A Multibeam Feed for the Parkes Radio-telescope

T.S. Bird
CSIRO Division of Radiophysics
PO Box 76 Epping NSW 2121 Australia

Introduction

The Parkes radio-telescope is as busy as it ever was in its more than 30-year lifetime. To improve the telescope further, a multiple beam capability is being investigated. This would have considerable impact on a proposed detailed study of the southern sky in the frequency range 1.27 to 1.47 GHz. With the present, single, prime-focus feed, this would take about 10 years to complete, but by using multiple beams, each with two orthogonal linear polarizations, the survey time would be reduced to a more manageable observing period. A combination of reflector scan-gain loss, as the feeds are displaced from the focus, and the limited number of available correlator units, restricts a practical array to about nine elements which, nevertheless, gives a substantial order of magnitude reduction in observing time. We describe here a preliminary study of the Parkes antenna performance with a cluster of nine feed horns, where each horn in the cluster is responsible for two orthogonal linear polarizations within a beam.

A possible multibeam feed system for the Parkes antenna is shown in Figs 1 and 2. Circular waveguide is preferred throughout, from the orthogonal mode transducers (OMT), for easy access to the Dewar, to the circular horns. A circular horn of about one wavelength diameter is preferred to a square horn because it has excellent pattern symmetry and cross-polar performance.

The 3x3 cluster shown in Fig. 2 makes for a compact feed system because the OMTs (in the Dewar) can be attached directly to the rear of the horns to extract both linear polarizations. Such a feed arrangement produces an approximately rectangular grid of beams on the sky. Sampling conditions dictate beam spacings ~HPBW (half-power beamwidth) in u-v space and the feeds must be spaced to give beams an integer multiple of HPBW apart. Physically this is impossible without dielectric-loading the horns. Dielectrics are unattractive because of the attendant losses and mismatch to free-space, corresponding to increased noise temperature. Therefore, conventional horns are selected and arranged in the focal region so that the beam spacing is approximately 2HPBW. The required sampling in u-v space is achieved by this rectangular grid of beams by simple two-fold interleaving in each spatial dimension.

Stepped Circular Horn Design

The design approach adopted was to obtain the best possible performance with a single feed horn and to then account for array effects. Circular and rectangular elements are candidate feed horns and both yield comparable gain. However, circular horns have better pattern symmetry, lower spillover and lower cross-polarization than square horns. In designing the circular horns attention was paid to reducing both cross-polarization and spillover while simultaneously maintaining high beam-efficiency and high return-loss. For any parabolic reflector fed at the focus by a circular waveguide there is an optimum waveguide diameter for maximum gain. In the case of the Parkes antenna, a feed of about one wavelength diameter maximizes the gain. Also, a feed of this diameter has very low cross-polarization. There is, however, an upper limit to the feed diameter in the array. This is specified by the beam spacing for effective sampling in u-v space and is chosen to be 1.2λ. Another important geometric parameter to establish is the diameter of the input waveguide. This was determined by the requirement that all modes other than the fundamental TE_{11} mode be cut-off in the frequency range 1.27 to 1.47 GHz. A 153 mm diameter pipe satisfies this requirement.

The feed-horn array was designed using mode-matching software for circular stepped horns. This software includes mutual coupling between the horns and is based on earlier work by the author [1],[2]. After an investigation of several configurations it was found that most objectives were attained with the two-step horn design shown in Fig. 1. Low cross-polarization is easily achieved with the single isolated feed but, in an array of circular apertures, the TM_{01} and TE_{21} modes are generated. These modes can cause high cross-polar levels which, in some instances, are as high as for the square horn. However, by judicious choice of the output aperture diameter and length of the circular waveguide steps, low cross-polar illumination (>35 dB) of the reflector at the centre frequency was ultimately achieved. The calculated reflection coefficient and insertion loss over the frequency band of interest is shown in Figs. 3 and 4. Both mismatch and loss (including ohmic loss) are least near the centre of the band and degrade at the band limits. Fig. 5 shows the co- and cross-polarized radiation patterns of the array when element 1 is excited, and this is only slightly degraded by the array environment, as is the horn mismatch and loss. Across the band good beam symmetry is maintained, although the cross-polar level deteriorates to 27 dB at the lower band edge, which is still acceptable.

