A Smooth Walled Four Pixel Feed Horn Array Operating at 1.4 THz

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Abstract— We have designed and fabricated a feed horn array to operate between 1300 – 1500 GHz. It consists of four smooth walled, two section feeds with a single flare angle discontinuity near the throat of each horn. The design was carried out using a modelling package that employs modal matching together with genetic algorithm and downhill simplex optimisation techniques. This determines the optimum horn dimensions given a set of stringent requirements on beam circularity and cross polarisation levels. The simulated far-field radiation patterns exhibit very good beam circularity, low sidelobes and low cross polarisation levels across the frequency range of operation.
The array has been fabricated out of brass by the workshop of Oxford University using a direct machining technique that employs drill tools shaped to the profile of the designed horn. Far-field beam pattern measurements presented in this paper were carried out at the Harvard-Smithsonian Center for Astrophysics and suggest good agreement with the theoretical predictions.

INTRODUCTION

Multiple pixel feed horn arrays are a popular choice to efficiently couple astronomical and local oscillator signals into Superconductor-Insulator-Superconductor (SIS) or Hot-Electron-Bolometer (HEB) mixers. Such arrays consist of a number of horns and offer high aperture efficiencies, low sidelobes, low stray light sensitivities and low cross polarisations required by many astronomical applications [2]. The style and properties of the individual feeds that make up an array determine how well astronomical signals couple to the receiver. Therefore, the performance of a feed horn array will largely depend on the horn design and the accuracy of fabrication.

Traditionally, corrugated horns have been the preferred choice for use as high quality astronomical feeds because they exhibit circularly symmetric antenna beam patterns with low levels of cross-polarisation and sidelobes over a wide frequency bandwidth [3]. The problem with such feeds however, is that they require many corrugations per wavelength to function which makes them increasingly more difficult, time consuming and expensive to fabricate at higher frequencies, particularly in the Terahertz (THz) range. This becomes especially important when fabricating arrays with large numbers of horns.

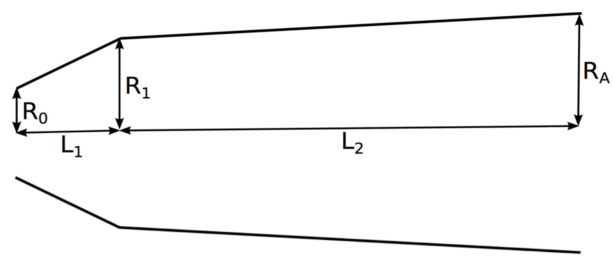

Fig. 1 Schematic diagram showing the inner profile of a smooth walled, two section feed horn.

A solution to the problem is to use a generalised version of the Potter horn with the phasing section removed [1], [4]. This type of horn has the advantage of being smooth walled and therefore easier to fabricate than a corrugated feed. On the other hand, it suffers from a relatively narrow bandwidth of ~ 10%. Nonetheless, such feeds have circular beams as it is possible to excite the TM11 mode within them by creating a sharp, step like discontinuity between the waveguide and the conical section of the horn. Provided that the incident TE11 and the excited TM11 modes arrive in phase at the horn aperture, this will result in sidelobe cancellation and low cross polarisation levels in the radiation pattern of the horn. Furthermore, by using a flare, rather than step, discontinuity it is possible to increase the operational bandwidth to ~ 15% and an even wider bandwidth can be obtained by adding more discontinuities at the throat of the horn [2].

In this paper, we describe the design, fabrication and beam pattern measurements of a smooth walled, four pixel feed horn array that operates between 1.3 and 1.5 THz which was designed and tested in collaboration with the Harvard-Smithsonian Center for Astrophysics. Our approach presents a fast and relatively simple solution to the issue of fabricating multiple feed horns at high frequencies and could, in principle, greatly speed up the fabrication of feed horn arrays in future instruments.

HORN DESIGN

A schematic diagram showing the inner profile of the horns in our array is presented in Fig. 1. This two section design, employing a single flare angle discontinuity, was obtained using a modelling package that determines the optimum horn dimensions given particular requirements on the far-field radiation pattern properties such as beam circularity and cross polarisation levels [5].

