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A 2-GHz Rectangular Corrugated Horn

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Abstract – We have designed, constructed and tested a large, rectangular horn antenna with a center frequency of 2.0 GHz, corrugated on the E-plane walls, made out of aluminum sheet. A new technique has been developed to solder thin aluminum strips onto the back plane to form the corrugations. The radiation beam pattern shows half-power beamwidths of 12^0 and 14^0 in the H and E planes respectively, and side lobe response below -40 dB at angles greater than 50^0 from horn axis. The measured return loss is less than -20 dB (VSWR < 1.22) between 1.7 and 2.3 GHz; insertion loss is less than 0.15 dB.

I. INTRODUCTION

We have constructed a rectangular, corrugated-horn antenna, employed for accurate measurements of the cosmic microwave background (CMB) radiation at a frequency of 2.0 GHz (or wavelength $\lambda = 15$ cm). Corrugated horns have proven suitable for such measurements as they can provide the very good sidelobe rejection necessary to minimize the radiation from unwanted sources (such as the ground and the sun), beam pattern symmetry, and low insertion and return loss over the operating band [1], [2]. Several conical corrugated horns have been successfully employed for CMB measurements at high frequencies, both from the ground and from space [3], [4], [5].

Ground-based, low-frequency (< 3 GHz) measurements of the CMB require large antennas transported to remote sites (White Mountain, California [6]; Alpe Gera, Italy [7]; South Pole, Antarctica [8]) so that minimization of the overall weight and ease of transportation are important factors. These requirements are well met by rectangular corrugated horn designs, although they do not provide the beam-pattern symmetry of conical corrugated horns. A previous rectangular horn design has been used by our group for measurements near 1.5 GHz [9]. This communication describes the design and construction technique of a new 2-GHz antenna, as well as its measured radiometric characteristics.

II. DESIGN AND CONSTRUCTION

Our CMB measurement technique (described in detail elsewhere [6],[7],[8]) uses the full antenna (throat and extension sections, as shown in Fig. 1) for some portions of the measurement and the throat section alone for others. The two sections are mated by means of a flange and a spring-loaded latching mechanism.

The measurements require frequent rotations of the antenna. The throat section is inverted during each measurement cycle [6] to compare the signal from the sky to the signal from a liquid-helium-cooled calibrating source, so stability of performance under gravitational stresses is critical. The full horn (throat and extension sections) is tilted to several zenith angles of up to 40^0 for measurements of the emission from the Galaxy and from the Earth's atmosphere. Different construction techniques have been adopted for the two stages to accommodate their individual requirements.

a) Throat Section

At the horn throat is a 5-cm length of standard WR-430 waveguide, whose internal dimensions are 10.92 cm by 5.46 cm (Fig. 1). A 12-cm long smooth-wall section, fabricated from 0.2-cm thick aluminum sheet, tapers from the waveguide dimensions to 19.1 by 13.7 cm, with a semiflare angle of 19^0 in both planes. The transition from smooth E-plane walls to corrugations is designed to optimize the match between the TE_{10} mode in the smooth-wall section and the HE_{12} (rectangular) mode launched in the corrugated portion of the horn at frequencies above the 1.32 GHz HE_{12} cutoff. The smooth H-plane walls as well as the E-plane surface (defined by the edges of the corrugations) continue the same 19^0 flare angle up to the aperture. The slot depth is initially $\lambda/2 = 7.5$ cm for optimum match and tapers linearly to $\lambda/4 = 3.75$ cm at the aperture of the throat section, with 23 corrugations spaced by 1.9 cm. A thin layer of dielectric material has been applied to the side edges of the corrugations (including those of the extension section) to avoid possible unstable contacts with the mating H-plane walls. The mouth of the throat section is 50.4 cm (E-plane) by 53.7 cm (H plane), or approximately 3.5λ on each side. This aperture is determined by the size of the liquid-helium-cooled calibrator to which the throat section must mate.

In our previous design [9] the corrugations were formed from thin aluminum strips bent at 90^0 and bolted to the back wall. To optimize the performance stability and reduce the insertion loss, we have adopted a different technique for fabricating the corrugated E-planes. Shallow (0.16 cm) grooves, spaced every 1.9 cm, are machined into a 0.32-cm-thick aluminum plate of the appropriate trapezoidal shape. The corrugations are cut out of 0.16-cm thick aluminum sheet, inserted in the grooves and firmly clamped in position. The assembly is then uniformly heated to a temperature of about 440^0 C in a top-opening oven and the corrugations are soldered to the backing plates using an alloy of aluminum, zinc, copper, tin, nickel and silver (*4.3.1 Ideal Rod*, by Ideal Sales).

