COMPACT CIRCULARLY-POLARISED COAXIAL FEED

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INTRODUCTION

This paper describes a circularly-polarised 4-port feed for use with f/0.4 parabolic reflectors. The horn is a dual choke circular waveguide radiator with low crosspolarisation over a wide band. Diplexing is performed immediately behind the horn aperture where the high and low frequency bands are separated into concentric waveguides, the outer one carrying the lower frequency via the coaxial TE\(_{10}\) mode. A septum joining the inner and outer conductors of the coaxial guide acts as a circular polariser: left- and right-hand components in the low frequency band are extracted at pairs of 50 ohm coaxial connectors opposite sides of the guide. The inner circular waveguide is filled with a dielectric mated and passes through the centre of the low frequency section and is coupled to a conventional septum polariser in square waveguide.

The feed waveguide is modelled as a coaxial guide with vanishing small centre conductor, while the chokes are modelled as larger waveguides terminated in reactive loads. From the mutual admittance matrix we calculate an S-matrix relating the incident and reflected mode amplitudes in the feed waveguide, then use this to compute the electric fields in the apertures of the feed waveguide and chokes, from which the far-field pattern follows.

The horn is designed for minimum crosspolarisation over the full usable bandwidth of circular waveguide between the cut-off frequencies of the TE\(_{10}\) and TM\(_{10}\) modes. The chokes are of equal depth and approximately one half wavelength deep at the top of the band, where they behave as a conducting ground plane around the aperture, which is ~1.1 wavelengths in diameter and thus radiates with low crosspolarisation [2]. In the lower band the chokes behave more as conventional current suppressors around a circular waveguide with diameter near 0.7 wavelengths, again giving low crosspolarisation.

The calculated return loss and crosspolarisation are plotted in Figure 1. The beamwidths are suitable for an f/0.4 dish. In the low band the edge illumination is near -10 dB, while in the high band it is approximately -14 dB, producing a secondary pattern with low sidelobes.

DIPLEXER

The diplexer is based on Tun’s concept [3] and consists of a stepped flare followed by concentric circular and coaxial waveguides, with the inner circular guide loaded with PTFE. Matching irises are used in both sections, those in the inner guide being grooves cut into the PTFE. The design and optimisation of this structure is carried out using mode-matching software which incorporates the S-matrix of the radiating aperture. By optimising the diplexer in the presence of the feed aperture we remove the need for intermediate matching elements.

We use the formulation of the mode-matching problem described in [4]. First, a projection matrix is set up containing the ‘overlap integrals’ between the mode functions on either side of a discontinuity. The elements of this matrix are

\[
T = \int \phi^1 \phi^2 \, ds
\]

In our model we treat the inner and outer guides together. This means that the projection matrix between the modes on either side of a discontinuity is partitioned, the top left-hand submatrix, \(T_{II}\), containing coupling coefficients between the two inner guides, and the lower right-hand submatrix, \(T_{II}\), those between the two outer guides. The off-diagonal submatrices, \(T_{II}, T_{II}\), contain cross-couplings between inner and outer guides. Two kinds of discontinuity are of interest in the present application, namely, one in which inner and outer guides remain separate \(T_{II} = T_{II} = 0\) and one in which both guides connect to an enlarged outer guide while the
inner guide disappears. To calculate the S-matrix of a discontinuity requires some further matrix algebra and a single matrix inversion. The S-matrix of the diplexer is then built by combining cascaded sections of guide [4] and, if required, the S-matrix of the horn, computed as described above. To optimise the diplexer we use standard routines to minimise reflection coefficient and high-band-to-low-band coupling.

Calculated results for a diplexer optimised with the common port connected to a perfect load are shown in Figure 2.

**COAXIAL GUIDE POLARISER**

The low band polariser consists of a single septum about one wavelength long joining the coaxial inner to the outer. It is followed by a short length of bifurcated guide whose inner and outer radii are stepped, forming a transformer to a pair of 50 ohm N-type connectors, placed on opposite sides of the feed and +/-90 degrees round from the septum. One connector provides right-hand and the other left-hand circular polarisation. The axial ratio of this device is in the range 2-4 dB, which is adequate for monitoring purposes on a small transmitting antenna.

This polariser is believed to be a new device. Its operation is analogous to that of the well-known septum polariser in square waveguide (see below). Referring to Figure 3, a coaxial TE$_{11}$ mode incident from the direction of the horn, with electric field in the y-direction, is unaffected by the septum and couples to an antiphase pair of modes in the bifurcated guide. However, a TE$_{10}$ mode, with electric field parallel to the septum (a), couples to the fundamental TE mode of the septate guide (b), which then couples to an in-phase pair of modes of the bifurcated guide (c). If the correct length is chosen for the septum, these ‘difference’ and ‘sum’ modes are excited in phase quadrature. As a result, each half of the bifurcated guide couples to a different hand of the circularly-polarised TE$_{11}$ mode in the coaxial guide.

**SEPTUM POLARISER**

A septum polariser in square waveguide provides left and right-hand circular polarisation in the high band. Connection between the square waveguide and the dielectric-loaded circular guide is provided by a two-stage transformer in partially-loaded circular guide.

Analysis of the polariser uses the mode-matching approach, complicated in this case by the need to compute the TE and TM mode sets for each of the ridged waveguide sections making up the device. The modes are not known explicitly but are approximated by series expansions whose coefficients are derived numerically [5]. To do this, the ridged guide is divided into two rectangular regions, I and II, and the field in each region expressed as the sum of rectangular waveguide modes. Matching tangential fields at the boundary between I and II and imposing the transverse resonance condition leads to sets of equations for the expansion coefficients, $a_k$, which may be written in matrix form

$$M(k) \ a = 0.$$  

We solve this set for the cut-off wavenumbers $k$, and the expansion coefficients $a$, by a systematic search, using singular value decomposition [6]. Mode-matching is applied to compute the individual S-matrices at each change in ridge height, and also at the final change to bifurcated guide, then these are combined to give the overall S-matrix of the polariser. Pairs of analyses for orthogonal linear polarisations are combined to produce the characteristics of the device for circular polarisation.

Using this method of analysis we have optimised a 5-step septum polariser to give the differential phase response shown in Figure 4. This is equivalent to an axial ratio of less than 0.30 dB over a 15% bandwidth.

**CONCLUSION**

The above components have been assembled to form a compact 4-port feed, shown schematically in Figure 5. In a realisation for the 4.6 GHz bands, the feed is 300 mm long and 90 mm in diameter and forms a convenient feed for small, low sidelobe parabolic dish antennas. When used as a 2-port device change of polarisation can be effected by tuning the feed 180 degrees and reconnecting to the waveguide and coax feeders.
REFERENCES


Figure 1. Calculated return loss (dashed) and crosspolar level at $\theta = 50^\circ$ (solid) for dual choke horn with choke depth = 0.27A, $f_c$ is cut-off frequency of TE$_{11}$ mode in circular waveguide.

Figure 2. Calculated return loss (solid) and isolation (dashed) of diplexer. $f_c$ is cut-off frequency of TE$_{11}$ mode in input waveguide.

Figure 3. Transformation of modes in coaxial guide polarizer.

Figure 4. Calculated differential phase for square waveguide septum polarizer. $f_c$ is cut-off frequency of TE$_{10}$ mode in square guide.
Figure 5. Schematic view of assembled 4-port feed.