DESIGN AND PERFORMANCE OF A THREE DIMENSIONAL ROTMAN LENS FOR A PLANAR ANTENNA ARRAY

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1. Introduction

Rotman and Turner[1] described a two-dimensional "bootlace" lens suitable for multiple beam forming with a linear array. They analysed the phase performance of their lens, which has three focal points and small phase aberrations for angles between the focal point angles (usually 0, $\pm\alpha$). Recently the amplitude performance of Ruze[2] and Rotman lenses has been studied both theoretically and experimentally by Smith and Fong[3], who constructed a waveguide fed lens with low insertion loss ($\simeq$2dB) and low sidelobes ($\simeq$-20dB). Several authors[4,5] have recently analysed the phase performance of some possible configurations for a three-dimensional lens to form multiple beams with a planar array. Here we shall study a 3-D lens with a Rotman type configuration, analysing both its phase and amplitude performance. Array factors for multiple beams scanned to $\pm$ 30° in both principal planes are derived for a planar array with a $4\lambda_o$ diameter aperture, using a waveguide fed lens of length $6.2\lambda_o$.
A waveguide fed three-dimensional lens has been constructed, with 12 beam ports and 37 array ports. The amplitude and phase performance has been measured at X-band (8-12 GHz). The measured amplitudes and phases have been used to calculate array factors for a 37 element planar array fed by the lens, assuming that reflections from the radiating array would not affect the lens performance significantly. This was found to be a reasonable assumption for the two-dimensional lens, linear array case[3]. In general, good agreement between the theoretical and practical lens performance is obtained. Some differences are found, but these do not degrade the multiple beam formation.

2. Lens Design

Figure 1 shows the lens geometry in schematic form. Sole and Smith[6] have described the theoretical analysis of the lens in detail, and discuss some design trade-offs. The design for the practical lens uses four converged focal points at the centre of a spherical beam port surface of radius equal to R. The beam port subtended angle θ is chosen to be less than the beam steering angle ψ, with $\sin\theta/\sin\psi = 0.6$. Fig. 2 shows a central section through the lens geometry derived for R = 18.6 cm. The radiating array spacing is $0.62\lambda_o$ (λ_o = 3 cm), arranged on a 7 x 7 square grid with 3 elements removed from each corner to give a near circular aperture.

Each beam port and array port is designed to be a flared waveguide horn. Fig. 3 shows a planar projection of the 37 array ports. The beam port "array" consists of 12 horns, 4 x 3 in the E and H planes respectively. This arrangement gives a 6 or 7 dB edge taper at the array ports, in both planes (at f_o). The coupling between the beam port and array port apertures is found from a near field calculation[6]. The phase distribution across the radiating array for a particular beam is found from the lens geometry, plus a small phase correction from the near field coupling formula. The theoretical array factors are shown in fig. 4, and the predicted insertion loss for the various beam ports is given in table 1.

3. Experimental Work

Amplitude and phase measurements have been made on the practical lens, feeding each beam port in turn. The measured amplitudes and phases, allowing for the "bootlace" line lengths, were used to predict "experimental" array factors at 10 GHz, and these are shown in fig. 4, in comparison with the theoretical beam shapes. The measured insertion loss for the different beam ports is given in table 1. Clearly the practical lens provides well formed multiple beams, in general agreement with the theoretical predictions. There are several interesting differences between theory and experiment. Firstly the beams are steered by slightly greater angles than predicted; secondly, the insertion loss is less than predicted. The predictions assume a half cosine H plane distribution (and uniform E plane) over the internal dimensions of the horn aperture. The measurements suggest that the effective gains of the lens ports are higher, i.e. the effective apertures are greater than assumed theoretically. This may be a mutual coupling effect when the horns are placed in the array port and beam port arrays. Swept frequency amplitude measurements (8-12 GHz) suggest that the lens performance is maintained over the band; the amplitude "ripples" due to internal reflections are at least as low as in the 2-D case[3].

