Multi Octave Prime focus Feeds for a Paraboloid Reflector

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1. Introduction

A paraboloid reflector is inherently capable of operating over several decades in frequency, with low frequency limitation coming from its sheer physical size and high frequency limitation from the accuracy of the surface profile. Normally, the range of frequency supported by the paraboloid reflector is far greater, than can be provided by any feed. However it is highly desirable in general, to have a single feed assembly which can be used for multifrequency observations using a radio telescope. The greatest advantage that lies in going for a broad band feed is a significant reduction in the number of receiver systems required for observing various frequencies. In an attempt to design a broadband feed, we have investigated two types of feeds – i) Quad-ridged horn ii) Non planar tooth trapezoidal structure, both belonging to the class of multi-octave antennas.

2. Quad-ridged horn

Our main objective is to design a dual linearly polarized quad-ridged horn which can be used as a prime focus feed for the 12m prestressed parabolic dish (PPD) being built at the Raman Research Institute, Bangalore. The dish is expected to operate over the frequency range of 0.5 – 8 GHz. The frequency range of this dish will be covered using three receiver systems – one operating in the prime focus mode (0.5 – 1.5 GHz) and two (2 – 4 GHz and 4 – 8 GHz) in the cassegrain mode. The quad-ridged horn has been designed for the prime focus operation for the following electrical specifications – i) Bandwidth of operation: 0.5 – 1.5 GHz, ii) Input return loss : < –15 dB , iii) Sidelobe level less than –20 dB, iv) Cross polar coupling less than –20 dB and v) Symmetrical E & H plane patterns. The novelty in our design has been the use of sine square profile for the ridges in the flared section for achieving a broad band performance.

The diameter of the input waveguide section is chosen in such a way that it is equal to 0.58 times the wavelength corresponding to the cut-off frequency (400 MHz) which is slightly less than the minimum operating frequency. The aperture is maintained at 0.75 times the maximum operating wavelength. The length of the input wave guide section is kept at a fraction of the wavelength at the lowest frequency of operation. Based on the extensive study made by J K Shimizu, Stanford Research Institute [1], on the effect of the ridge thickness and height on the maximum useable bandwidth of the horn, we have chosen the ridge dimensions to achieve 2 to 3 octaves of bandwidth. We find in literature [2] the use of sine square profile for maintaining the cut off frequency in waveguides of varying cross section for broad band operation. We have extended the same technique to the ridge horn by giving a sine square profile for the ridges in the flared section. A conical backshort has been used to terminate the input waveguide section. A short circuited probe is used to excite the input waveguide.

2.1 Simulation using CAD Package

The performance of the ridge horn structure was simulated in a computer using CST microwave CAD package. Various antenna parameters like diameter of the input waveguide, ridge dimensions, profile of the ridge, the length of the input wave guide section and the aperture diameter were optimized to get the best performance over the specified bandwidth. The ridge gap and the profile had major impact on the symmetry of the radiation patterns and the maximum useable bandwidth.

A ridge horn was fabricated in aluminium (Ref. Fig.1) with the optimized physical dimensions. The optimized dimensions are – i) diameter of the input waveguide = 250 mm, ii) diameter of the aperture = 300 mm,iii) length of the input waveguide section =150 mm, iv) length of the conical back short = 150 mm, v)length of the flared section = 500 mm, vi) ridge thickness = 10mm and vii) ridge gap = 20mm. Various measurements were carried out to characterize its performance.

Fig. 1. Quad-ridged Horn

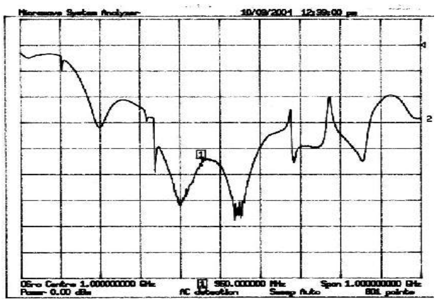

Fig. 2. Input return Loss plot of the quad-ridged horn

2.2 Measurement of Input Return Loss

The input return loss of the horn was measured using a scalar IFR network analyzer. The dimensions of the probe were tuned iteratively to obtain reasonably good impedance match. Further improvement was carried out by shorting all the four ridges using a circular metal ring introduced in between the back short and the input waveguide. Measurement results indicate (Ref. Fig. 2) that the antenna structure has a good match over 0.7 – 1.6 GHz

