A Modular 100-GHz High-Gain Scalar Corrugated Nonbonded Platelet Antenna

Miikka Kangas, Keith Copsey, and Philip Lubin

***Abstract*—A compact 100-GHz corrugated platelet array antenna has been developed based on a corrugated feed design for the background emission anisotropy scanning telescope (BEAST). The antenna results in a gain of 20 dB, and a bandwidth across the full range of W-band 75–110 GHz. The sidelobes are down by about $-$ 25 dB, a requirement comparable to feed horns used for observation of the cosmic microwave background. The design and fabrication presented in this paper is straightforward and inexpensive. A feature is that because the plates are not permanently bonded, the horn can be disassembled and modified to change its properties.**

***Index Terms*—Corrugated feed, cosmic microwave background, millimeter waves, platelet horn.**

I. INTRODUCTION

CORRUGATED millimeter- and submillimeter-wave feed arrays are important for low background measurements of the cosmic microwave background [1]. Smooth walled horns tend to have significant cross-polar contamination, but are simpler to make than corrugated feeds. The typical manufacturing process for corrugated horns is either direct machining for longer wavelengths or electroforming. Another method is the machining or lithographic patterning of metal plates and bonding them together. Previously, Rebeiz *et al.* [2] have constructed and tested a platelet array with diffusion bonded copper or aluminum plates. However, since the process of diffusion bonding plates is specialized, diffusion bonded platelet horns have not gained use in corrugated feed array based instruments such as background emission anisotropy scanning telescope (BEAST) and other cosmic microwave background (CMB) experiments [3].

This paper presents a new and very inexpensive platelet horn design that is manufactured in a simple computer numerically controlled (CNC) machining setup. These corrugated horns were all constructed in our lab with a CNC. This ease of construction allowed the manufacture of sophisticated low-sidelobe corrugated platelet horn arrays by undergraduate student assistants.

Typically corrugated horns utilize $\lambda/4$ ribs on the inner walls of the horn and the resulting destructive interference to reduce interaction between the propagating waves and the metallic walls of the horn [4]. The construction requirements are particularly difficult for millimeter-wave corrugated horns as they require direct machining or sacrificial electroformed mandrels.

Manuscript received December 3, 2004; revised February 2, 2005. This work was supported by NAG5-4078, CS-10-98, and UCSB WMNT FY02-03.

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Digital Object Identifier 10.1109/LAWP.2005.845908

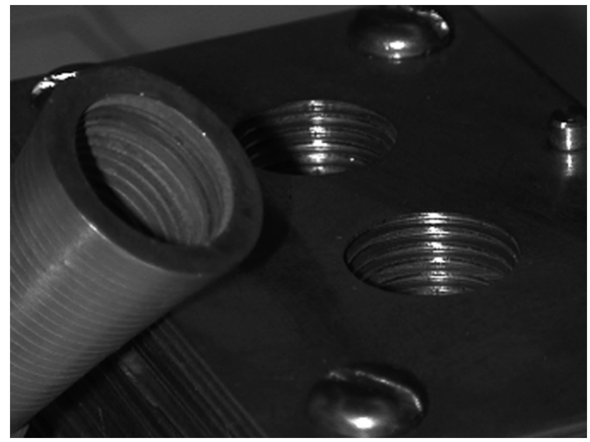


Fig. 1. 100-GHz platelet and electroformed horns.

In this novel design brass plates are CNC machined and then stacked together to form the array, which is held together with stainless-steel screws and pins; see Fig. 1. The performance of platelet horns is slightly inferior but comparable to our electroformed copper horns of a similar design; however, this is offset by the fact that platelet horns are much cheaper and simpler to make than the electroformed variety. The construction procedure was iterated and improved until it took only a few days and less than $100 in materials and tooling to manufacture much larger arrays of horns.

II. ELEMENT ANTENNA

A. Antenna Design and Manufacture

A W-band corrugated broad-bandwidth scalar feed horn design had been implemented previously for the BEAST telescope [1], and the possibility of constructing similar horns with the platelet technique was explored. The cross section of the existing horn is shown in Fig. 2.