The simulated radiation patterns from our final design are shown in Fig. 2. These results have excellent beam circularity, low sidelobes and low cross polarisation levels between 1300 and 1500 GHz.

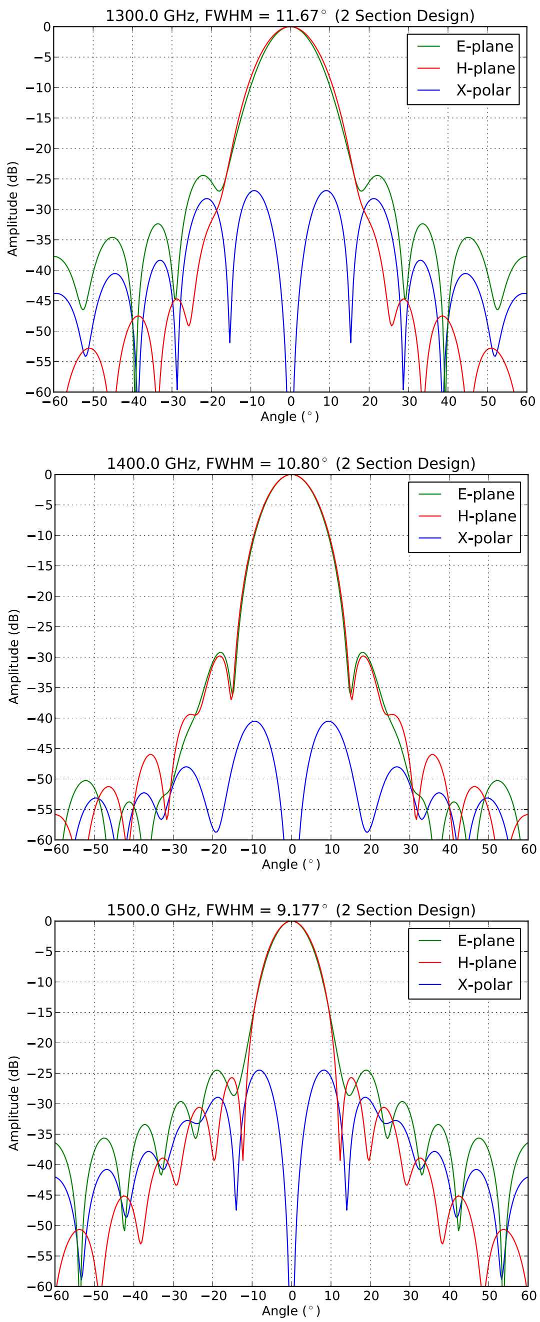

Fig. 2 Simulated far-field radiation patterns at 1300, 1400 and 1500 GHz.

Array Fabrication

The array was fabricated out of a brass block by the mechanical workshop of Oxford University. In order to create each of the horns in the array, a direct machining technique was used that employs a drill tool shaped to the horn's profile [6], [7]. A zoomed in, microscope image of such a tool is shown in Fig. 3.

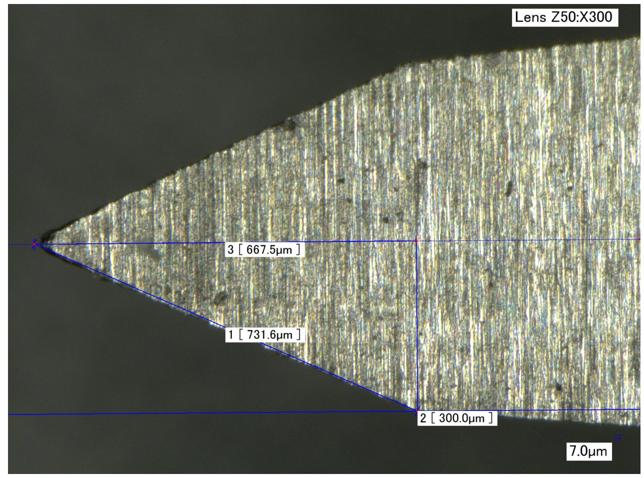

Fig. 3 High frequency (1.4 THz) feed horn fabrication tool.

The fabrication process itself begins with the creation of the circular input waveguide by direct drilling from one side of the block. The size of the drill required depends on the size of the waveguide. In our case, a 0.22 mm diameter drill was used.

