A 100-GHz High-Gain Tilted Corrugated Nonbonded Platelet Antenna

Miikka M. Kangas, Markus Ansmann, Keith Copsey, Briony Horgan, Rodrigo Leonardi, Philip Lubin, and Thyrso Villela

***Abstract*—A compact 100-GHz corrugated platelet array antenna with an internal tilt has been developed based on a untilted platelet antenna design similar to W-band electroformed horns for the background emission anisotropy scanning telescope (BEAST). The antenna results in a gain of 20 dB, and a beam launching bandwidth across the full range of W-band 75–110 GHz as measured by a vector network analyzer (VNA), with beam tests performed at 90 GHz. The side lobes 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. One innovative feature of this array is that the horn can be disassembled and modified to change its properties since the plates are not permanently bonded. A second innovative feature is the ability to direct the horns with an internal tilt without significantly adversely affecting sidelobes and cross-polar pickup. This is useful for large focal plane arrays of detectors where horns must be directed toward a central region such as a telescope mirror.**

***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]. Because cryogenic detectors have begun reaching the photon-noise limit, the only way to increase detector system sensitivity is to increase the size of the detector arrays. Smooth walled horns tend to have cross-polar contamination, but are simpler to make than corrugated feeds. The ability to construct corrugated feeds cheaply and simply would enable the construction of large arrays of corrugated horns in compact focal planes for instruments. Previously, Kangas *et al.* [2] have constructed platelet antennas with nonbonded brass sheets. Nonbonded platelet arrays hold promise for corrugated feed array based instruments such as background emission anisotropy scanning telescope (BEAST) and other cosmic microwave background (CMB) experiments [3].

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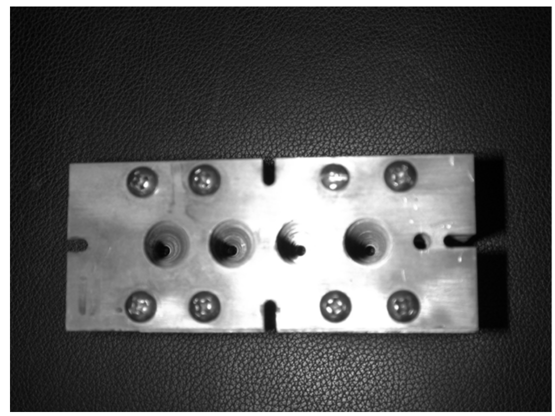

Fig. 1. 100-GHz tilted platelet horns.

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.

In this novel design brass plates are computer numerical control machined and then stacked together to form the array, which is held together with stainless steel screws and pins. The number and thickness of plates is identical to the straight design and is given in [2]. See Fig. 1. The construction procedure was iterated and improved until it took only a few days and less than a hundred dollars in materials and tooling to manufacture much larger arrays of horns. The S parameters were not sensitive to plate alignment, as disassembling and rebuilding the array by hand reproduced the same vector network analyzer (VNA) S parameters and sidelobe patterns. This lack of sensitivity to assembly indicates this method could be used to construct higher frequency horns, possibly into the THz.

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 platelet horns of a similar design had been implemented in single pixels [2] and in arrays [5]. For large focal plane arrays of such horns, directing the horns toward a central point such as

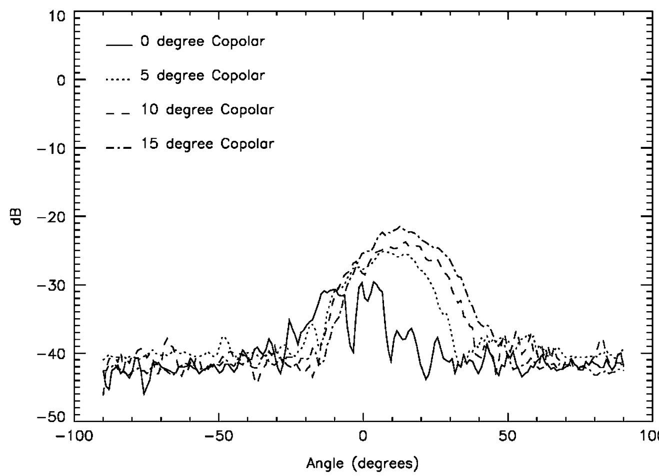

Fig. 2. Cross-polar E-plane tilted horn beams.

the center of a telescope mirror is desirable. The ability to construct an internal tilt in horns made with the platelet technique was explored.

The structure of the straight platelet horn in [2] was replicated except with the machined apertures shifted linearly as a function of depth in the stack. A strip of four horns was implemented in brass. One horn was straight for cross checking with the previous straight horn design, and the other horns were tilted at a 5°, 10°, and 15° tilt. The tilt is measured from the axis of the horn.

