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COAXIAL FEED ARRAY FOR A SHORT FOCAL-LENGTH REFLECTOR

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1. INTRODUCTION

The design of array feeds for deep dishes is made difficult by the need to closely pack the elements to minimize scan gain loss and coma sidelobes. A recent example was the design of a 4-element multibeam feed for the Lovell radio telescope at Jodrell Bank, UK, which is prime-focus fed reflector with a diameter (D) of 76.2m and a focal length (f) to diameter ratio f/D = 0.3. The multibeam feed was developed to reduce the time required for large-area surveys of the sky near 21 cm wavelengths (1.33 - 1.43 GHz). A suitable multibeam feed for the Lovell radio telescope has been designed by CSIRO. However, the design approach could be used in other applications requiring an array feed for a short focal length reflector. To design the multibeam feed, new software was used that analyses circular/coaxial horn arrays by a mode-matching method [1]. The effects of mutual coupling between the feeds, discontinuities and steps in the elements and a finite-sized ground plane are included in the analysis.

This paper describes the design of the feed array and gives the predicted and measured results for a model. Results are described also for when the array is used as a feed for the Lovell radio telescope.

2. COAXIAL WAVEGUIDE FEED DESIGN

The design of the multibeam feed for the Lovell telescope is challenging because the elements of the array must be relatively small and close together. This limits the aperture diameter (2a) to a maximum of about 0.9 λ. As a result, many feed types used successfully with deep dishes, such as the Koch feed (circular waveguide with a wide parasitic ring) [2], [3] or a feed with an offset corrugated flange [4], cannot be used. A coaxial feed element excited in the TE_{11} mode was chosen because, compared to a small diameter circular feed, the beam produced is more symmetric and the spillover and cross-polarization is lower. The inner conductor diameter at the aperture (2b) was chosen from the combined requirements of widest possible beamwidth, good beam symmetry and low cross-polarization. Curves in [5] show that this is achieved at the centre frequency of 1.38 GHz (ka = 2.21, where 2a = 153 mm) when the $b/a \approx 0.5$. An inner conductor diameter of 80 mm meets this requirement.

Coaxial feeds with large inner conductors have found limited use in the past because of the very high mismatch at the aperture [6]. A matching method was found that improves the input match over a significant frequency band. Inductive and capacitive irises are used alternately in the input waveguide as described in [6], but this approach is most effective for matching apertures where $b/a \sim 0.2$ to 0.3. It was found that by stepping down the inner conductor diameter so that a short way back from the aperture $b/a < 0.3$, the combined load of the aperture plus waveguide step can be matched in the coaxial waveguide with the smaller centre conductor using the method in [6]. Starting with a return loss at the aperture of about 5 dB, matching circuits can be designed that increase the return loss to > 20 dB over a 10 to 15% bandwidth. In carrying out the feed design 12 modes were used initially in the mode-matching method (TE/TM_{1n}, n=1,..., 6) and the results were confirmed with an 18-mode calculation. The final design of the feed for the Lovell telescope is shown in Fig. 1. The calculated reflection coefficient is given in Fig. 2. The match easily meets the 1.33 - 1.43 GHz frequency band required by Jodrell Bank.

The centre conductor of the feed is supported mechanically by high-density, low-loss polystyrene foam (loss tangent ~ 10^{-4}) and, to avoid adverse effect on the match, the dielectric constant of the foam should be < 1.06 (see Fig. 2). When a single coaxial feed is at the focus of the Lovell telescope at 1.38 GHz, the antenna efficiency is 64% (including blockage), the spillover efficiency of 98% and the peak cross-polar level is -36 dB.

To test the feed design a C-band model was built and tested. The calculated and measured reflection coefficient shown in Fig. 3 demonstrates that the matching method works satisfactorily, although there is some discrepancy near 3.8 GHz due to the dielectric foam supports. At C-band the match is more sensitive to the location and dielectric constant of these supports than the design in Fig. 1. The radiation pattern of the model was measured also and the 45 degree radiation patterns at 3.9 GHz are shown in Fig. 4. The radiation pattern of the feed depends strongly on the size of the metallic flange (50 cm square plate) surrounding the aperture and this is included in the calculated pattern. Fig. 4 shows the calculated and measured patterns are in excellent agreement.

3. ARRAY DESIGN

The layout of the elements in a multibeam feed is determined by a need for the highest possible beam efficiency while simultaneously arranging the beams to simplify inter-beam sampling. For the Lovell telescope, the four elements were chosen to lie on a hexagonal grid with a spacing 173.2 mm in a '4-hex' configuration, as shown in Fig. 5, to provide the densest beam sampling.

In the array environment new effects occur within the feed elements; these effects are taken into account in the design software. The coaxial waveguide is rotationally symmetric and alone excites TE/TM_{1n} modes from a TE_{11} mode excitation. This symmetry is lost in the array and consequently other modes can be excited. Of particular importance here is that the TEM mode can be produced in the aperture, and this will produce a standing wave in the feed because it is unable to propagate beyond the last section with an inner conductor. The analysis takes account of the TEM mode as well as the high-order waveguide modes. Provided the TEM mode is not generated to any great extent, the effect on the performance of the array is small and seen mainly in the cross-polar pattern.

