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A High Performance 700 GHz Feed Horn

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Abstract We present a design of a high performance horn operating at 700 GHz. The feed, which comprises three smooth-walled conical sections, is easy to machine and yet has comparable performance to a corrugated horn. The measured radiation patterns show high main beam circularity, low sidelobe level and good agreement with theoretical predictions. The cross-polar level is below −20 dB across a frequency bandwidth of 140 GHz. The new design allows the fabrication of high performance, large format feed arrays cheaply and rapidly.

Keywords Horn antenna · Electromagnetic horn · Smooth-walled conical horn · Focal plane arrays · Submillimetre astronomy · Corrugated horn

1 Introduction

Corrugated horns are used extensively in radio telescopes as a result of their excellent radiation properties over a large operating bandwidth. Fabrication of corrugated horns at millimetre and submillimetre wavelengths, however, is time-consuming and expensive. In recent years, there has been a lot of interest in finding alternatives to replace the use of corrugated horns without compromising the radiation pattern quality.

A novel design for a smooth-walled horn that has comparable radiation characteristics to those of a corrugated horn [1, 2] comprises multiple flare-angle conical sections, and a simple geometry that lends itself to a simple fabrication process (see Fig. 1). Using this method, a horn array can be fabricated by repeatedly milling a profiled drill bit into an

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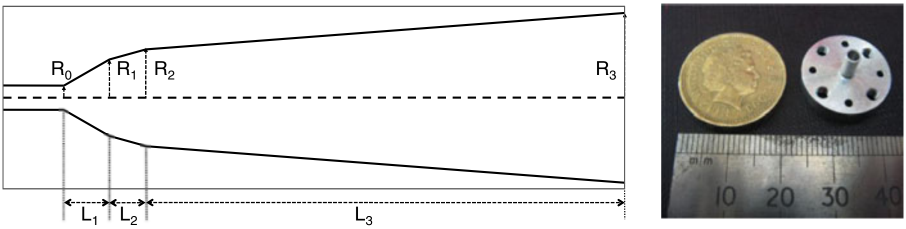

(a) (b)

Fig. 1 **a** Schematic drawing of a three flare-angle sections horn. **b** The actual horn with a modified UG-387/U flange.

aluminium block using a computer-numerical-control (CNC) milling machine. This enables rapid mass production of feeds at only a fraction of the cost of corrugated horns. This new technique has been extensively investigated and verified in the 230 GHz frequency range [3, 4] and a software package combining genetic algorithm (GA) optimisation and modal matching analysis has been written for the horn design. The reproducibility and the consistency of the fabrication process were demonstrated by testing an array of 37 multiple flare-angle horns using the direct drilling method.

In this letter, we describe the design and testing of a smooth-walled horn with three flare-angle steps, centred at 700 GHz. We show that the design and fabrication of these horns at this frequency is feasible and can easily be extended to the terahertz frequency range.

2 Design and fabrication

Conventional Potter horns [5, 6] employ a single groove discontinuity, near the throat of a conical horn, to excite the TE_{11} and TM_{11} modes at a specific amplitude and phase ratio. If the superposition of the modes reaches the aperture in phase, a uniformly polarized field with similar E-plane and H-plane distributions is synthesised across the aperture, within a relatively narrow frequency bandwidth. The multiple flare-angle design, in contrast, uses several discontinuities in order to excite additional higher order modes. This is because the excitation of an optimised combination of a few higher order modes other than the TM_{11} helps to increase the bandwidth that reaches 20% with three discontinuities and 30% with four discontinuities.