B. Pattern Measurements on a Single Element

Preliminary measurements of the first iteration of the horn design appear in [6]. The sidelobe data in this paper were taken with a computerized azimuth elevation stage with synchronized movement and data acquisition.

The detector was a monolithic microwave integrated circuit HEMT amplifier-based radiometer 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 one mV. The source was a fixed frequency 90-GHz Gunn diode with a variable attenuator and a KHz modulated power supply. The detector signal was locked in to the Gunn power modulation. The DAQ was a 12-b 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.

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

C. E and H Plane Results

Sidelobe measurement results were at levels comparable to straight platelet and electroformed, but altered in position based on the horn tilt (see Figs. 2–5). 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.

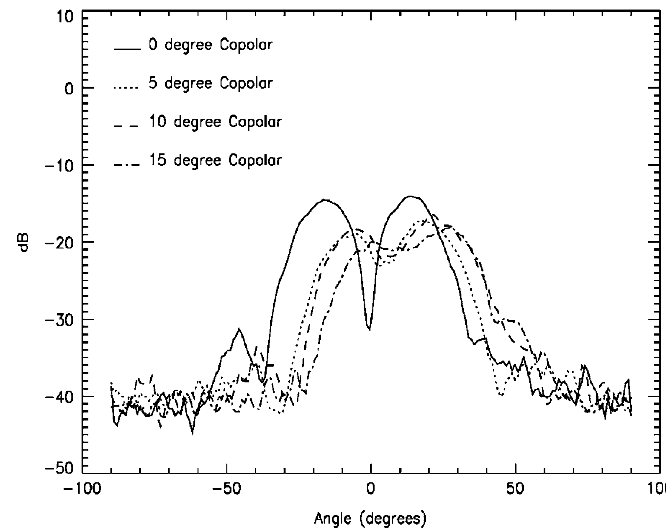

Fig. 3. Cross-polar H-plane tilted horn beams.

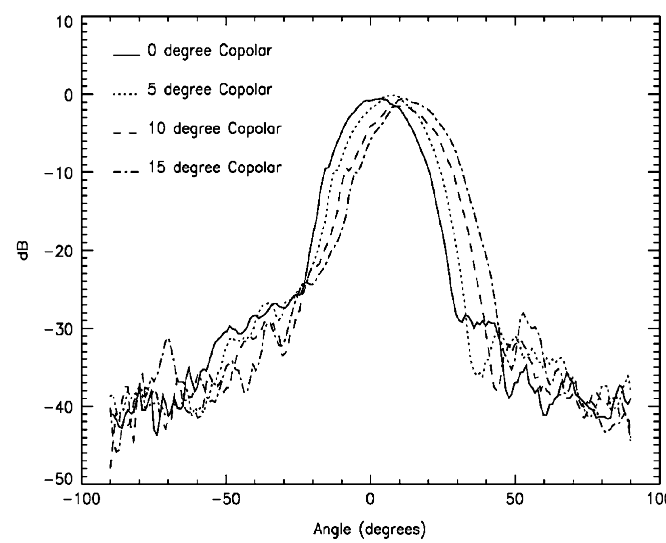

Fig. 4. Copolar E-plane tilted horn beams.

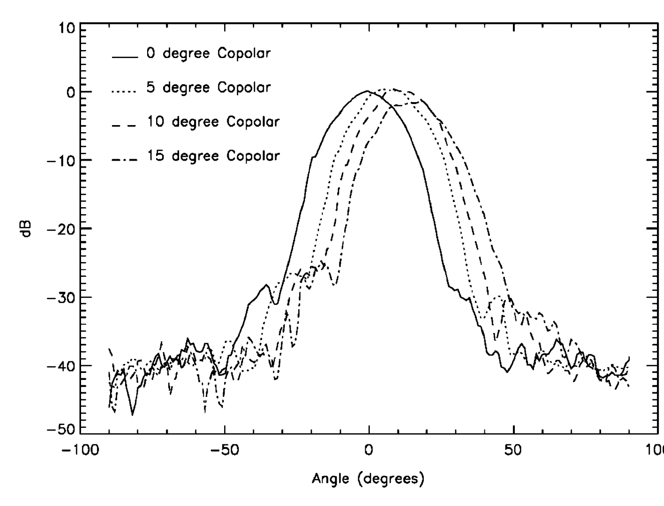

Fig. 5. Copolar H-plane tilted horn beams.