The corrugated platelet horn test arrays were designed in AutoCAD, G code was generated with MasterCAM, and the plates were then manufactured with a modified MAXNC tabletop CNC mill. 8-32 stainless slotted pan-head screws hold the plates down onto a brass base block and also serve for alignment with a tight clearance hole in the first iteration horn, while in later iteration steel pins were used. The thickness of the base block is set by the length of the uncorrugated section of the existing electroformed control horn.

The corrugated rib structure was based on the ribs in the Bersanelli horn, but were adjusted to match the convenience of

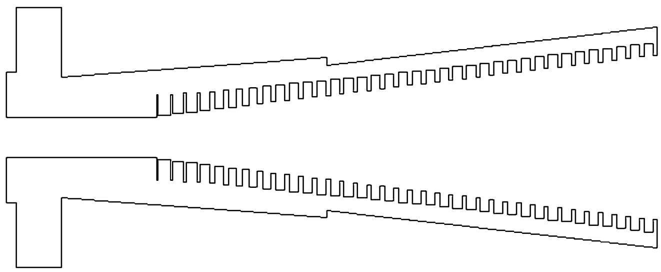
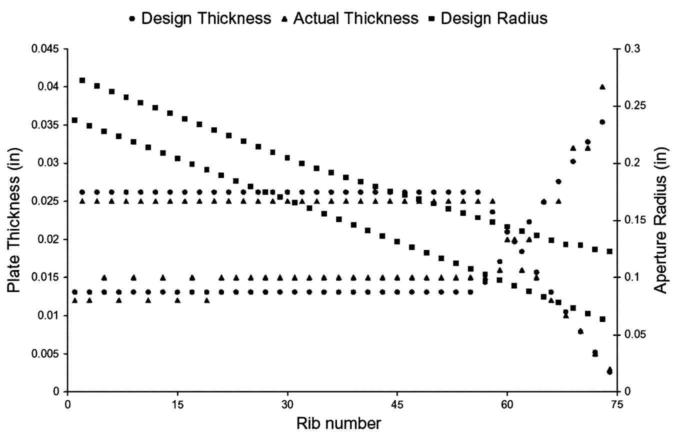


Fig. 2. Cross section of electroformed horn.

TABLE I
INTERNAL CORRUGATION RIB STRUCTURE



metal sheets available for machining. The exact plate thicknesses and positions are given in Table I.

B. Pattern Measurements on a Single Element

Preliminary measurements of the first iteration of the horn design appear in [5]. The sidelobe data in this paper was taken with a computerized azimuth elevation stage with synchronized movement and data acquisition. The detector was a monolithic microwave integrated circuit (MMIC) high-electron-mobility transistor (HEMT) amplifier based detector with an auto ranging feature with a computer-controlled amplifier that reduced the gain when the voltage on the diode went into the saturated or under stimulated nonlinear region above about 70 mV or below about 1 mV. The source was a fixed-frequency 90-GHz Gunn diode with a variable attenuator and a kilohertz modulated power supply. The detector signal was locked in to the Gunn power modulation. The data acquisition system (DAQ) was a 12–bit analog-to-digital (A to D) based board. The bit limited of about 36-dB dynamic range on the DAQ was also a factor in the computer control of the detector chain. The bit noise can be seen in some of the cross polar data sets. The same detector system was used for variations on this horn described elsewhere [6].

Eccosorb sheets were placed to reduce multipath and sidelobe pickup. Scans were made in E-plane and H-plane, with positive sidelobe detection at the 20–25-dB level. A full two-dimensional scan of the sidelobe pattern was made with the azimuth-elevation stages, and sidelobes were positively detected at the expected level.

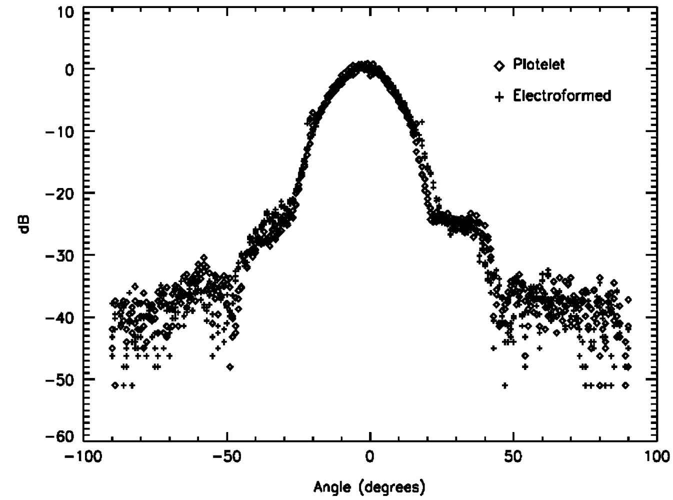


Fig. 3. E-plane copolar sidelobes.

