Antenna With Two Orthogonaly Polarised Beams

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***Abstract* - In the paper, the optimisation of a 32 metre Cassegrain type antenna at the Ventspils International radio astronomy Centre (VIRAC) is described. The existing conical horn is not optimised for reception from circularly polarised sources in the 3-cm band. A multimode circularly polarised rectangular horn antenna generating a circular shaped beam is described. This antenna operates in two orthogonal mode sets, namely the H_{10} plus H/E_{12} and H_{01} plus H/E_{21} modes. By usage of higher order H/E modes, the aperture E-field distribution can be modified so that the effective E-plane far field beam width is approximately equal to H-plane beam width of the orthogonal set of modes, resulting in low off-axis polarisation ratio. Because of the modified aperture distribution, the radiation patterns also have low side lobes. The performance of this antenna has been evaluated experimentally.**

1 Introduction

A radio astronomy antenna is often required to receive circularly polarised signals with a symmetrical beam width. A rectangular horn antenna has an elliptical shaped beam in the case of equal size of rectangular horn aperture. However if it is designed to propagate only the H_{10} and E_{01} modes (dominant modes), signals received off the axis of the beam will not be circularly polarised nor will the polarisation ratio be near unity. This paper describes a concept, which enables a rectangular horn to receive a circularly polarised beam with good off-axis ratio by using higher order H/E_{12} and H/E_{21} modes together with the dominant modes. The following discussion will show the operational principle of this antenna and that the wanted higher order modes can be generated by a flare angle changes. Experimental results are shown to be in conformity with the theory.

2 The Antenna Pattern In Far Field Region

To efficiently receive a circularly polarised wave from aperture, the two orthogonal far-field spherical components Eϕ and Eφ, must have equal amplitude and proper phase [1]. For example, consider only the two principal orthogonal planes of a conventional rectangular horn simultaneously propagating only the H_{01} and H_{10} modes [2]. If a portion of the H_{10} and H_{01} mode energy is now converted to the higher order H/E_{12} and E/H_{21} modes (beam shaping modes) with proper amplitude and phase, the E-plane aperture field distributions can be modified as shown in fig.1 [3] .

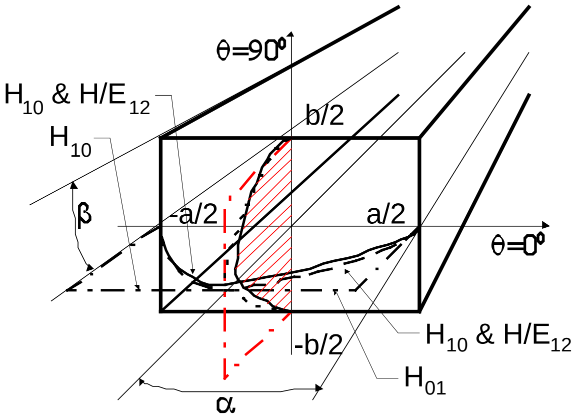


Figure 1: Aperture E-field distribution.

A pyramidal horn with square aperture has a theoretical ratio of H-plane to E-plane 3-dB beam width equal to 1,35 [4]. This assumes H_{10} aperture fields with half-sine wave H-plane distribution and uniform E-plane distribution. The respective side lobe levels are 23 and 13 dB below the peak of the main beam. For use as a high gain, low-noise feed the E-plane and H-plane beam widths should be equal, and sidelobes should be down by at least 20 dB [5]. Since the H-plane pattern is already satisfactory, a means was sought for introducing E-plane aperture modification in order to increase the beam width and reduce the side lobes of the E-plane pattern. The technique adopted is conversion of part of the H_{10} energy in the horn to H_{12} and E_{12} energy with proper magnitude and phase to yield the desired magnitude distribution. This mode conversion is accomplished by some small changes of flare angle within the horn.

Thus the effective E-plane far-field beam width is broadened to closely match the H-plane beam width of the other orthogonal set of modes as shown in fig.2 and 3.

Because of modified aperture distribution, the side lobe levels of the E-plane antenna pattern also show significant reduction.