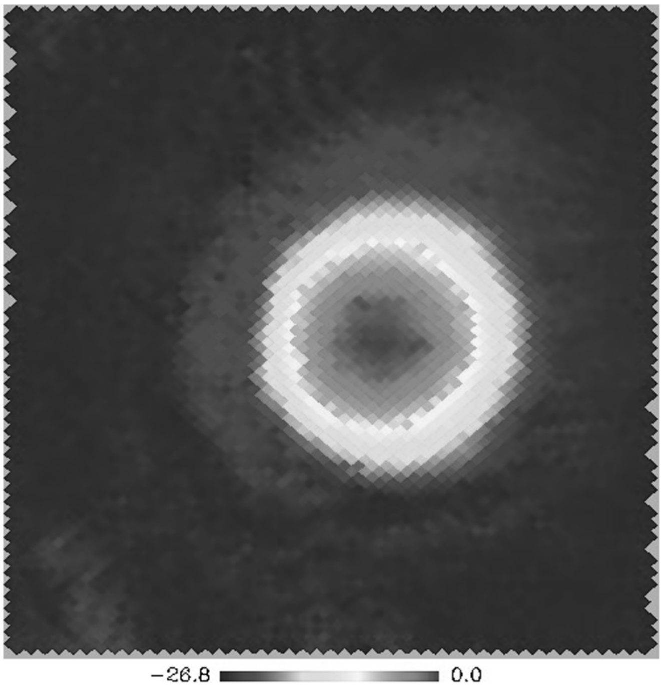

Fig. 6. Copolar tilted horn beam.

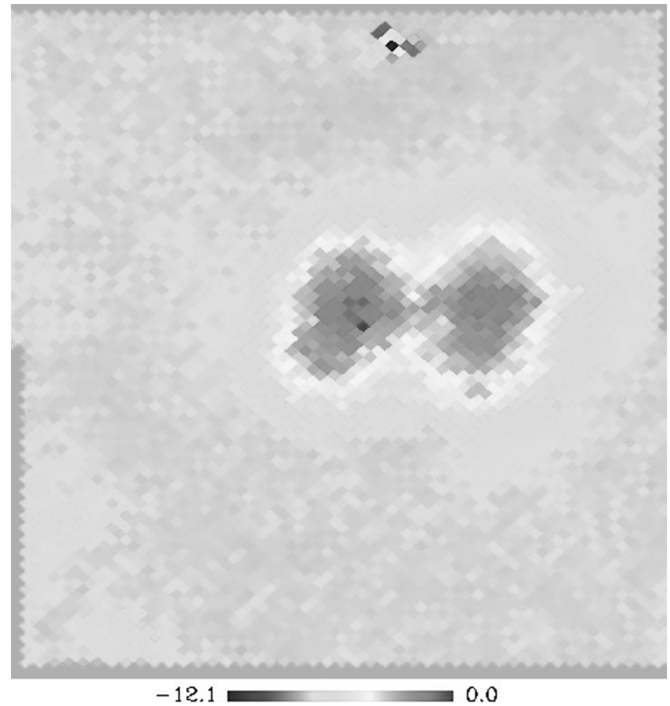

Fig. 7. Cross-polar tilted horn beam.

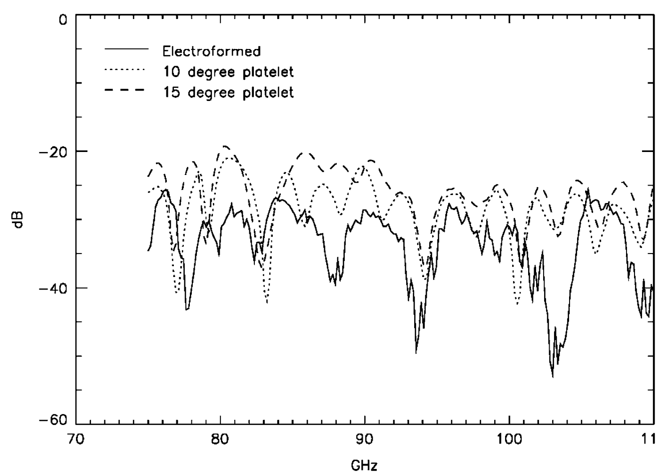

Fig. 8. S11 tilts open horn.