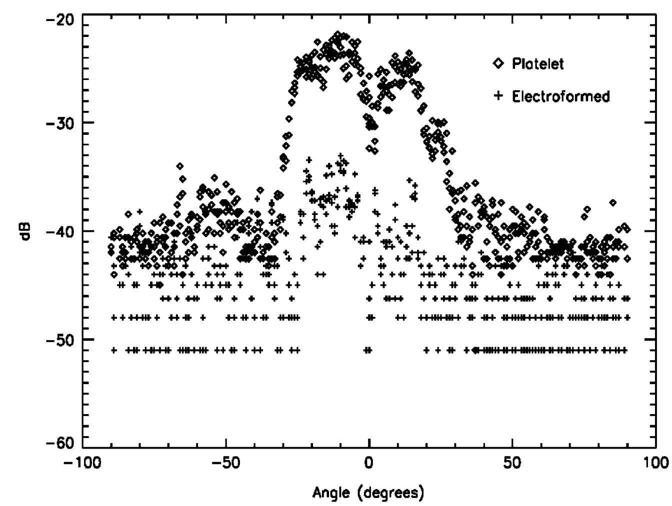


Fig. 4. E-plane cross-polar sidelobes.

C. E- and H-Plane Results

Scans along the E- and H-plane resulted in sidelobe measurements at levels comparable to similar design electroformed silver horns. For CMB instruments typical first sidelobe levels are at -25 dB.

The detector and source were simultaneously rotated 90° to perform the E-plane scan as well as the H-plane scan on the same azimuth stage. The neighboring pixels in the 2- and 4-pixel strip arrays were separated by one or more center frequency lambda, and were not important as they were covered with metal sheets and did not impact the sidelobes at the measured levels.

The E-plane sidelobes were measured directly by scanning in azimuth (see Figs. 3 and 4), while the H-plane sidelobes were scanned by adding 90° waveguide twists into the source and detector and also scanning in azimuth (see Figs. 5 and 6). This was because of the range of motion of the azimuth was greater than the elevation in the scanning mechanism.

The weight of the horn arrays and detector was offset with a gimbal mechanism to remove load strain on the relatively small stage. Cross-polar measurements on the E and H planes were performed by removing or adding the 90° twist to the source.

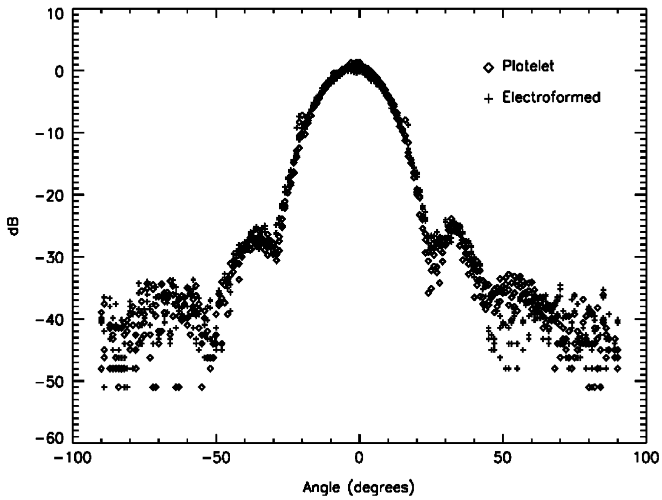


Fig. 5. H-plane copolar sidelobes.

