  315.350  380.000
  315.350  377.880
  325.350  377.880
  325.350  380.000
  386.540  380.000
  386.540  380.000
  396.540  380.000
  396.540  380.000
  419.350  380.000
  419.350  400.000
  469.350  400.000
  469.350  450.000
  529.350  450.000
  529.350  500.000
  599.350  500.000
  599.350  550.000
  679.350  550.000
  679.350  600.000
  769.350  600.000
  769.350  650.000
  868.350  650.000
  868.350  650.000
  869.350  650.000
  869.350  660.000
  519.350  660.000
  519.350  810.000
  869.350  810.000
  869.350  840.000
  500.350  840.000
  500.350  600.000
  350.350  500.000
   0.000  500.000
   0.000  380.000

To draw the inner-part:
   0.    225.000
     50.0000    225.000
     50.0000    300.000
     60.0000    300.000
     60.0000    225.000
     134.970    225.000
     134.970    225.000
     144.970    225.000
     144.970    225.000
     216.880    225.000
```

216.880	229.100
226.880	229.100
226.880	225.000
315.350	225.000
315.350	225.000
325.350	225.000
325.350	225.000
386.540	225.000
386.540	331.580
396.540	331.580
396.540	225.000
419.350	225.000
419.350	225.000
469.350	225.000
469.350	225.000
529.350	225.000
529.350	225.000
599.350	225.000
599.350	225.000
679.350	225.000
679.350	225.000
769.350	225.000
769.350	225.000
868.350	225.000
868.350	260.000
869.350	260.000
869.350	217.000
819.350	217.000
819.350	216.700
814.350	216.700
814.350	216.320
809.350	216.320
809.350	215.870
804.350	215.870
804.350	215.340
799.350	215.340
799.350	214.740
794.350	214.070
789.350	214.070
789.350	213.330
784.350	213.330
784.350	212.520
779.350	212.520
779.350	211.650
774.350	211.650
774.350	210.730
769.350	210.730
769.350	209.750
764.350	209.750
764.350	208.720
759.350	208.720
759.350	207.650
754.350	207.650
754.350	206.540
749.350	206.540
