# Broadband Direct-Machined Corrugated Horn for Millimeter Observation

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***Abstract*—We developed a broadband 4 pixels corrugated horn array with simple corrugation design. Because of the simple geometry of corrugations, the horn array can be directly machined from a bulk of aluminum with an end-mill. The design achieved over an octave-band (80 - 180 GHz) with good beam shape and -20 dB cross-polarization have been realized at all frequencies. All horns of the array have got similar beam pattern and return loss with simulation. This design provides an octave bandwidth of the corrugated horn array at reasonable cost.**

## I. Introduction

CORRUGATED horn has been widely used in the millimeter-wave astronomy as a cryogenic feed, thanks to its good symmetric beam, low sidelobe, and low cross polarization [1]. It has been deployed for frequency band receivers of Atacama Large Millimeter/submillimeter Array (ALMA) [2]–[4]. A broader bandwidth, easier methods of array fabrication, and manufacturing with low cost are required for the large focal plane feeds.

Bandwidths of corrugated horns used in millimeter-wave astronomy are usually less than $\sim$ 40 %. A ring-loaded structure expanding the internal corrugation has been used as one of the technique to extend the bandwidth [5]. An octave bandwidth ring-loaded corrugated horn array fabricated by Si platelet with micro-machining has been demonstrated [6].

To increase mapping speed of observation, an array of feeds is necessary [7]. Platelet or stacking thin sheets technique is one of the method to fabricate corrugated horn array easily [8]. Several research groups have developed the corrugated horn array by platelet or stacking of the silicon or aluminum [9]–[11]. However, it needs to bind all plates tightly so that the weight of the platelet corrugated horn is limited.

It is preferable to manufacture a corrugated horn array at reasonable cost, in order to cover a larger focal plane area with a wide field-of-view. Electroforming is a primarily corrugated horn fabrication process, which manufactures horn shape accurately [1]. However, it is hard to fabricate corrugated horn array with electroforming since it takes time and cost.

We have developed a millimeter wave corrugated horn array which overcomes these items.

## II. Design

We have designed broadband conical corrugated horn with 80 - 180 GHz bandwidth. The cross-section of horn is shown in Fig.1. Horn aperture diameter is 12.4 mm and horn backside is a circular waveguide with the 2.4 mm diameter. The broadband bandwidth has been achieved with simple plane 24 corrugations which have thin grooves and tooth structure.

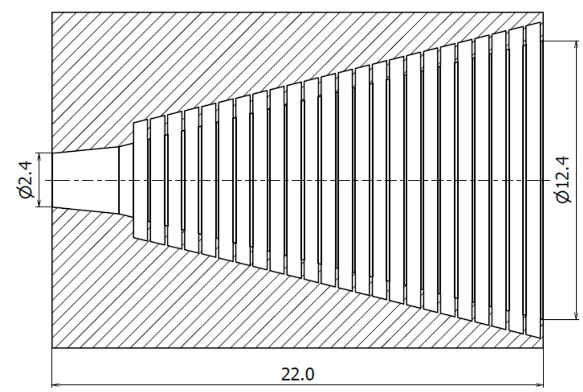


Fig. 1. Cross-section of a broadband corrugated horn. The unit of length is millimeter.

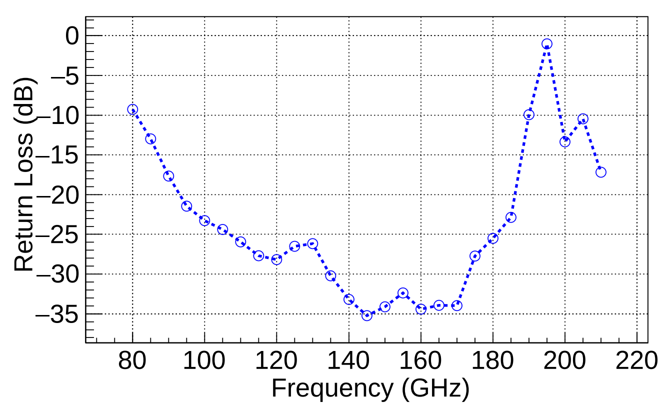


Fig. 2. Return Loss of a broadband horn.

Horn properties, return loss and beam pattern, are simulated using ANSYS HFSS software [12]. Return loss shown in Fig.2 is realized less than -15 dB level in most design frequency. Beam pattern, in Fig.3, is also simulated every 10 GHz in 80 - 180 GHz range. E-plane, H-plane of co-polar and diagonal plane of cross-polarization are superimposed. This simulation shows excellent performance in terms of broadband, symmet-