Multibeam Performance

CSIRO's array-feed software was combined with the reflector analysis software to compute the radiation pattern of the overall antenna. The reflector parameters of the Parkes antenna are listed in Table 1.

Table 1: Parkes geometry

diameter (D)	64 m
focal-length (f)	26.270 m
f/D	0.41047
semi-angle	62.69°

Table 2:
Summary of the beam performance at 1.37 GHz with blockage diameter of 5m

Beam No.	Efficiency %	Spillover dB	X-polar peak dB	Beam maximum u deg	v deg
1	62.6	-0.186	-39.1	-0.467	0.467
2	66.5	-0.180	-39.5	-0.467	0.0
4	66.8	-0.191	-39.7	0.0	0.467
5	70.9	-0.184	-40.2	0.0	0.0

The radiation pattern of the reflector with the array was computed for each beam. It was assumed that the sources to be observed are essentially uncorrelated and, therefore, the signals radiated by the horns are not summed coherently. The co- and cross-polarized radiation patterns of the most extreme antenna beam at the band-centre frequency of 1.37 GHz are shown in Fig. 6. The patterns were obtained by exciting horn 1 and include reflector aperture blockage, 5m in diameter, that is due to the feed cabin. The performance of four beams is summarized in Table 2. Radiation data for other beams are obtained by symmetry. At the extremes of the frequency band the beam efficiency decreases. For example, at 1.27 GHz the efficiency of beam 5 is 69% and at 1.47 GHz the value is 67%. Spillover efficiency rises with frequency, due to narrowing of the feed horn pattern, from 94% at the lower to 97% at the higher frequency.

The energy received by horn i is due mainly 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, blockage and feed mutual coupling. The relative signal received by horn j due to cross-coupling from beam i is calculated approximately from the radiation pattern at (u_j, v_j) when horn i only is excited. The results are listed in Table 3. The cross-polar isolation on the rectangular grid is >60 dB.

Table 3:

Cross-coupling between beams for Parkes with aperture blockage 5m diameter

Beam	1	2	3	4	5	6	7	8	9
1	-2.03	-27.5	-46.5	-28.6	-37.6	-50.7	-49.9	-49.9	-43.0
2	-43.5	-1.78	-43.4	-45.0	-29.1	-45.0	-44.6	-49.3	-44.6
4	-54.4	-45.4	-45.4	-1.75	-28.2	-46.5	-54.4	-45.4	-46.5
5	-36.9	-49.2	-36.9	-51.7	-1.49	-51.7	-36.9	-49.2	-36.9

References

1. T.S. Bird, “Mode coupling in a planar circular waveguide array”, *IEE J. Microwaves, Opt. Acoust.*, Vol. 3, pp. 172-180, 1979.
2. T.S. Bird, “Mode matching analysis of arrays of stepped rectangular horns and application to satellite antenna design”, *IEE Conf. Antennas Propagat.*, University of York, UK, pp. 849-852, 1991.

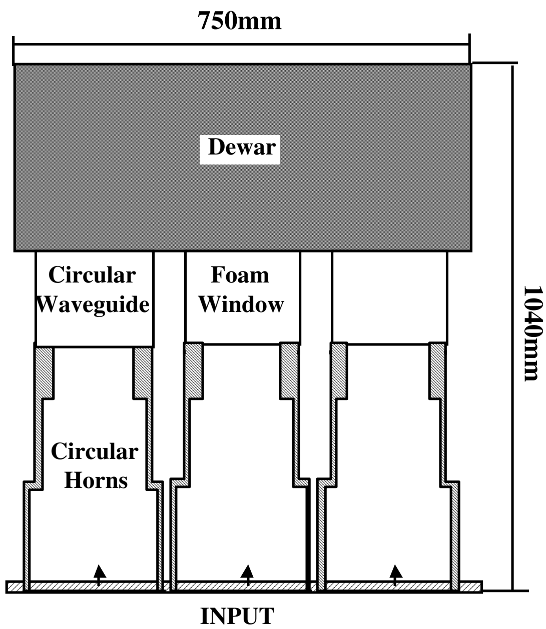

Fig. 1: Schematic view of the multi-beam receiver.