To design these horns, we have developed a self-contained software package, *hornsynth*, which calculates the optimum location and magnitude of the discontinuities using the GA optimisation. We begin by encoding each key parameter describing the horn geometry which we would like to optimise, R_1, R_2, L_1, L_2 and L_3 (see Fig. 1), into a binary string known as a *chromosome*. The collection of chromosomes describing a particular horn geometry is the *individual* and an initial *population* of individuals is formed, where each of the individual's horn parameters are chosen randomly within sensible constraints. We fixed the input waveguide radius, R_0, and the horn aperture, R_3, to give a main beamwidth of ~14° FWHM. The *fitness* of each individual is determined by evaluating a *cost function* which measures the quality of the horn's far-field pattern using the modal matching technique. We have chosen a fitness criterion that optimises the far-field beam circularity and minimises the peak cross-polarization level, within a bandwidth of 20%. After a sufficient number of new generations, formed using *crossover* and *mutation*, the fittest individual horn design is selected, and further optimised using simplex minimisation.

The simple geometry of the feed interiors allows the fabrication of a horn using a machine tool whose cutting edge has the required shape of the horn interior. The tool is then used to drill the feed horn directly into a block of aluminium. The process is very rapid and does not require the time-consuming electroplating and dissolving stages used in electroforming. Once the machine tool and the working metal block have been properly aligned, one can quickly fabricate a large horn array by simply repeating the drilling process.

3 Measurement setup

To test the feasibility of the manufacturing technology of these horns at submillimetre wavelengths, we have fabricated a three flare-angle sections horn to operate in the frequency range of 600–700 GHz. Optimisation with the GA gave the parameters: R_1= 0.488 mm, R_2=0.595 mm, L_1=0.487 mm, L_2=0.398 mm and L_3=7.886 mm. The input waveguide radius R_0 and the horn aperture R_3 were set to 0.203 mm and 1.2 mm, respectively. The far-field patterns were measured in a test range equipped with a 4 K cryogenic bolometric detector in an anechoic chamber. The horn under test was used as a transmitter fed by a solid state RF source between 600–740 GHz, and was aligned to the cooled receiver horn feeding the bolometer. The radiation patterns were measured by logging the signal received from a lock-in amplifier while rotating the transmitter under

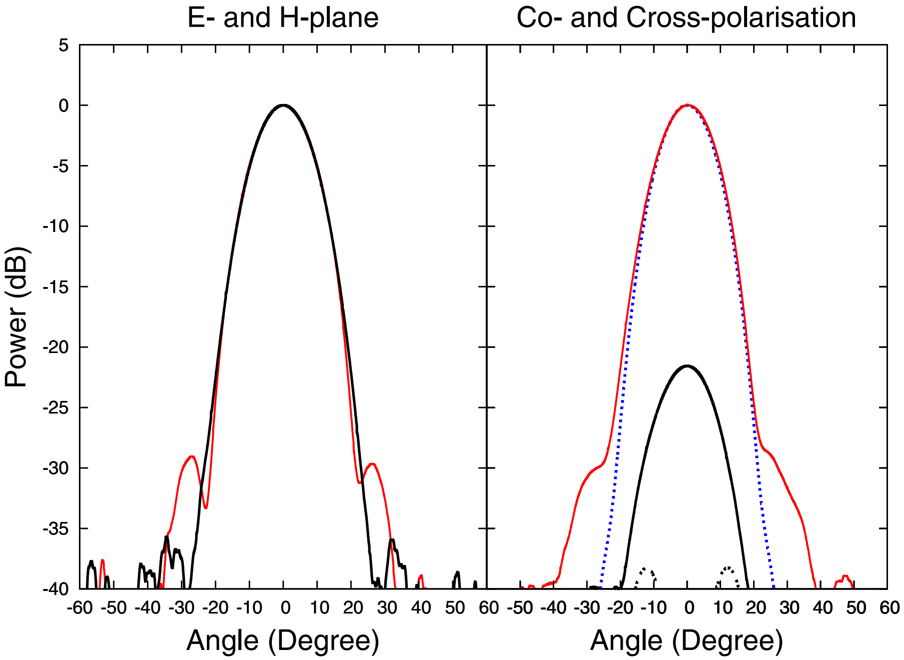

Fig. 2 Measured and computed E-plane, H-plane, co-polar and cross-polar radiation patterns at the designed central frequency of 700 GHz (Left pane: red solid—measured E-plane; black solid—measured H-plane. Right pane: red solid—measured co-polar; black solid—measured cross-polar; blue dash—computed co-polar; black dash—computed cross-polar).