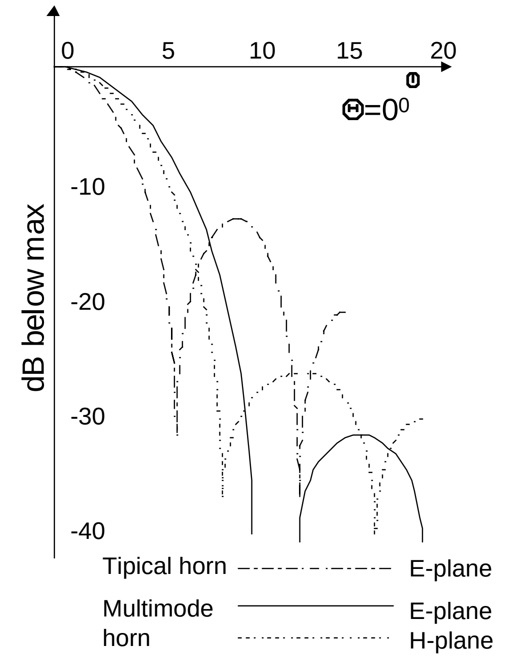


Figure 2: Comparison of tipical and multimode horn antennas patterns in E plane.

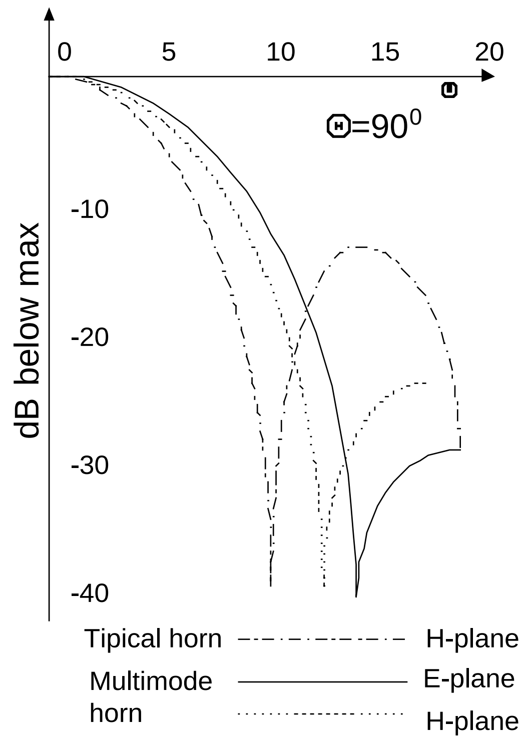


Figure 3: Comparison of tipical and multimode horn antennas patterns in H plane.

3 Analysis Of Flare Angle Changes

Mode conversion at a flare angle change is analysed in approximate manner [3]. Phase velocity of H_{10} mode differs from that of the H_{12} and E_{12} modes (which have equal velocity). A length of uniform wave-guide or horn introduces a differential phase shift between the H_{10} mode and the pair of H_{12} and E_{12} modes: therefore, proper phasing of the modes occurs only in a limited frequency band.

Assume now that the horn is sectorial with E-plane flare and constant H-plane width. Then with a small flare-angle change, an incident H10 arriving from the left yields predominately H_{10} on the right plus small amplitudes of the H/E_{12} , H/E_{14} , etc., where H/E denotes H, E pairs superimposed in amplitude and phase such that $E_x = 0$ at all points. The formula for the amplitude A_2 of the H/E_{12} mode is given by

$$A_2 = j\frac{2a_2(\theta_1 - \theta_2)}{3\lambda},$$

where a_2 is the E-plane height at the flare change point,
Θ_1 - the flare angle to the left from flare angle changes,
Θ_2 -it one to the right from flare angle changes,
λ -operating wavelength.

It can be used to design the flare angle changes that yields the desired ratio of H/E_{12} amplitude to H_{10} amplitude. Note that the phase angle of mode A_2 lags mode A_0 by 90^0 when $\Theta_1 - \Theta_2 < 0$. That is, if the length of horn between the flare change and the aperture has differential phase shift between the H_{10} and H/E_{12} modes, these modes will be in phase at the centre of the aperture. Similarly, when $\Theta_1 - \Theta_2 > 0$, 270^0 differential phase shift is required. Thus, the decrease in flare angle in fig.4 should be followed by 270^0 differential phase shift and the increase in flare angle in fig.5 by 90^0.

