A MODERATE COST 2.5THZ HIGH PERFORMANCE FEEDHORN

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Abstract

Corrugated waveguide feedhorns operating at terahertz frequencies were first demonstrated in 1994 and have been used successfully since this time. Whilst offering unrivalled performance their production requires state of the art precision machining and can be time consuming. Also, each has to electroformed around an aluminium mandrel. Feedhorn fabrication is carried out on a one for one basis as the mandrel is eventually destroyed as part of the manufacturing process. The cost of the end product is therefore very high.

A modified version of the Potter horn was demonstrated to operate at these frequencies in 1998 but these feedhorns whilst being easier to machine than their corrugated counterparts were still fabricated using an aluminium mandrel. We have now developed the machining and electro-forming procedure to allow such horns to be made using an extractable stainless steel mandrel that incorporates the circular to reduced height waveguide transition. This approach has so far allowed six identical feedhorns to be made from one mandrel which has subsequently shown no sign of damage or degradation.

The resulting horns radiation characteristics have been measured and are found to be in excellent agreement with theory.

In addition, we have developed a technique that allows the feedhorn to be removed and replaced whilst maintaining near perfect alignment of the waveguides.

This paper describes the manufacturing process and presents the radiation properties of the horn.

Introduction

Since the introduction of corrugated feedhorns at true terahertz frequencies in 1994[1], it has become possible to realise terahertz receivers that have near perfect Guassian coupling efficiency[2]. This is of paramount importance for microwave limb sounding where the field of view of the radiometer must be more or less completely restricted that portion of the limb being observed. However, the cost associated with such feedhorns is still very high as the fabrication process requires the machining of a complicated aluminium former or mandrel that possesses micron scale features. The electro-forming process that must be used necessitates the removal of this mandrel via chemical etching. Therefore horns are realised on a one for one basis.

An alternative design[3] that also offers adequate performance for limb sounding has also been fabricated and demonstrated in working 2.5THz mixers [4,5].However, whilst this design of horn in principle allows the mandrel to be extracted it was still machined from aluminium because of its desirable machining properties. This paper describes how a new manufacturing process has been realised whereby the mandrel is machined from stainless steel which allows the mandrel to be released after electro-forming allowing it to be subsequently re-used. So far six feedhorns have been pulled from the same mandrel with no apparent wear . This process has several advantages, firstly, it promises to dramatically reduce the future cost of terahertz feedhorns fabricated in this way and also ensures that provided the master mandrel has been machined correctly the tight tolerances required are easily maintained .All horns produced are effectively identical to the master. Finally there is no degradation of the surface finish of the horn as the stainless steel mandrel requires no pre-treatment etch of its surface prior to gold electroplating as is the case with aluminium.

The Fabrication Process

Firstly the circular sections of the stainless steel mandrel are machined on a precision lathe. This lathe is fitted with high precision positional slides that allow tool placement to within +/-1μm. The tool used is a conventional lathe turning tool fabricated using a precision grinder and hand lapped to a point. The lathe is also fitted with high performance microscopes with large working distances and magnifications of 50-100X.

In order to machine the rectangular waveguide section and circular to rectangular taper the mandrel is then moved to a ultra high precision milling machine. This can achieve repeated tool placement to within +/- 0.5μm. This detail is machined using a 150μm diameter carbide endmill. An optical non-contacting measurement system is used at all stages to ensure that the tight tolerances required by this design are met. Dimensions can be determined to an accuracy of +/-1μm. The finished 2.5THz stainless steel mandrel with a human hair to give an idea of scale is shown below in figure 1.

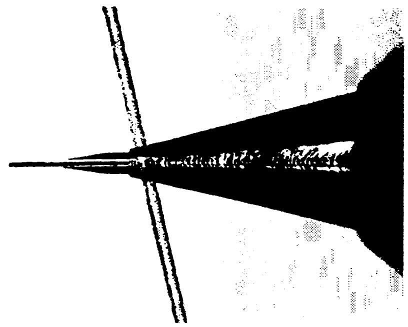

Figure 1: A finished 2.5THz stainless steel mandrel and human hair

Once machined and inspected the mandrel is coated in a $2\mu m$ thick layer of electroplated gold followed by copper electro-forming. Compared to the electro-forming of aluminium the process is quicker, more straightforward and has less risk associated with it as the solutions are near neutral pH. The only area of uncertainty is in obtaining sufficient adhesion between the mandrel and the gold to stop the gold lifting but allow the mandrel to be easily extracted. Once the required thickness of copper has been formed the profile of the feedhorn package is machined and the mandrel extracted. For extraction a simple non-rotating sliding pulling mechanism is employed. Very little force is required for the removal as the surface area of the horn is so low.