computer control. This method gave a good dynamic range of around 50 dB. For measuring co-polar and cross-polarization patterns, a terahertz grid was placed in front of the detector cryostat window, with the polarization axis aligned at 45° to the plane of rotation. The input polarization of the horn under test was then aligned parallel to the grid polarization axis for measuring a co-polar pattern, or perpendicular to the grid axis for measuring a cross-polar pattern.

4 Results and conclusion

In Fig. 2, we show E-plane and H-plane radiation patterns in addition to co-polar and cross-polar patterns, measured at the designed central frequency of 700 GHz. It can be seen that the measured first sidelobe level is below −30 dB, the main beam has excellent beam circularity down to the −30 dB level. The co-polar pattern agrees very well with the computed prediction and the peak cross-polarization level is below −22 dB, limited by the grid performance. This limitation can be realized by noting that the level of cross-polarization remains approximately fixed across a bandwidth of 140 GHz.

Figure 3 shows co-polar and cross-polar patterns measured at the edges of the RF source's frequency range, at 600 GHz and 740 GHz. At both extremes, the cross-polar level is below −20 dB, showing good agreement with theoretical predictions. Notice that the measured performance shows good performance across 140 GHz bandwidth, covering the entire atmospheric window centred at 650 GHz.

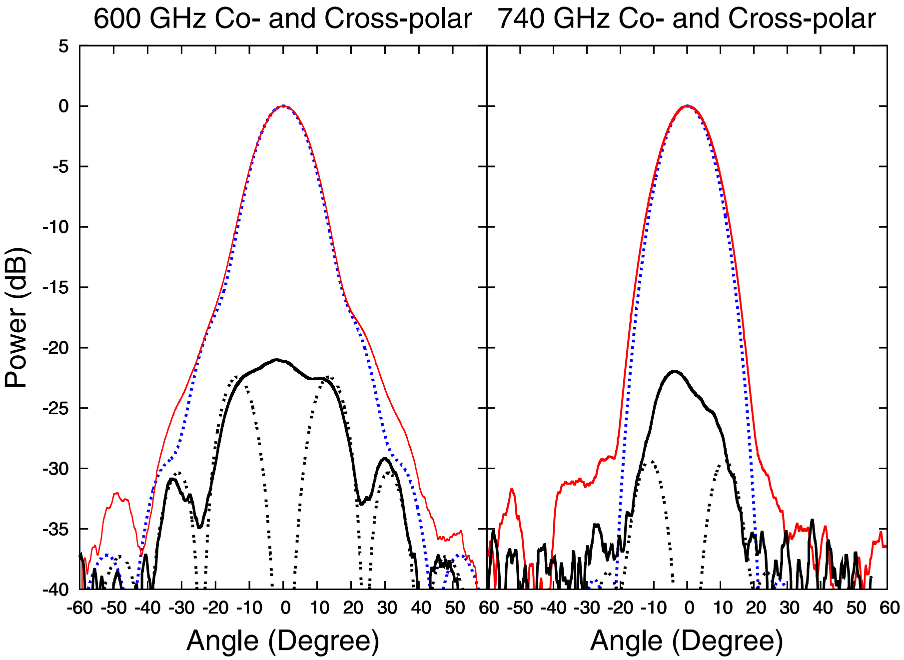

Fig. 3 Co-polar and cross-polarization patterns measurements at 600 GHz and 740 GHz (red solid—measured co-polar; black solid—measured cross-polar; blue dash—computed co-polar; black dash—computed cross-polar).

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