The co- and cross-polarized radiation pattern of beam 4 of the 4-hex is shown in Fig. 6. Compared with the patterns for the isolated feed the radiation is somewhat distorted. At the same time the reflection coefficient of the feeds is changed little in the array.

4. MULTIBEAM PERFORMANCE

The energy received by horn i in the focal plane array is mainly due to a source located at (u_i, v_i) plus a small amount due to cross-coupling from other sources at (u_j, v_j) caused by the reflector diffraction limit and feed mutual coupling. The relative signal received by horn j arising from cross-coupling from beam i is here calculated approximately from the radiation pattern at (u_j, v_j) when horn i only is excited. The cross-coupling (isolation) between beams i and j is approximately given by the difference between the directivity of beam i when this beam is excited, and the directivity of beam j. To analyse the reflector and feed, a well-tested program based on the method of physical optics was used in conjunction with the feed array software.

The performance of the reflector with the 4-hex array is indicated in Table 1 for vertical polarization and 1.38 GHz; the results are similar for horizontal polarization. The half-power beamwidth (HPBW) of the telescope at 1.38 GHz is about 0.195° and therefore the beam spacing at this frequency is about 1.66 HPBW. At 1.33 GHz the worst beam efficiency is -2.0 dB, while at 1.43 GHz it is -2.4 dB for beams 2 and 4. The minimum isolation between beams is about 17 dB and is due to the hexagonal grid. When the feeds are moved roughly diagonally from the focus, coma increases the first sidelobe nearest to boresight. The effect of this increased sidelobe is to increase cross-coupling between beams that lie on the sidelobe. By contrast. for feeds in a rectangular grid the isolation is 3 dB higher. Other array configurations could have been tried in an attempt to move the beam centres further away from the coma lobes of other beams. However, the best isolation we are likely to achieve is probably about 23 dB, which is the mutual coupling between the horns. Provided the effect of the beam interference can be subtracted in processing the data it is likely that 17 dB isolation is not a limitation.

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5. REFERENCES

1. T.S. Bird, "Modelling arrays of circular horns with choke rings", *IEEE Antennas & Propagation Society Symposium*, Baltimore, USA, 21-26 July 1996, pp. 226-229.
2. G.F. Koch, "Coaxial feeds for high aperture efficiency and low spillover of paraboloidal reflector antennas", *IEEE Trans. Antennas Propagat.*, vol. 21, pp. 164-169, 1973.
3. A. Kumar, "Reduce cross-polarization in reflector-type antennas", *Microwaves*, pp. 48-51, March 1978.
4. R. Wohlleben, H. Mattes & O. Lochner, "Simple small primary feed for large angles and high aperture efficiency", *Electron. Lett.*, vol. 8, pp. 474-476, 1972.
5. T.S. Bird, "TE_{11} mode excitation of flanged circular coaxial waveguides with an extended centre conductor", *IEEE Trans. Antennas Propagat.*, vol. 35, pp. 1358-1366, 1987.
6. T.S. Bird, G.L. James & S.J. Skinner, "Input mismatch of TE_{11} mode coaxial waveguide feeds", *IEEE Trans. Antennas Propagat.*, vol. 34, pp. 1030-1033, 1986.

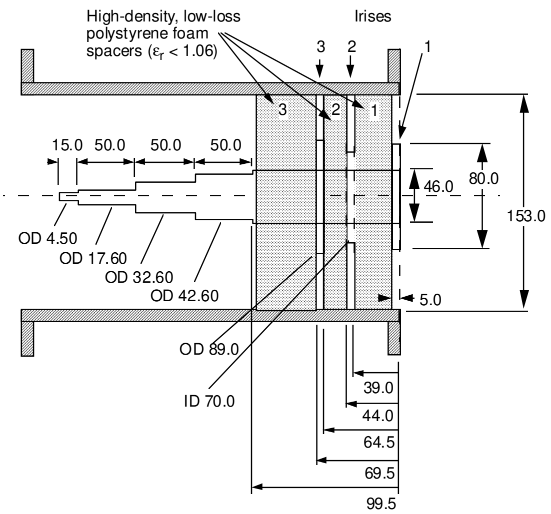

Fig. 1: Coaxial waveguide feed geometry (dimensions in mm).

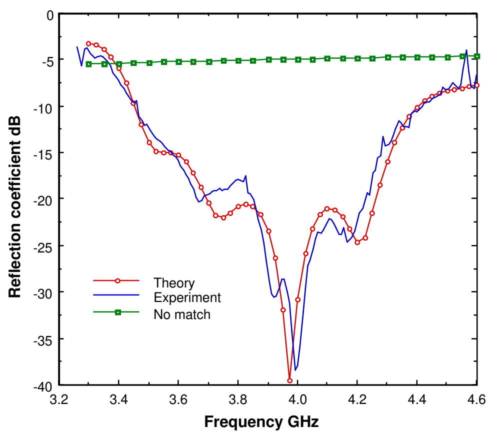

Fig. 3: Reflection coefficient of C-band test coaxial feed.