4. Conclusions

A waveguide fed, three-dimensional Rotman lens has been designed, constructed and tested. A theoretical model has been developed, and the predictions are in generally good agreement with experimental measurements. The multiple beams formed scan between ± 30° in both E and H planes, as shown in Fig. 4. Further work will include measurements with a 37 element planar array fed by the lens, and the addition of a beam port overlap network[3] to give more beams (with consequent higher crossovers) in the H plane.

Acknowledgements

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References

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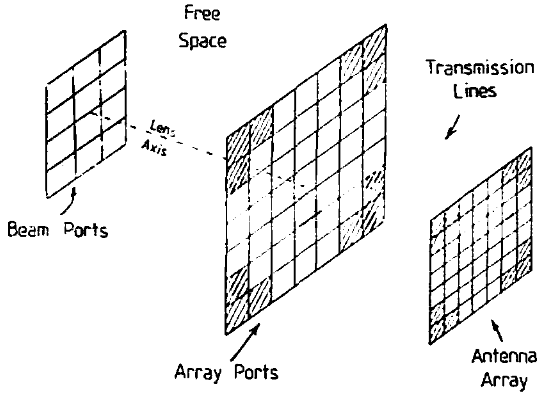


FIGURE 1

Lens Schematic

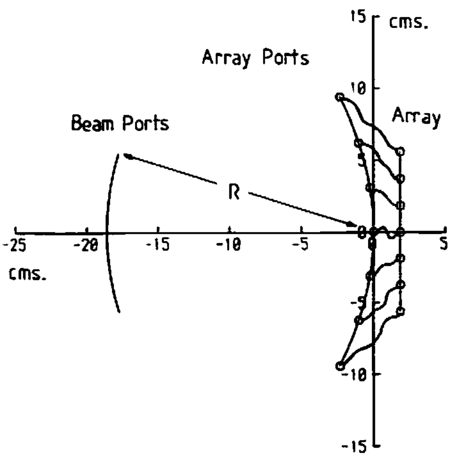


FIGURE 2

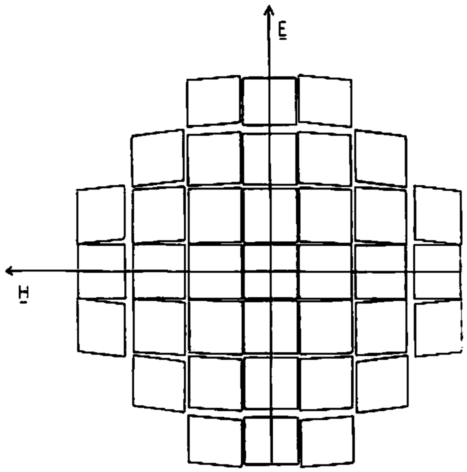


FIGURE 3

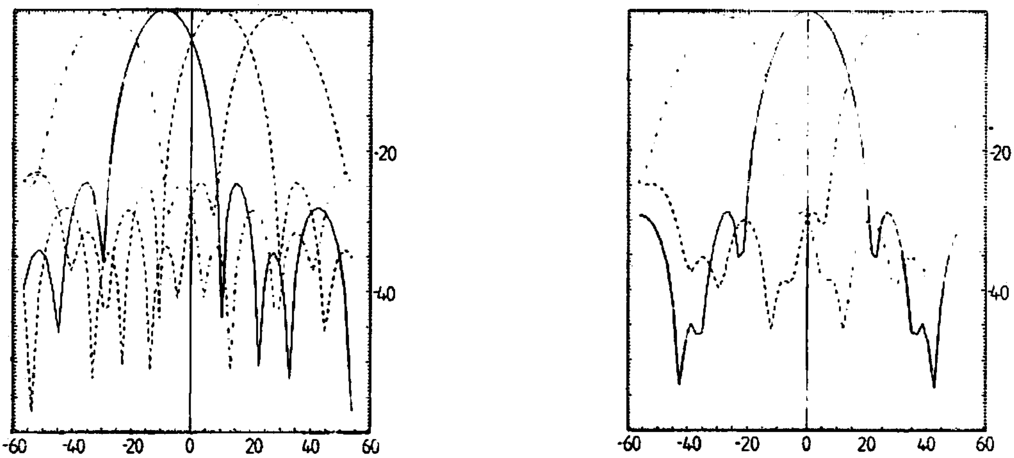
1	2	3
4	5	6
7	8	9
10	11	12

E ↑

Beam Port Numbering

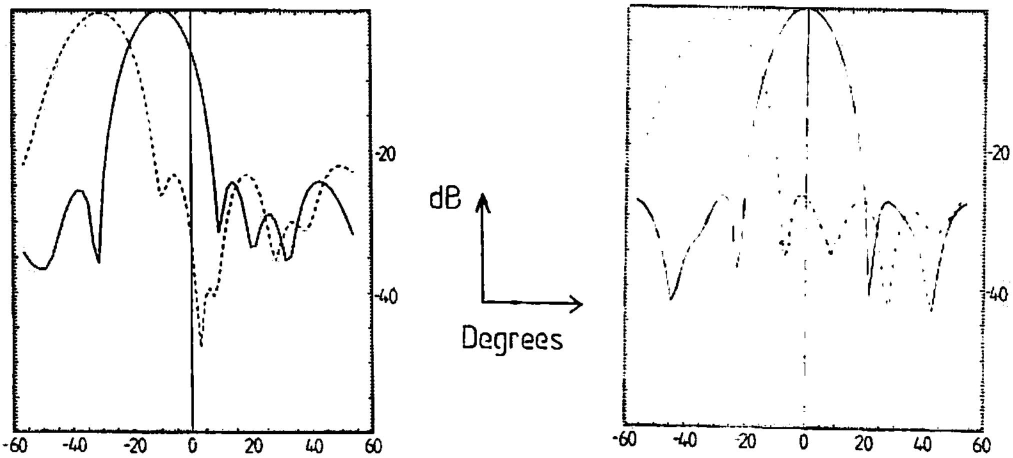
INPUT BEAM PORT	INSERTION LOSS (DB)	
	PREDICTED	MEASURED
5	3.7	2.0
2	4.3	2.4
6	4.4	3.6
12	5.0	4.7

TABLE 1



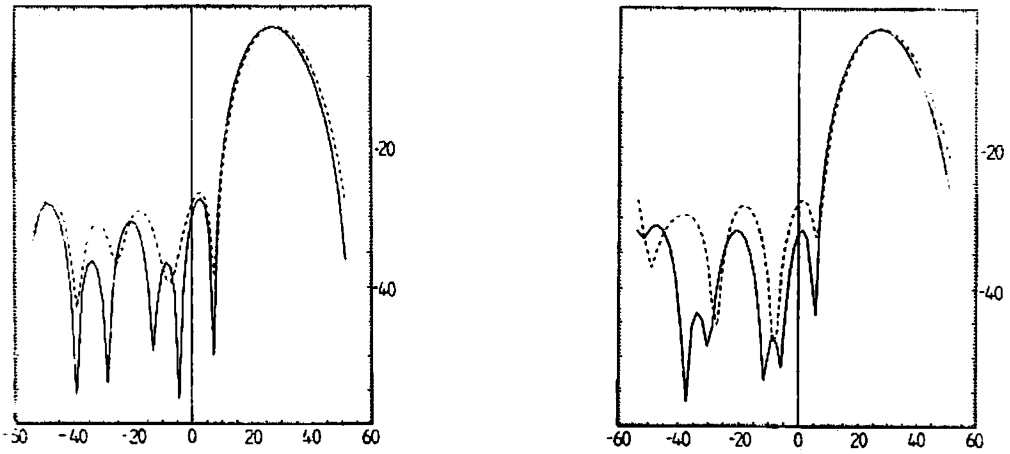
PREDICTED (E PLANE)

PREDICTED (H PLANE)



MEASURED (E PLANE)

MEASURED (H PLANE)



BEAM PORT 12 (E PLANE)

BEAM PORT 12 (H PLANE)

FIGURE 4

MEASURED (DASHED) AND PREDICTED

Multiple beam array factors in the two principal planes