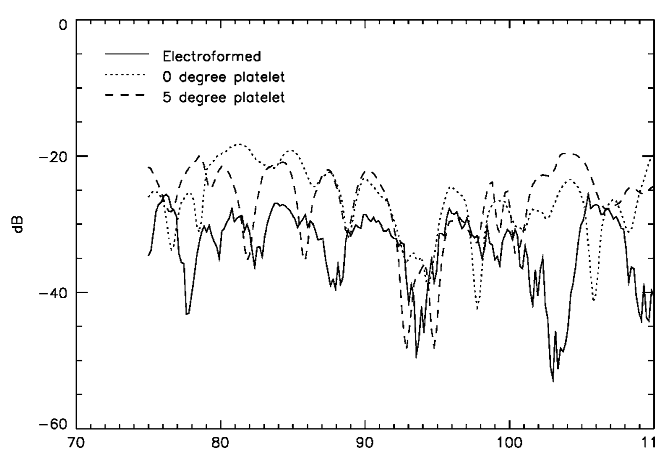

Fig. 9. S11 tilts open horn.

The neighboring pixels in the 4 pixel strip array 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, while the H-plane sidelobes were scanned by adding 90° waveguide twists into the source and detector and also scanning in azimuth. This was because of the range of motion of the azimuth was greater than the range of motion in elevation.

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. H-plane results in Fig. 3 are an upper bound, the -20–-25 dB performance of previous horns with a straight structure indicate the source may have been shifted in roll angle with respect to the detector table but because of the structure of the detector it was not simple to have an orthomode transducer (OMT) and measure both polarizations at the same time where in the previous measurements it was possible to insert an OMT and maximize and minimize the co- and cross-polar signal before the measurement.

D. Two-Dimensional Sidelobe Pattern

The cross-polar pattern is the same as for a straight horn but shifted (see Figs. 6 and 7). This indicates the horn functions as a straight horn with a pointing shift as intended.

E. Reflection and Loss Measurement

Reflection coefficients were measured with a W-band VNA. The results for S_{11} with the horns pointed at a room temperature Eccosorb load are given in Figs. 8 and 9. The results with the apertures of the horns shorted with a brass plate are given in Figs. 10 and 11. The S_{11} measurement of the straight platelet pixels was different but comparable in general magnitude to the S_{11} measurements of a copper electroformed horn. The losses

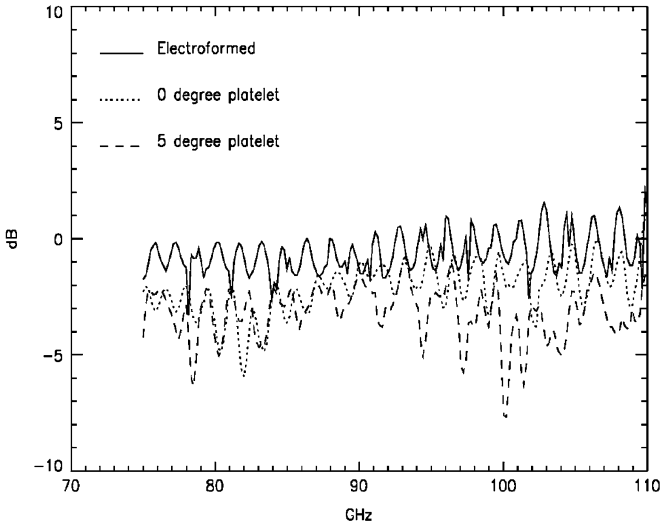

Fig. 10. S11 tilts shorted horn.

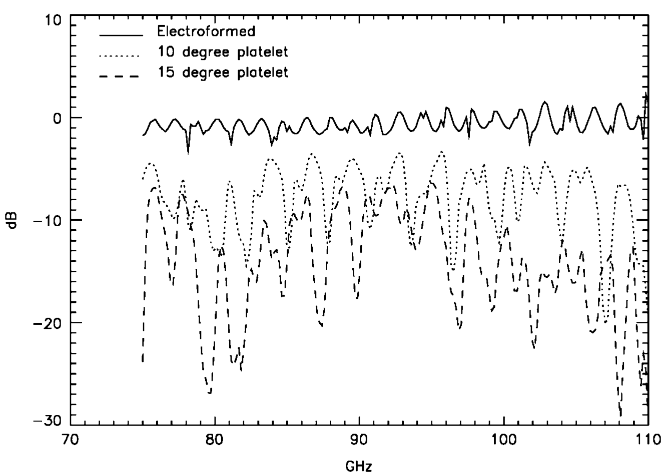

Fig. 11. S11 tilts shorted horn.

in the shorted tilted horns may be from oblique reflection inside the horn at the shorting aperture since the dimensions of the aperture are several times the wavelength, with signal not being efficiently reflected back toward the throat of the horn.

This difference in reflection coefficient is not important for many applications [7] such as millimeter-wave astronomy. The 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.

Eccosorb loads that required multiple bounces from multiple angled sheets from the aperture of 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 with an internal tilt has been developed. The internal tilt of the horn allows steering the beam by several degrees to allow arrays to point at common targets or independently to optimize the performance in a telescope array. 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

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