Once the waveguide is complete, a high speed fabrication tool, such as the one shown in Fig. 3, is used to drill the required horn profile within the brass block.

The dimensions of our optimised horn design are given in Table 1 while the fabricated feed horn array is shown in Fig. 4 and 5.

TABLE I
FEED HORN DESIGN DIMENSIONS

Parameter	**Length (mm)**
R_0	0.112
R_1	0.304
R_A	0.764
L_1	0.420
L_2	5.110

When drilling feed horns from two different sides of a metal block, great care must be taken as any misalignment between the input waveguide and the horn itself will lead to deviations from theory in the measured radiation patterns.

Having said that, this method of fabrication has the advantages that it is more robust and reliable than electroforming. As well as this, once the machine tool and the metal block have been aligned, it is possible to repeat the process and quickly manufacture any number of identical feed horns.

Following repeated tests, we found that in order to get good experimental agreement with the simulations at these frequencies, the tolerances on the dimensions of the drill tool must be approximately 5 microns.

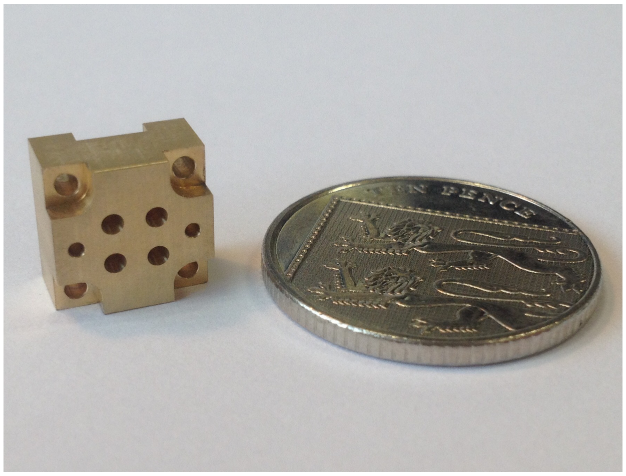

Fig. 4 The completed 1.4 THz array, shown beside a coin for scale.

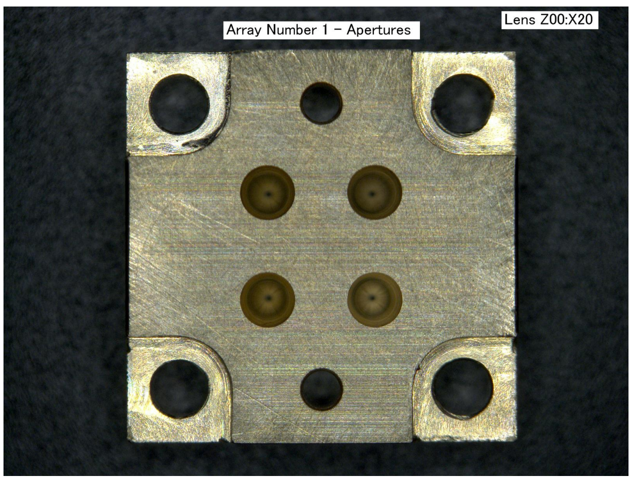

Fig. 5 Close up view of the completed 1.4 THz feed horn array.

MEASUREMENT AND RESULTS

The beam pattern measurements were carried out at the Harvard-Smithsonian Center for Astrophysics using an x-y stepper stage and a diagonal horn with an aperture diameter of 0.7 mm. The diagonal horn was used as the transmitter while our array was placed on the detector side. The separation between the two feeds was ~ 80 mm which ensured that the horn was in the far-field regime. A two dimensional beam scan at 1.35 THz is shown in Fig. 6. This result looks promising and it can be seen that the beam has good circularity and symmetry.