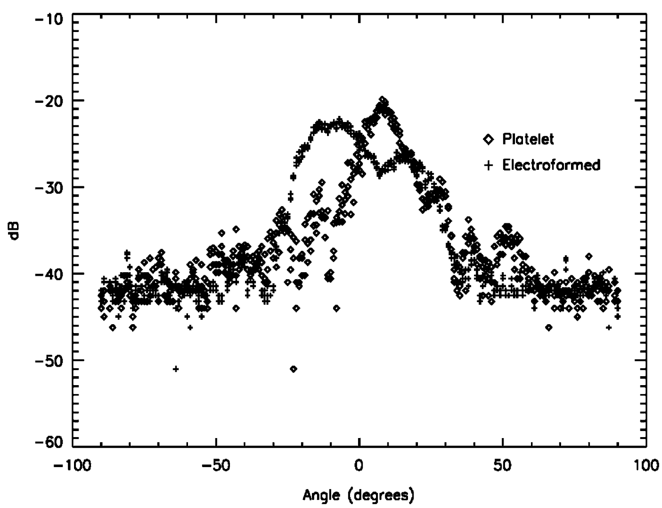


Fig. 6. H-plane cross-polar sidelobes.

Eccosorb covered parts of the gimbal mechanism but no significant difference was seen in data taken with Eccosorb on the deloading mechanism versus those performed without Eccosorb.

D. Two-Dimensional (2-D) Sidelobe Pattern

There exists a small horizontal residual line because of the compositing of two scans in some maps but is almost undetectable. This compositing was required because of limitations of the stage movement. The 2-D maps are not as deep as the one–dimensional (1-D) sidelobe scans because of the reduced integration per pixel (see Figs. 7 and 8).

E. Reflection and Loss Measurement

Reflection coefficients were measured with a W-band vector network analyzer (VNA). The S_{11} measurement of the platelet pixels were different but comparable in general magnitude to the S_{11} measurements (see Fig. 9) of a copper electroformed horn. This difference in reflection coefficient is not important for many applications [7] such as millimeter-wave astronomy. The

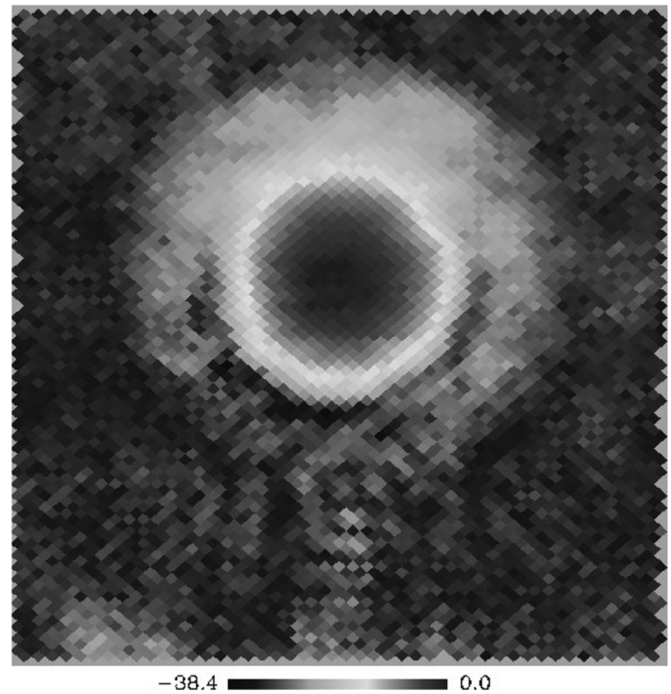


Fig. 7. 2-D copolar sidelobes, 1 dB from max.

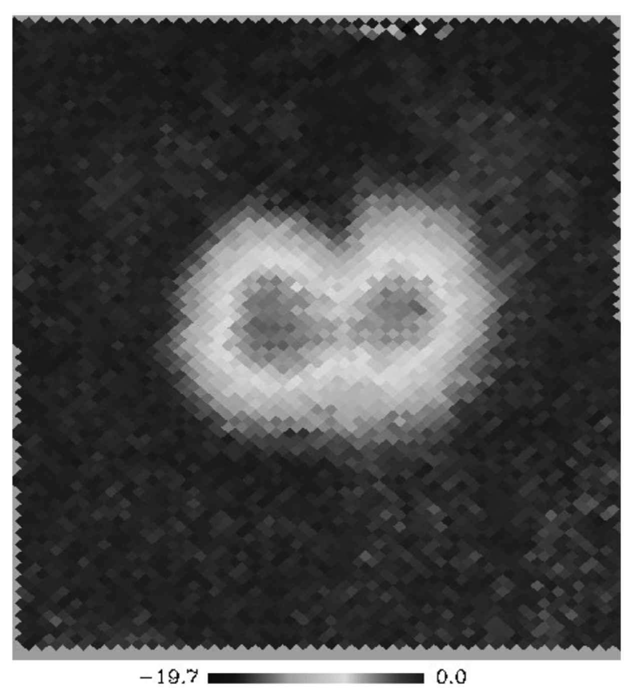


Fig. 8. 2-D cross-polar sidelobes, 1 dB from max.