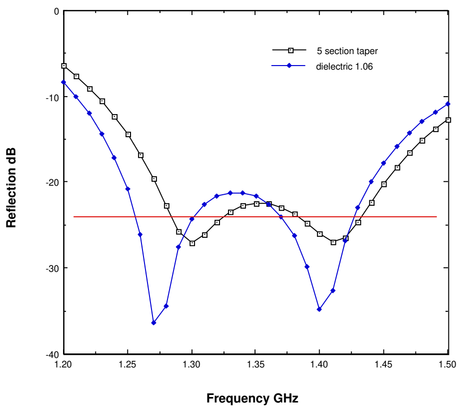

Fig. 2: Reflection coefficient of coaxial feed in Fig. 1.

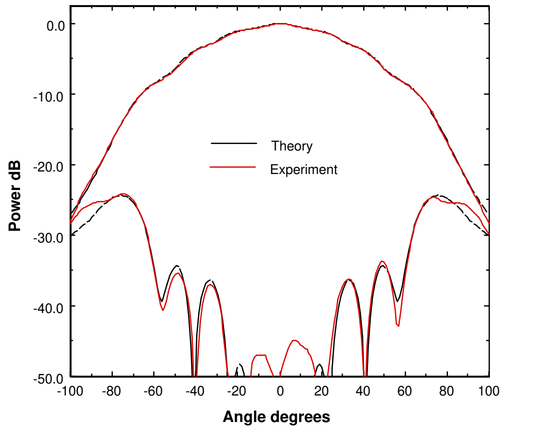

Fig. 4: Radiation patterns of C-band test feed at 3.95 GHz.

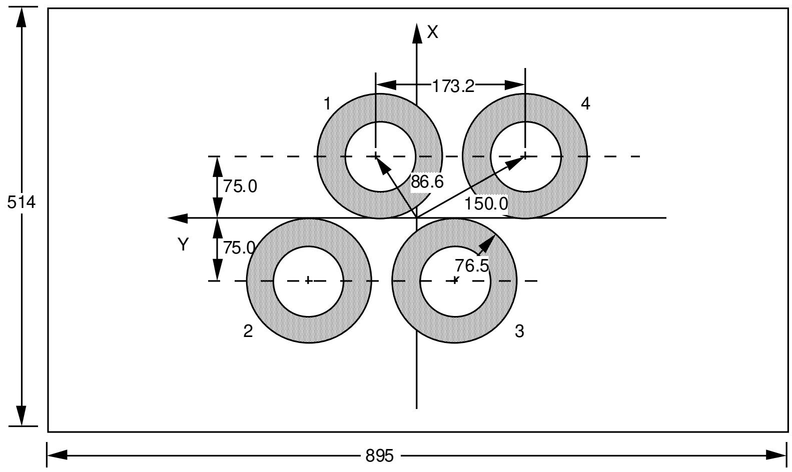

Fig. 5: Geometry of the 4-hex array the for Lovell telescope (dimensions in mm).

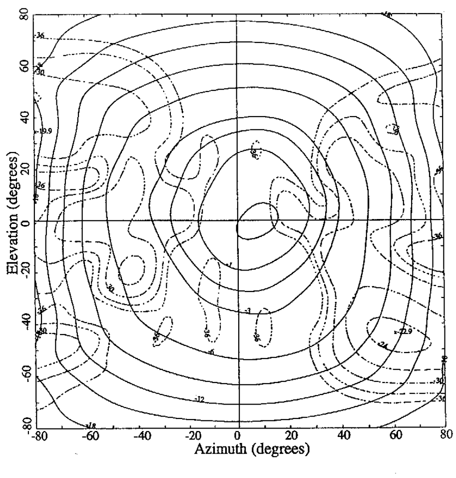

Fig. 6: Vertically polarized radiation pattern of at 1.38 GHz of element 4 in the 4-hex array. Solid contours are co-polar pattern and dashed contours are cross-polar pattern.

Table 1
Beam efficiency of Lovell reflector with 4-hex array for vertical polarization at 1.38 GHz. Cross-polar level given in brackets.

	Efficiency dB Beam			
Horn	1	2	3	4
1	-1.99 (-59.8)	-26.8 (-53.0)	-22.5 (-48.7)	-24.8 (-48.7)
2	-19.4 (-64.7)	-2.20 (-58.4)	-19.2 (-53.4)	-41.1 (-55.5)
3	-22.5 (-48.7)	-24.8 (-48.7)	-1.99 (-59.8)	-26.8 (-53.0)
4	-19.2 (-53.4)	-41.1 (-55.5)	-19.4 (-64.7)	-2.20 (-58.4)