2.3 Measurement of Radiation Pattern

The radiation patterns were measured at several frequencies. The patterns obtained follow very closely the simulated patterns. Even here good radiation patterns were obtained over the frequency range 0.7 – 1.6 GHz. It should be noted that the introduction of a metal ring in between the back short and the input waveguide has not affected the radiation patterns. The edge taper of the horn @ ± 60° ranges from 5 – 6 dB at 700 MHz to 16 – 18 dB at 1600 MHz. Fig. 3 shows the measured patterns at 700 MHz and 1600 MHz.The quad-ridged horn has been measured to have a moderate cross polarization in the range -10 to -13 dB. The moderate value obtained is attributed to the non usage of higher order modes in the operation of the horn. The phase center is found to lie very close to the aperture independent of the frequency.

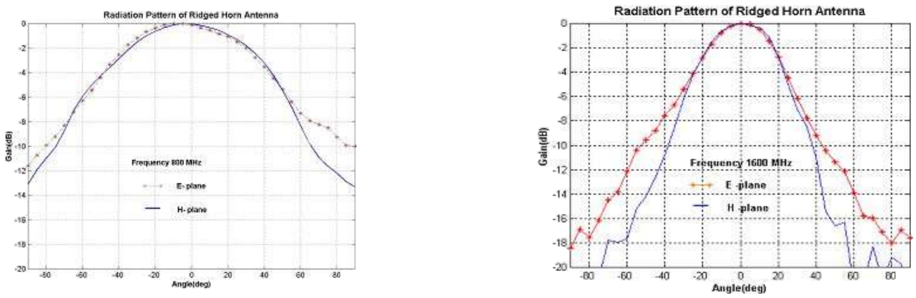

Fig.3. Measured radiation patterns at 700 MHz and 1600 MHz

2.4 Conclusions

We have successfully designed and developed a quad-ridged horn having a bandwidth ~ 2.3 : 1 in the low frequency regime. This horn can be effectively used as a prime focus feed in a parabolic reflector having an F/D ratio of 0.4 with an aperture efficiency ranging from 70 to 80 % [3].

3. Non Planar Tooth Trapezoidal structure

Most of the conventional antennas work efficiently over a narrow frequency range having a moderate bandwidth of about one octave. They are physically scaleable to make them operate over different frequency ranges. Hence there always exists a challenging task to design a single antenna which can cover several octaves of bandwidths meeting simultaneously most of the electrical specifications required. Frequency independent antenna is one of the most appropriate candidates for a broad band application.

The most important requirement of a frequency independent antenna has been to have its impedance, polarization and radiation patterns invariant to the change of wavelength. In addition, the structure also should be invariant to a change of scale. This is possible only when the shape of the antenna is determined entirely by the angle rather than any linear dimension. Two important properties that a frequency independent antenna should have are i) self scaling and ii) truncation of the current along the transmission line[3] .Spiral antennas and log periodic antennas are the two broad classes of frequency independent antennas. We have investigated the performance of the trapezoidal tooth structure belonging to the class of log periodic antenna.

3.1 Evolution of Trapezoidal Tooth Structure

The evolution of trapezoidal tooth structure is shown in Fig.4. A simple half wave dipole is a primitive antenna having a moderate bandwidth of about 10%. A half wave thick dipole has slightly broader band compared to the thin dipole. The biconical antenna on the other hand has more band width compared to the earlier two. However this structure does not satisfy one of the requirements (truncation principle) of the frequency independent antenna. In order accomplish this, resonating elements are added to the biconical antenna. The resonating elements radiate the energy resulting in a rapid attenuation of the current on the antenna surface.

3.2 Salient features of the trapezoidal tooth structure

A conventional planar log periodic antenna will have asymmetrical beam width in E and H planes giving rise to elliptical beam in the sky. This limitation is overcome in the trapezoidal tooth structure by separating the two halves by a definite angle and hence controlling the beam width in the H plane. This structure being complimentary in nature offers a constant impedance over a wide range of frequencies.