reflection coefficient was insensitive to variations in the tightness of the screws pressing the platelet stacks together. This was measured by adjusting the tightness of the screws by hand while watching the output of the VNA. The output did not change significantly until the array began to visibly fall apart because the screws had been loosened. Eccosorb loads that required multiple bounces from multiple angled sheets from the aperture of

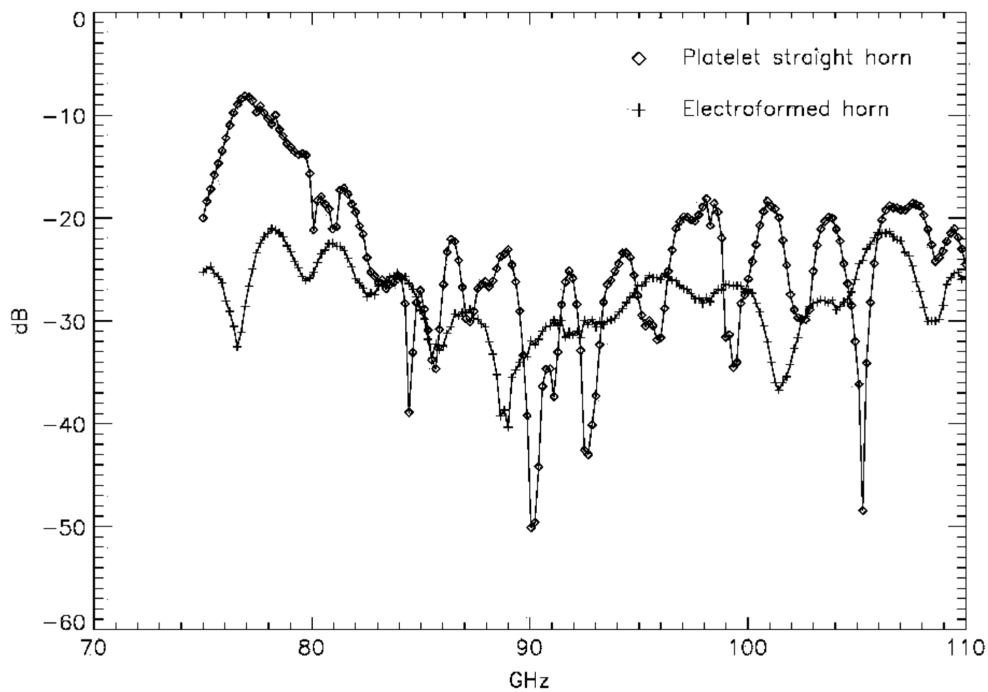


Fig. 9. S_{11} measurements.

the horn were utilized as the type of Eccosorb sheet used typically reflects at -15 dB at W-band at normal incidence. The open room was also utilized as a blackbody load as the test room with the VNA was surprisingly efficient as a blackbody absorber.

III. Conclusion

A new form of platelet horn has been developed. The low cost and ease of construction allows manufacture of arrays of corrugated feeds in laboratory settings, and the ability to disassemble and reassemble the horn allows for modification of the feed post-installation in a millimeter-wave instrument. Although the performance of the horn is quantitatively slightly different from electroformed copper horns of the same design, qualitatively it is the same. For many applications including millimeter-wave astronomy [8] the difference may not be important.

Acknowledgment

M. Kangas wishes to thank the UCSB physics machine shop for their suggestions in tuning and setting up the MAXNC CNC mill years ago, and P. Meinhold for lending a W-band amplifier and variable attenuator, and M. Ansmann for writing Delphi code. A. Levy helped with the Vector Network Analyzer (VNA). Prof. M. Rodwell from the UCSB ECE Department allowed us to use his W-band VNA. M. Kangas also thanks K. Yamaguchi for help with the DAQ and R. Pizzi for providing a test room. Some of the results in this paper have been derived using the HEALPix package. http://www.eso.org/science/healpix

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