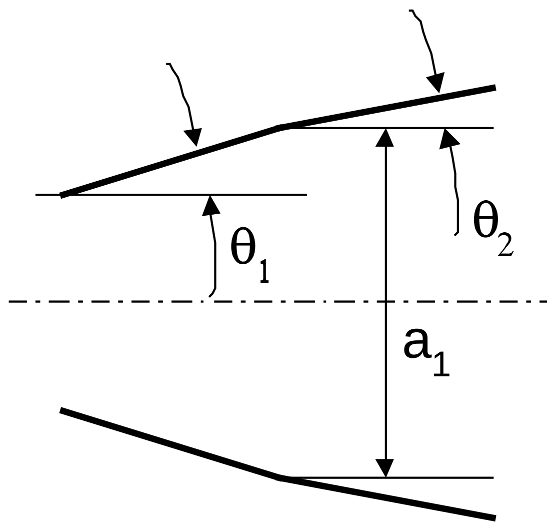


Figure 4: Flare angle change $\Theta_1 - \Theta_2 > 0$.

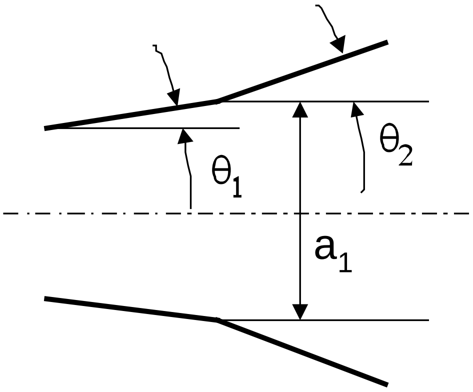


Figure 5: Flare angle change $\Theta_1 - \Theta_2 < 0$.

The phase shift Φ_0 of H_{1n} and E_{1n} modes in a square pyramidal horn is given in radians by:

$$\Phi_0 = \Phi_{02} + \Phi_{01} ,$$

where:

$$\Phi_{02} = \frac{\pi}{tg\Theta}\left\{\frac{a_2}{\lambda}\sqrt{k_1} - \frac{a_1}{\lambda}\sqrt{k_2}\right\}$$

$$k_1 = 1 - (1+n^2)\left(\frac{\lambda}{a_2}\right)^2 ;$$

$$k_2 = 1 - \left(1+n^2\right)\left(\frac{\lambda}{a_1}\right)^2$$

$$\Phi_{01} = \frac{\pi}{tg\Theta}\left\{0,5\sqrt{1+n^2}\left[k_3^{-1} - k_4^{-1}\right]\right\}$$

$$k_3 = \sin\left(\frac{\lambda}{2a_1}\sqrt{1+n^2}\right);$$

$$k_4 = \sin\left(\frac{\lambda}{2a_1}\sqrt{1+n^2}\right);$$

- a_1 is the aperture height and width at the left, a_2 is the same at the right, and Θ_t is the flare angle. This formula is valid for small flare angles. The axial length is :

$$l = \left(\frac{a_2 - a_1}{2}\right) ctg\,\Theta \ .$$

When $\Theta = 0$ and $a_2 = a_1$, Φ_0 is simply :

$$\Phi_0 = \frac{2\pi l}{\lambda}\sqrt{1 - \left(\frac{\lambda}{2a}\right)^2\left(1+n^2\right)}$$

Equations with n set equal to 0 and 2 is used to calculate the differential phase shift $\Phi_2 - \Phi_0$ for the H_{10} and H/E_{12} modes.

4 Performance Of Experimental Horn

Figure 4 shows a horn designed for use in modified Cassegrain antenna system developed for optimum aperture control in the 11 GHz band.

A ratio of H/E_{12} to H_{10} amplitude of 0,66 at the aperture would yield equal E- and H-plane beam widths at the –10 dB points.

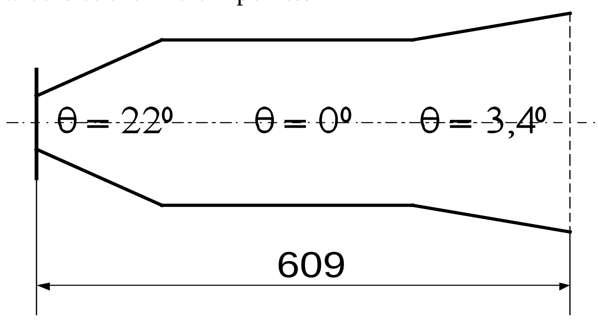
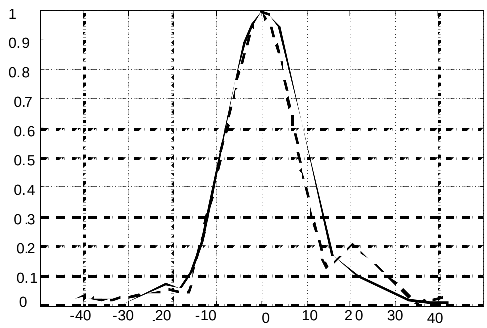