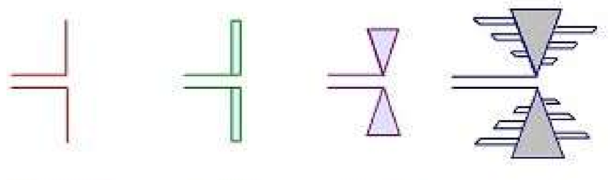

Fig.4. Evolution of the trapezoidal structure

3.3 Design parameters of the trapezoidal tooth structure

The parameters (Ref. Fig. 5) involved in the design of trapezoidal antenna are i) included angle between monopoles in each planar structure - α ii) taper angle of the central transmission line - β, iii) included angle between the two planar structures - χ , and iv) the ratio of the frequencies at which the performance of the antenna repeats -τ. The angle χ is chosen in such a manner as to have equal 10 dB beamwidths in both E and H planes.

We have designed and developed an antenna (Ref. Fig. 6) to operate in the frequency range of 0.5 – 5 GHz. We have considered in our design the most optimum values available in the literature [5] for various angles defining the structure. The values used in our design are - α =45° , β = 10°, χ = 60° and τ = 0.707. We have used Tchebycheff tapered balun transformer [6] to transform antenna impedance to 50 ohms. The salient feature of the Tchebycheff transformer is that it offers a constant impedance match over a frequency range as large as 100:1.

3.4 Measurement of Radiation patterns and Return Loss

The input impedance match of the antenna was measured in the laboratory using a HP scalar network analyzer. After tuning the structure for nullifying the reactive impedances, we were able to get an average return loss of about –10 dB over the frequency range 0.5 – 5 GHz. The radiation patterns were measured at several frequencies in both E & H planes. We were able to get reasonably good patterns over a bandwidth of 1:3. However further improvements are being made to increase the maximum useable bandwidth. The typical patterns obtained at 1.4 Ghz and 2.2 GHz are shown in Fig. 7.

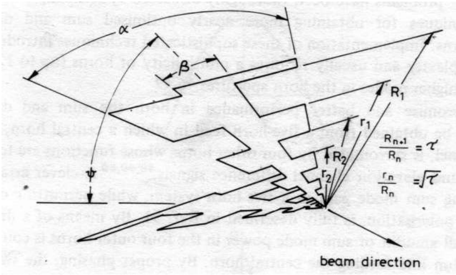

Fig. 5 Trapezoidal tooth structure
showing all the design parameters

Fig. 6 Single polarization trapezoidal
tooth structure

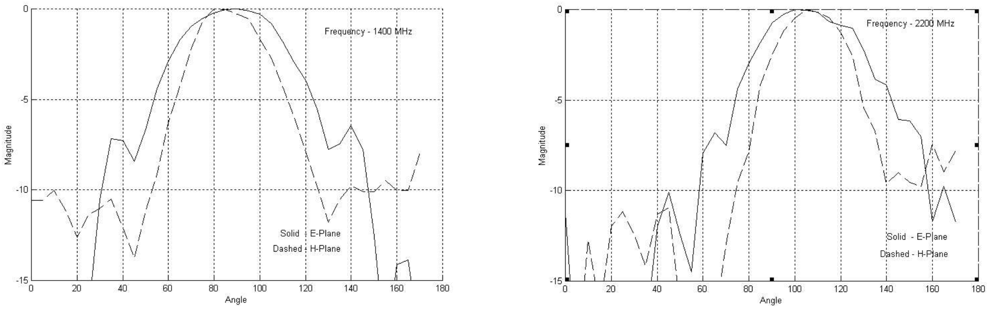

Fig. 7. Typical radiation patterns measured at 1.4 GHz and 2.2 GHz

3.5 Conclusion

Even though the structural bandwidth of the antenna is 1:18, we have been able to get acceptable input return loss performance and radiation patterns only over 5:1 and 3:1 bandwidths respectively. Efforts are ON to improve these over larger bandwidth by optimizing the structural dimensions through simulation.

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