The basic construction of the mixer is the same as that described in Ref:4. The backshort waveguide section that also houses the RF circuit and Schottky diode is formed in two parts. A machined waveguide/RF filter channel and micromachined diode pill package which is soldered in to form the waveguide roof. However, whereas in the earlier design the feedhorn had to be optically realigned each time the mixer was modified for the Engineering Model mixers this was not possible because of the requirement for an integrated bias circuit and the mixer mounting scheme adopted. Therefore it was decided to use a self aligning approach whereby the feedhorn is automatically aligned to the waveguide upon assembly. This is achieved by the use of two 0.7mm stainless steel dowels. An external clamping fixture is used to hold the feedhorn securely in place. An assembly drawing is shown in figure 2 alongside a photograph of a finished mixer block.

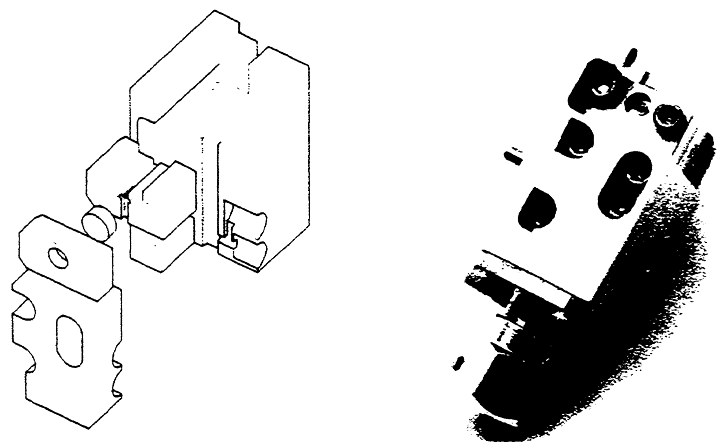

Figure 2: An assembly drawing and photograph of a 2.5THz mixer block

To achieve the alignment required, +/-1μm, the feedhorn is backlit and moved whilst observing through a powerful microscope. When the waveguide in the feedhorn and the mixer are aligned it is clamped and the two dowel holes are drilled and reamed. Some care was required to obtain a sufficiently close fit between the dowels and holes to allow easy removal and replacement without the loss of positional accuracy. In order to check that the feedhorn could be removed and replaced without the waveguides becoming mis-aligned it was carried out several times and checked visually. A series of photographs showing the alignment of the waveguides before and after removal and replacement are shown below in figure 3. The entrance to the filter channel can also be seen.

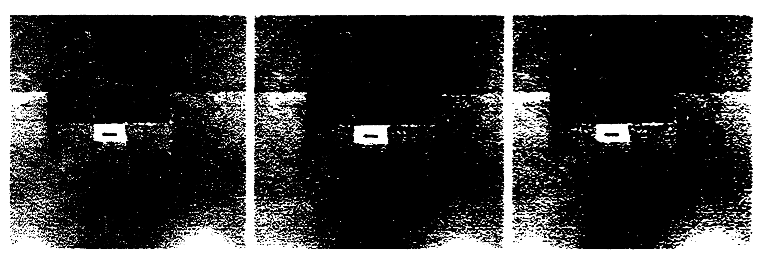

Figure 3: The alignment between feedhorn and waveguide after removal 3 times

A photograph of the finished horn is shown below in figure 4 alongside a view of the waveguide aperture. For scale a human hair is shown, the waveguide dimensions are 27.5x105μm. The feedhorn alignment dowels can be clearly seen to the left and right of the horn aperture.

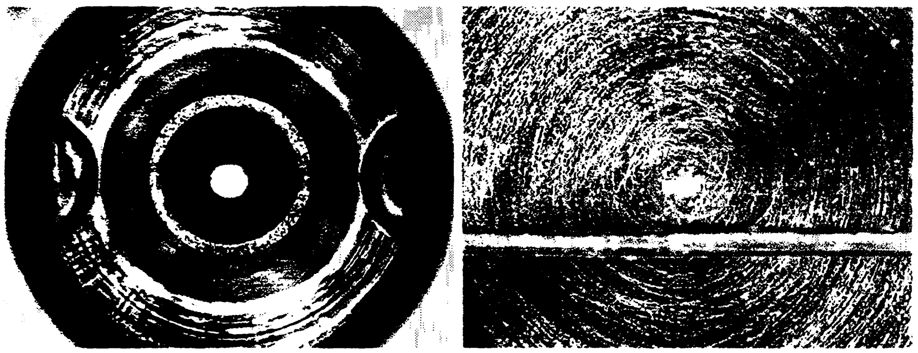

Figure 4: The feedhorn and waveguide apertures.

An early mixer was assembled which could then be used to carry out beam pattern measurements at JPL. The diode was used to detect the applied signal for a far infrared laser operating at 2.5THz whilst the mixers field of view was scanned in 2 axis. A photograph of the measurement system is shown below in figure 5. The laser is fired through a pinhole in order to shape the beam, then through a beam splitter to separate a small amount for power level reference. A chopper is using to modulate the beam and the bias of the mixer is used to determine the power level seen by the mixer.