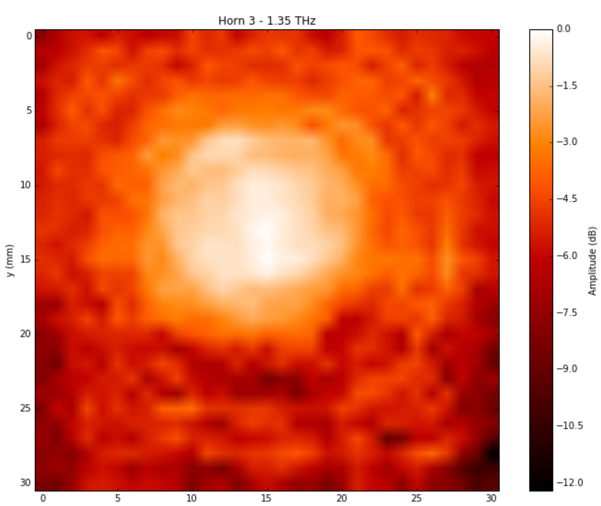

Fig. 6 Two dimensional beam scan at 1.35 THz.

As well as this, measurements were also carried out at 1.435 THz and a quadratic fit to the data is presented in Fig. 7 and 8. These results have been plotted over the theoretical predictions in the E and H-planes.

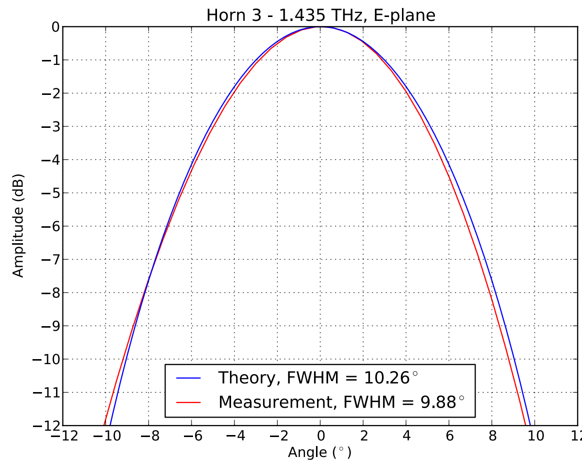

Fig. 7 E-plane theory and measurement at 1.435 THz.

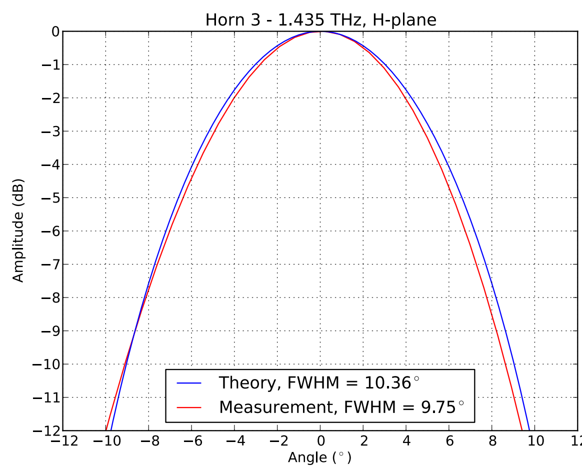

Fig. 8 H-plane theory and measurement at 1.435 THz.

From Fig. 7 and 8, it is evident that the measured beam patterns agree very well with the simulated predictions in both planes.

The Full Width at Half Maximum (FWHM) difference between the theory and result is 0.61 degrees in the H-plane and just 0.38 degrees in the E-plane. Furthermore, a FWHM difference of 0.13 degrees between the E and H-planes in the measured data suggests a highly circular beam. This is a very encouraging result which indicates that our method of horn design and fabrication is effective and viable for creating feed horn arrays that can operate at frequencies well into the THz regime.

Provided that careful attention is paid to the dimensions of the drill tools and that these can be accurately machined to the specified tolerances, there is no reason why this technology cannot be pushed to even higher frequencies.

CONCLUSIONS

We have designed, fabricated and measured a smooth walled, four pixel feed horn array operating between 1.3 and 1.5 THz.

The horns were designed using a modal matching technique that optimises the dimensions of the horn to produce excellent simulated far-field radiation patterns.

The array was fabricated at the University of Oxford using a highly accurate direct machining technique to match the dimensions of the fabricated horns to within 5 microns of the design specification.

Initial far-field radiation pattern measurements were carried out at the Harvard-Smithsonian Center for Astrophysics. They show encouraging agreement with theory suggesting that our method of horn design and array fabrication can offer a robust approach to making feed horn arrays operating in the THz regime.

In the future, we will aim to improve upon these preliminary results by extending the dynamic range to the sidelobe level and also increasing the frequency range of the measurements.

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