A spline-profile Diagonal horn with low cross polarization and sidelobes, suitable for THz split-block machining

Hugh J. Gibson*, Bertrand Thomas[2], Marc Warnke[2], Alain Maestrini[3], Peter de Maagt[4]
[1] *Gibson Microwave Design , 92160, Antony, France*
[2] *RPG Radiometer Physics GmbH, 53340, Meckenheim, Germany*
[3] *Observatoire de Paris, LERMA, 75014, Paris, France*
[4] *ESA/ESTEC, Noordwijk, The Netherlands*
*Contact: hugh.gibson@radiometer-physics.de

Abstract— This paper presents a novel diagonal horn design with improved performance over a standard diagonal horn. The cross polarization is reduced from -10dB to better than -20dB and co-polar side-lobes are also reduced. Power coupling to a single linear polarization fundamental Gaussian mode is improved from 84% to approximately 97%, similar to smooth-walled spline horns and only slightly worse than a conventional corrugated horn. The horn can be directly machined in split-block up to several THz with relative ease using standard milling techniques.

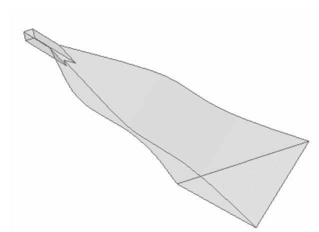
INTRODUCTION

Horn antennas which can synthesize a Gaussian beam are needed for coupling to Gaussian optics. Corrugated horns have traditionally been the preferred horn choice with best performance but are impractical to produce above about 1.5THz due to difficulty in machining very thin corrugations. Modern "dual-mode" horns including smooth walled spline-curve conical horns [1] [2] and multi-taper conical horn designs [3] have excellent properties but are still relatively difficult to manufacture. The only horn that is uniquely suited to easy direct machining in split-block form (with a Gaussian power beam-profile) is the straight-walled diagonal horn although the performance has up till now been significantly worse than that of other types of horns, especially in cross-polar losses.

BACKGROUND

The diagonal horn was first described by Love [4]. Johansson and Whyborn [5] suggested a transition from rectangular waveguide and an optimal value for the beam size at the aperture. Withington and Murphy [6] published a mode analysis. The diagonal horn is directly machined by cutting a deepening "V" groove into each half of a waveguide split-block. It is in widespread use and has excellent beam-coupling properties and good circular symmetry but performance is compromised by a relatively high cross-polarization component (-15dB) and sharp -16dB secondary lobes in the 45° radiation axis. Improvements have already been suggested [7] but most are not compatible with THz frequencies.

IMPROVEMENTS TO THE DESIGN



A smooth natural spline curve was added to the vertical axis (depth) of the "V" cutting tool. The horn antenna was optimised for the 1080 GHz to 1280 GHz frequency range for the Submillimeter Wave Instrument (SWI) onboard JUICE ESA Jupiter mission. The horn-antenna gain is about 23dBi which is compatible with similar horns. The cross-polarization is improved to < -20dB and the unwanted shoulders in the beam-shape (45° plane) reduced from -16dB to < -20dB. The horn is only slightly longer than the original diagonal horn for similar gain. Figure 1 shows the beam shape at three different frequencies, with cross-polar component, at 45° (green), and co-polar 45° plot (brown). The far-field phase of the antenna is flatter over a larger radiation angle, which improves antenna coupling efficiency as there is less de-focusing off-axis. All plots are using a spherical scan, far-field, with the origin set to optimised phase centre[8].

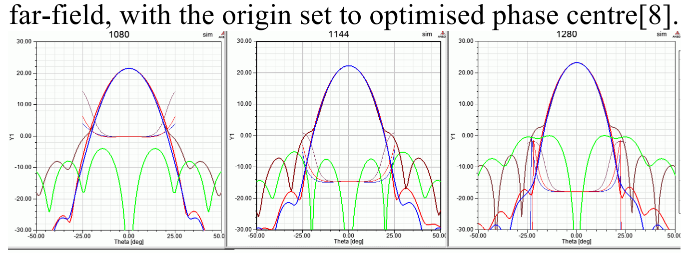


Fig. 1 Improved diagonal horn simulation for three frequencies. X-pol (45°) is in green. Ludwigs 3rd definition of cross-polarization[8] is used.

The estimated integrated power coupling to a fundamental mode, single polarization Gaussian is better than 95% (including cross-polar losses) which is a significant improvement with respect to the standard diagonal design which has approximately 84% coupling (with 9.5% loss in cross-polarization alone, or 0.43dB). We calculate the 2D coupling to a fitted Gaussian to be 98% for 0 and 90 degree cuts, and 92% for the 45 degree cut, including cross-polar losses.

Ease of manufacture at THz frequencies

Because the spline curve has no abrupt corners, a surprisingly large diameter milling tool can be used to create the gentle curve. It is estimated that a horn for 10THz can be directly machined with an end-mill tool with a diameter of 0.1 mm with relative ease. The horn is also extremely tolerant to machining errors [9].

Wide bandwidth tests

The diagonal horn using the Whyborn [5] direct-transition from waveguide to horn suffers from poor match at extreme low frequencies (bottom end of a complete waveguide band). Good performance can be regained using a slightly modified flared-waveguide transition to the horn. More details are given in [9].

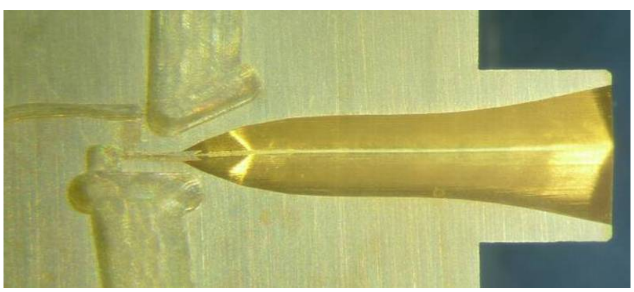


Fig. 2 1.2THz Sub-harmonic mixer split-block including spline diagonal horn antenna (design by GMD, machined by RPG Radiometer Physics GmbH)

Conclusion

A spline diagonal horn has been built as part of 1.2THz mixer developments and it is planned to extend this design up to 2THz as part of ESA contract AO/1-8271 in collaboration with Observatoire de Paris and RPG. The traditional diagonal horn design has been modified using a spline-curve “s”shape modulation in the depth of the “V” groove. This modification is similar in shape to smooth-wall spline horns and improves cross-polarization purity, side-lobe level and the spherical wave front of the beam. The result is a high quality horn which can be directly machined into split-block, exactly as the original diagonal horn. The technology is extendable to 10THz and promises to be an easy way to realise high quality horns at multi-THz frequencies with conventional split-block technology. Integrating the horn directly in the mixer block also solves the difficult problem of the alignment of waveguide flanges at THz frequencies. The reduction of waveguide losses due to a very short connecting waveguide is also very advantageous. Final measurement tests are on-going. Complete details of the new design and comparisons with other horns are to be found in [9].

Acknowledgements

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