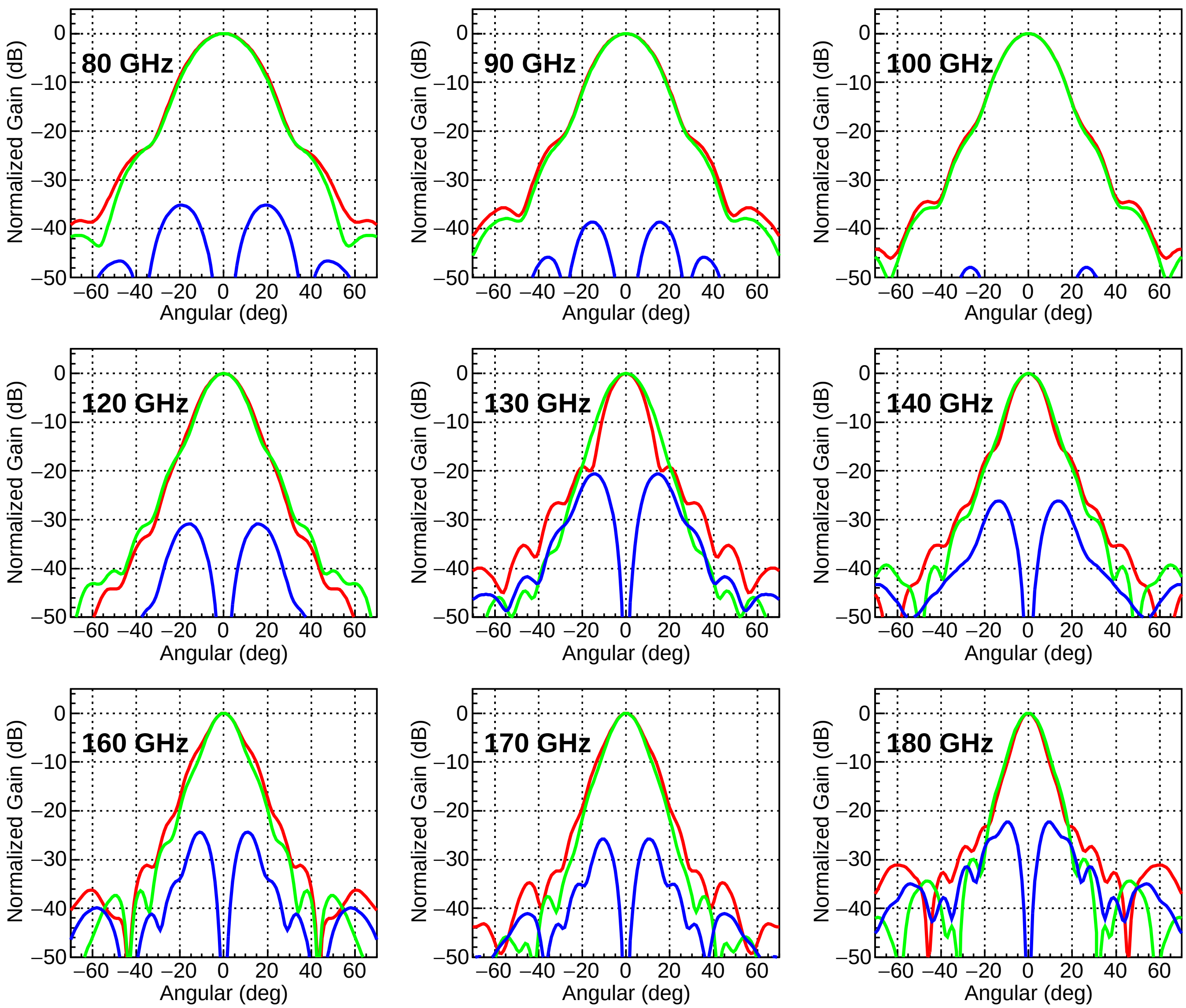


Fig. 3. Simulated beam pattern of an 80 - 180 GHz horn. Green, red and blue lines are E-plane and H-plane of Co-polarization and Cross-polar diagonal plane, respectively.

ric beam pattern, low cross polarization, and low side lobes.

## III. Manufacturing

A corrugated horn array has been fabricated by direct machining in the mechanical engineering shop of the National Astronomical Observatory of Japan. The corrugations are shaved by single special end-mill from the metal bulk because the pattern is only simple plane. The material of the horn is aluminum (A6061), which is suitable for cryogenic use. Aluminum is easy to manufacture and its not only weight also thermal conductivity and thermal capacity help us to reduce the cooling time of focal plane. Fig.4 shows the fabricated 4 pixel 80 - 180 GHz corrugated horn array.

The choke structure for coupling the planar OMT has been machined on the circular waveguide side. Since the critical temperature of aluminum is around 1.2 K, it works as a superconducting magnetic shield when the corrugated horn array is coupled with superconducting detectors such as Microwave Kinetic Inductance Detectors (MKID). It takes

Fig. 4. 4 pixel 80 - 180 GHz horn array.

about one hour to cut the corrugations of one horn. Thus, it is possible to fabricate the horn array at reasonable cost.

## IV. Prototype Detector

A prototype 80 - 160 GHz horn array detector coupled with MKID has been also designed. A large focal plane with this corrugated horn array has been designed for CMB B-mode observation [13]. The signal coming from horn is received by a planar ortho-mode transducer (OMT) antenna and detected by MKIDs. The OMT, MKIDs and other circuits fabricated on a silicon on insulator wafer are reported in a separate paper [14]. It detects 2 bands (80 - 115 GHz and 125 - 160 GHz) and dual polarization signals in single pixel horn. The size is 30 mm $\times$ 30 mm $\times$ 27 mm and total mass is around 50 g. For a prototype of large focal plane camera, we plan test observations using this detector with Nobeyama 45 m radio telescope.

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