749.350	205.400
744.350	205.400
744.350	204.230
739.350	204.230
739.350	203.030
734.350	203.030
734.350	201.830
729.350	201.830
729.350	200.610
724.350	200.610
724.350	199.390

```
  719.350    199.390
  719.350    198.170
  714.350    198.170
  714.350    196.970
  709.350    196.970
  709.350    195.770
  704.350    195.770
  704.350    194.600
  699.350    194.600
  699.350    193.460
  694.350    193.460
  694.350    192.350
  689.350    192.350
  689.350    191.280
  684.350    191.280
  684.350    190.250
  679.350    190.250
  679.350    189.270
  674.350    189.270
  674.350    188.350
  669.350    188.350
  669.350    187.480
  664.350    187.480
  664.350    186.670
  659.350    186.670
  659.350    185.930
  654.350    185.930
  654.350    185.260
  649.350    185.260
  649.350    184.660
  644.350    184.660
  644.350    184.130
  639.350    184.130
  639.350    183.680
  634.350    183.680
  634.350    183.300
  629.350    183.300
  629.350    183.000
0.    183.000
0.    225.000
```

Appendix B: Geometry of the feed system

The geometry of the feed system in a *.sat* format is provided in the accompanying disk.

The geometry is accurate, but there are some non critical dimensions, like the thicknesses of the walls, that are left to the GMRT to modify to suit their manufacturing technique. Also, the quadridged OMT has been placed so that the probes are easily accessible, but if the design happens to be too long, a mechanical arrangement like the one presented in Figure 24 could be considered.

Views of the geometry are shown below in Figure 25 and Figure 26.

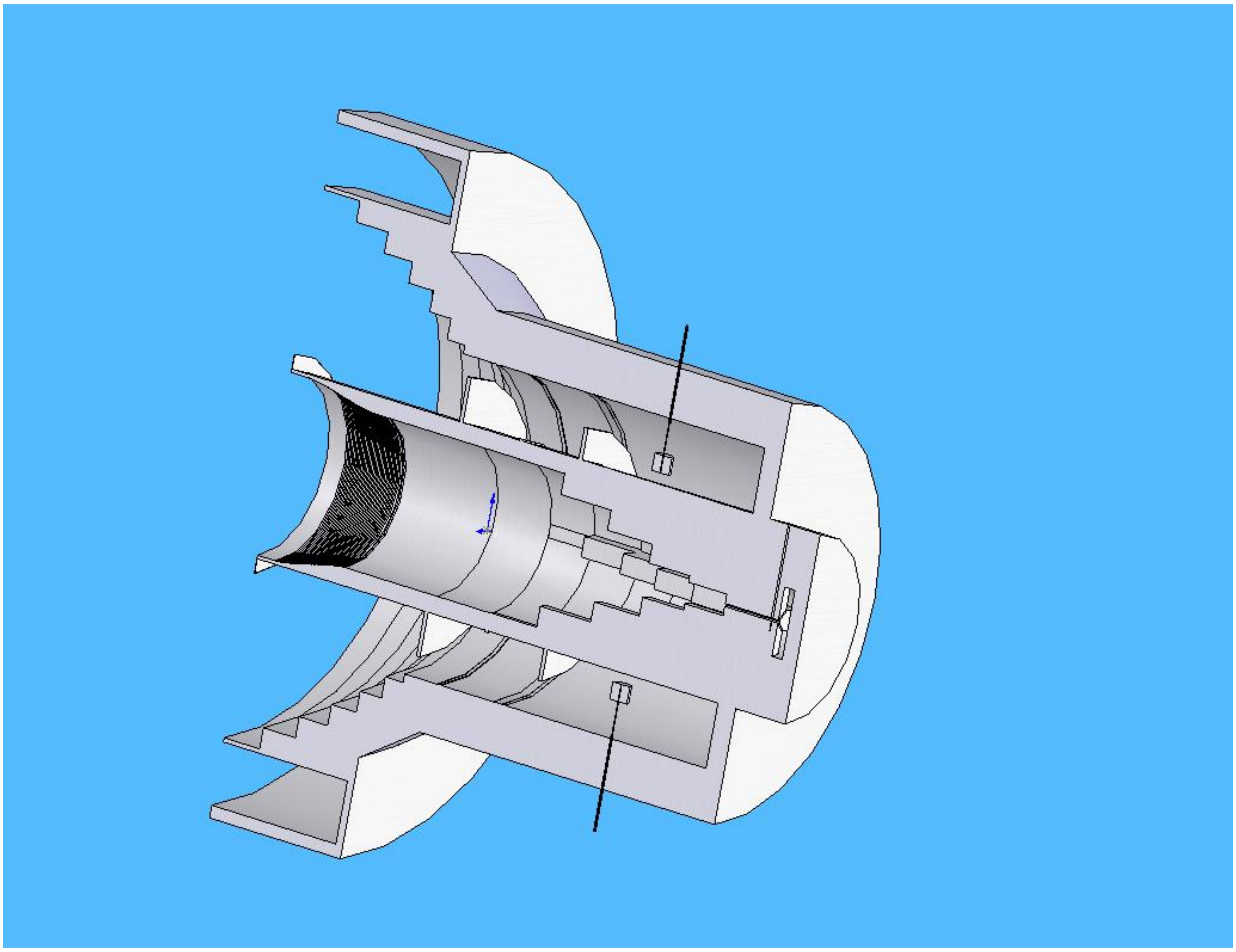


Figure 25: Cut-out view of the feed system.

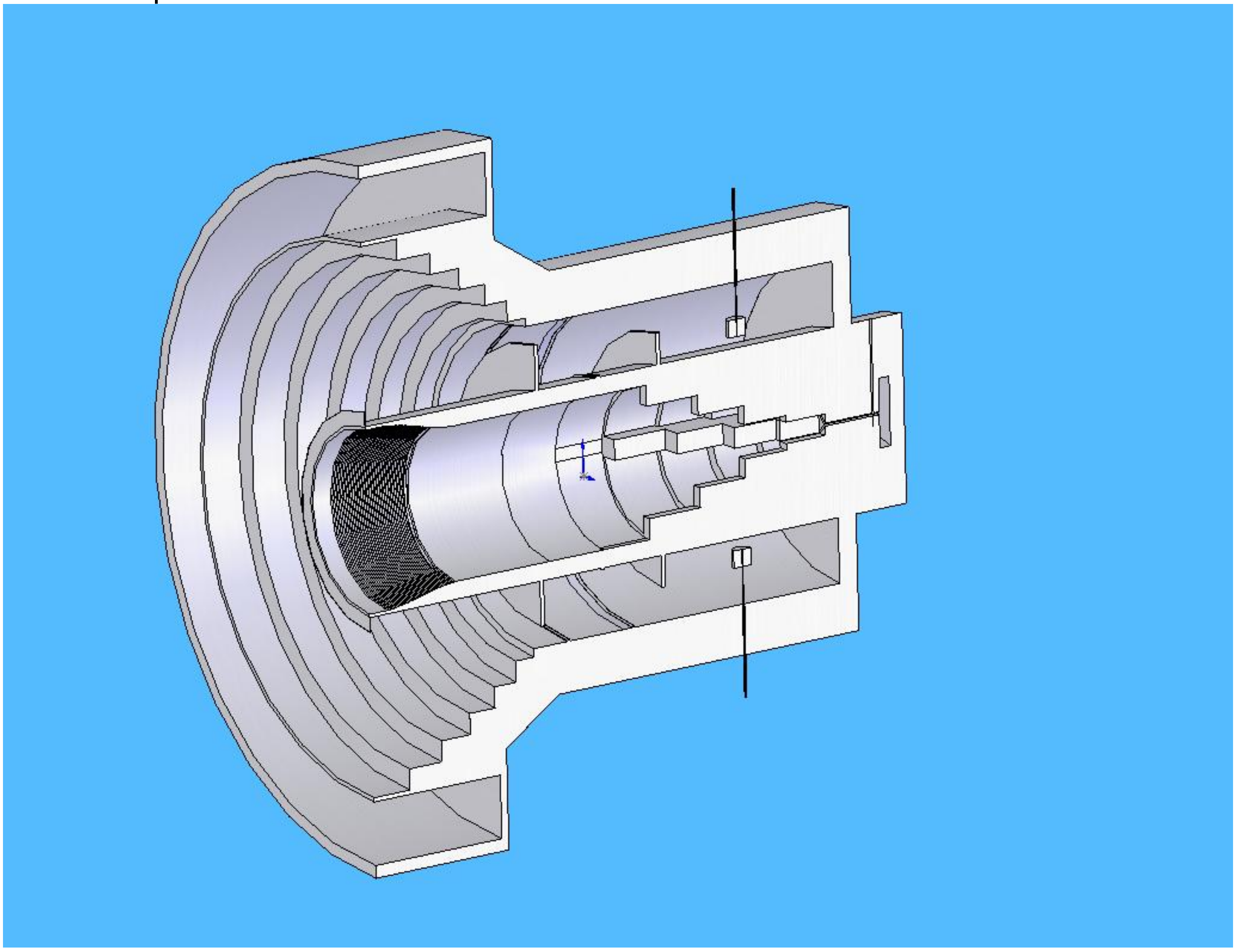


Figure 26: Cut-out view of the feed system.