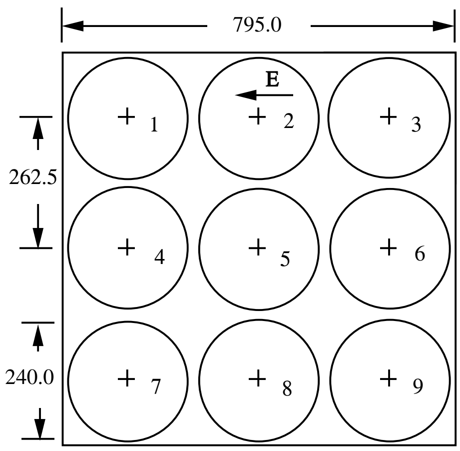

Fig. 2: Layout of array of circular horns in a ground plane.

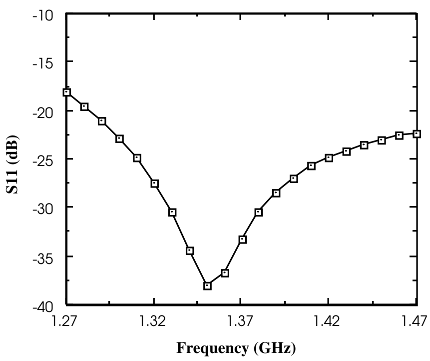

Fig. 3: Reflection coefficient of stepped circular horn with diameter 240 mm.

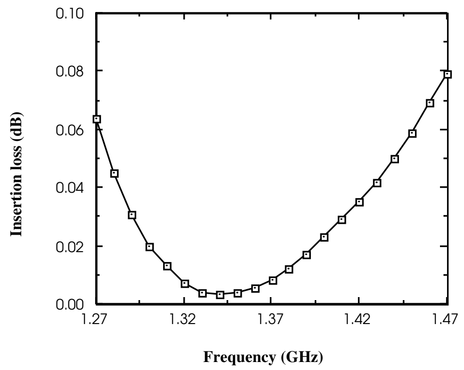

Fig. 4: Insertion loss of stepped circular horn versus frequency.

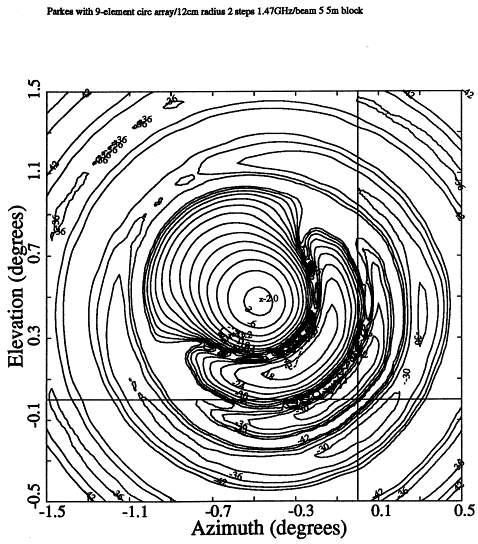

Fig. 6: Radiation pattern of beam 1 of Parkes reflector with nine-element array at 1.37 GHz. Contours are given in dB relative to a uniformly illuminated aperture at -2 and -3 dB and thereafter at 3 dB decrements down to -42 dB.
—– co-polar pattern, - - - cross-polar pattern.

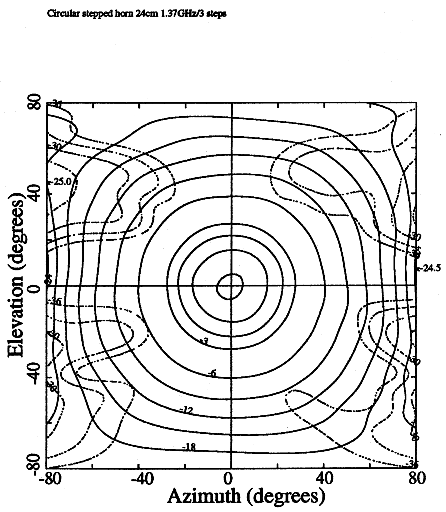

Fig. 5: Radiation pattern of horn 1 in array environment at 1.37 GHz.
—– co-polar pattern, - - - cross-polar pattern.