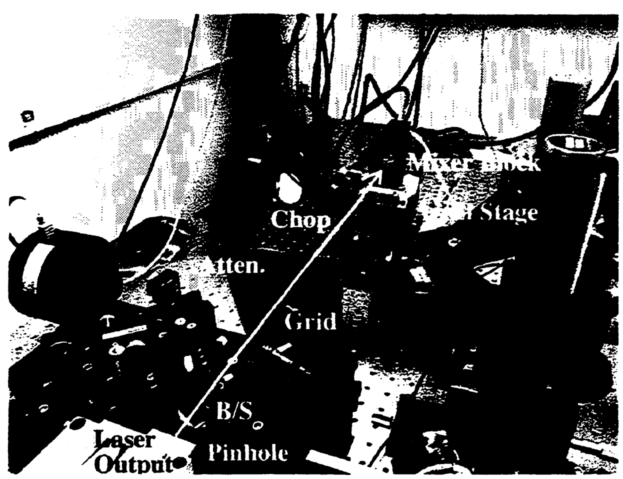

Figure 5: The measurement set-up used to determine the radiation pattern

The horns radiation pattern is shown below in figure 6.

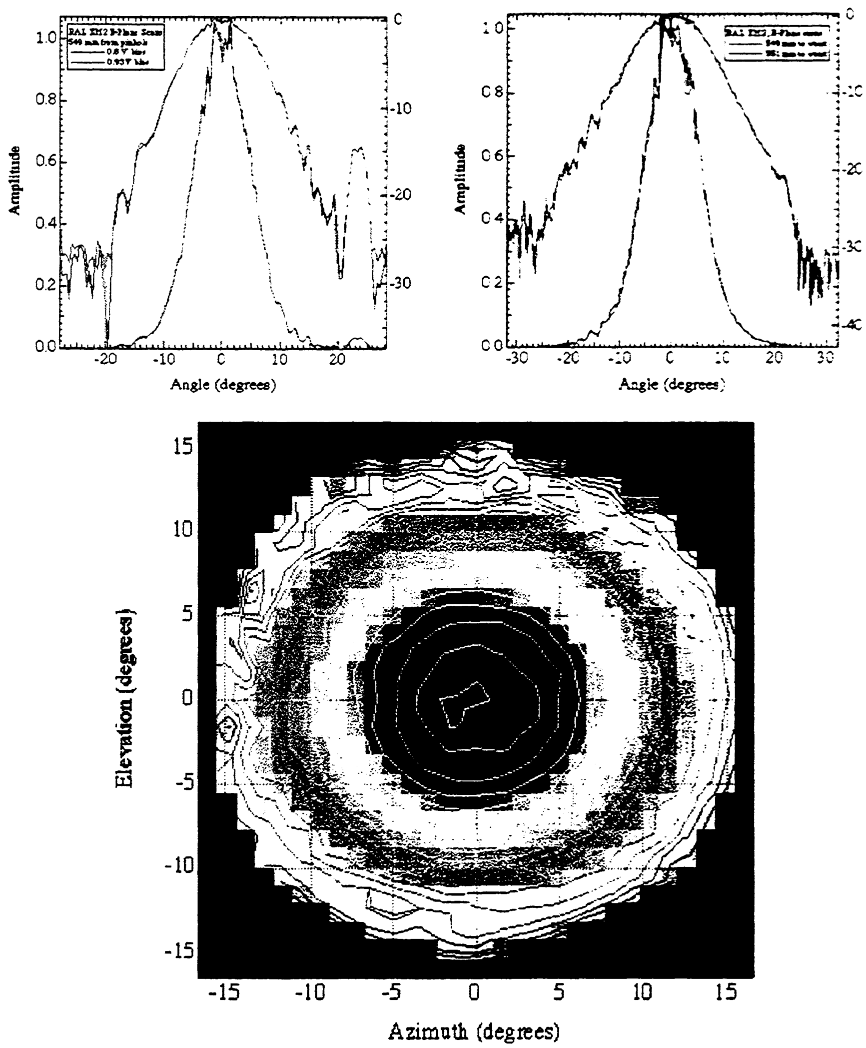

Figure 6: The measured radiation pattern of the feedhorn at 2.5THz

From the plots it can be seen that the horn as a very high quality radiation pattern. Some asymmetry exists between the E and the H plane, also, a spurious side lobe is present in the E-plane. This lies outside the antenna's field of view in the 2.5THz EOS-MLS system and its origin is at present unknown. More measurements will be required on subsequent mixers in order to determine if it is a characteristic of all horns extracted from this mandrel.

Discussion

The ability to automatically align the feedhorn to waveguide combined with the reduced cost allows the possibility of a miniature mixer package. The mixer and feed horn can be simply assembled and fixed together with adhesive. The potential exists for the completed mixer to be simply included in the backend low noise amplifier housing. This in term may allow the realisation of compact imaging arrays.

Conclusion

A new fabrication process has been demonstrated that can produce at moderate cost high quality waveguide feedhorns. It is expected that the technique could be extended to at least 5 THz. In addition to the reduced cost, the technique also has the advantage that each subsequent horn is an exact copy of the original therefore maintaining radiation properties between different horns.

Finally the removal of the need for a mixer block type housing by incopoporating automatic alignment opens the way forward for small compact terahertz imaging arrays.

Acknowledgements

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