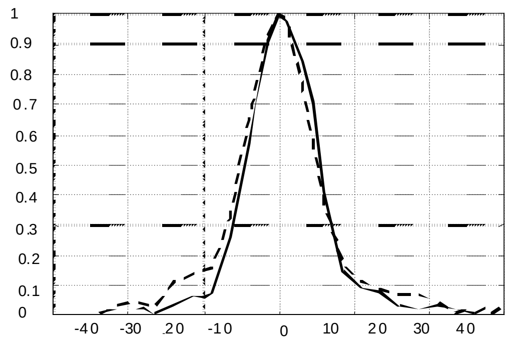
Figure 4: Feed horn for 32m Cassegrain antenna

Flare angle changes were designed by means of equation for Φ_0 to provide a ratio of 0,66. The length was computed to give a good approximation to a plane phase front in the aperture, and suppress H/E_{14} components.

Figure 5 shows measured E- and H-plane patterns in the 11200 to 11800 MHz band.

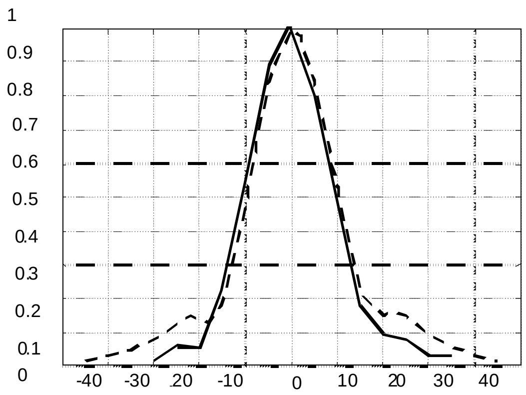


a) 11200 MHz.

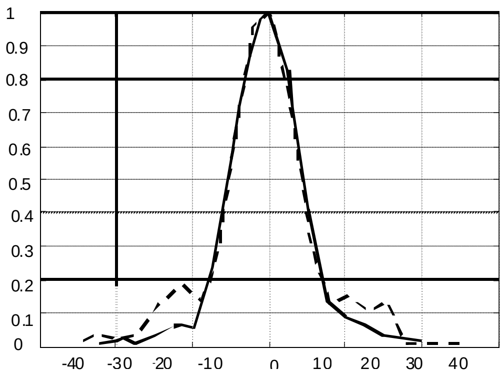


b) 11400 MHz

Figure 5: Multimode horn antenna pattern for 11 GHz band



c) 11600 MHz.



d) 11800 MHz

Figure 5: Multimode horn antenna pattern for 11 GHz band (continued)
(E-plane ——— H-plane ———).

These patterns reflect that the design has coincided with its intended objectives:

1. The E- and H-plane beam widths are closely equal;
2. The H-plane patterns are tightly affected by flare changes;
3. Both E - and H - plane sidelobes are highly suppressed.

5 Polariser

The output of horn as rectangular waveguide is connected to polarisation transformer for two separate orthogonal plane waves. For purpose of minimised

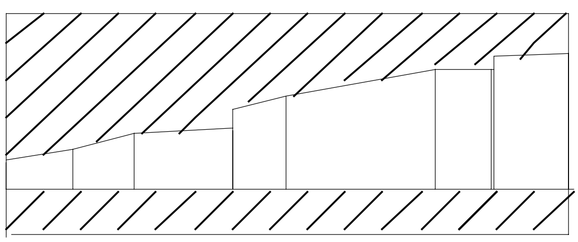


Figure 6: Crossection of the polarisation transformer.

size it will be used modified bridge [7] as shown in fig. 6.

This part is now under development and computer simulation.

6 Conclusions

This technique yields closely equal E- and H-plane beam width and low sidelobes. The horn's simple boundary, free of abrupt discontinuities, provides low standing wave ratio coefficient, minimum dissipation loss and economical fabrication.

7 Acknowledgements

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8 References

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