Each H-plane wall is shaped out of a single 0.2 cm thick aluminum sheet from the waveguide flange to the aperture. The H-plane walls, the E-plane smooth sections, the WR-430 flange and the waveguide section are also soldered together with *Ideal Rod.* Finally, the corrugated E-plane plates are bolted to the smooth wall assembly.

b) Extension section

Measurements of the galactic and atmospheric signals require maximal sidelobe suppression, which we obtain by extending the aperture with an extension section (Fig. 1). Two large, complementary flanges attached to the interface openings of the two stages allow precise and repeatable mating. The ultimate aperture of 103.4 cm (H-wall) $\times$ 100.3 cm (E-wall), or approximately 6.7λ on each plane, is determined by requiring that the phase change across the aperture be less than 180^0. All 39 corrugations on the E-plane are 3.75 cm deep and maintain the 1.9 cm spacing. They are made out of 0.08-cm thick aluminum strips bent at right angles along their lengths and rivetted to the back planes.

To further reduce the electric field at the aperture along the E-plane walls and thereby improve the sidelobe and backlobe suppression, we mount choke slots at the mouth of the extension [9] (no choke slots are installed at the mouth of the throat section). The six corrugations, 3.75 cm deep ($\lambda/4$) and spaced 1.9 cm apart along the E-plane edges of the aperture, are also fabricated out of bent aluminum sheet to minimize the weight.

III. PERFORMANCE

We have measured the radiation beam pattern of the antenna in the E and H planes by scanning the zenith angle at a distance of $\sim$ 26 m from a narrow-band broadcast signal. The signal was extracted with a low-reflection (VSWR < 1.1) transition from WR-430 waveguide to SMA coaxial. The results of the measurements at 1.8, 2.0 and 2.2 GHz are shown in Fig. 2. We were unable to measure the pattern at angles $\theta > 150^0$ due to reflections from nearby objects. However, successive measurements conducted in a reflection-free site at the South Pole on the L-band antenna described by Witebsky *et al.* [9] confirm that the response at $150^0 < \theta < 180^0$ is similar to the response at $90^0 < \theta < 150^0$ for this type of antenna.

In the H plane, the half-power beamwidth (HPBW) at the center frequency, 2.0 GHz, is about 12^0, and it increases both at higher frequencies (16^0 at 2.2 GHz) and lower frequencies (17^0 at 1.8 GHz). Similarly, in the

E plane the half-power beamwidth is 14^0 at 2.0 GHz, and increases to about 18^0 at both 1.8 and 2.2 GHz. The shape of the main lobe appears to be more frequency dependent in the H plane than in the E plane, a behaviour also exhibited by our 1.5-GHz horn [9].

We have also measured the beam pattern of the first section alone. At a frequency of 2.0 GHz the HPBW is 20^0 and 23^0 in the H and E planes respectively, and the response at angles greater than 20^0 is typically 10 dB higher than that of the full antenna in the H plane and 15 dB higher in the E plane.

The return loss measured with a directional coupler and the waveguide to coax transition is below -20 dB (VSWR < 1.22) between 1.7 and 2.3 GHz, with a minimum of -28 dB near 1.85 GHz. No measurable changes (± 0.5 dB level) are observed in the reflection pattern if the extension is removed, indicating low reflections levels in the extension section and good match between the throat section and free space. Because the measured VSWR of the transition alone is less than 1.10, we conclude that the measured return loss is dominated by reflections in the throat section and/or in the mating flanges which couple the throat section to the transition. Repeatability of the reflection after separation and recoupling of the two stages is also better than the ± 0.5 dB detection level.

To test the stability of the return loss from the throat section we have looked for variations in the output of our total-power receiver when the horn views a stable target (a blackbody at ambient temperature) completely filling the horn aperture while the horn, receiver, and target are repeatedly inverted [6]. Our results indicate that reflections are stable at the -39 dB level for complete inversion of the horn and at the -42 dB level for rotation at zenith angles up to 40^0.

By measuring the increase in the system temperature of a low-noise total-power receiver when the horn and transition are added to the transmission line, we find an insertion loss of $\sim$ 0.15 dB, a value consistent with the insertion loss specification for the transition. This places an upper limit on the insertion loss of the antenna.

IV. SUMMARY

We have described a simple technique to fabricate large corrugated horns from aluminum sheet with very good and stable electrical contact between the corrugations and the back wall for constant reflections and insertion loss. The properties of *3.4.1 Ideal Rod* make this alloy an attractive tool for fabricating light-weight aluminum antennas. The radiation pattern and reflection characteristics of this horn are close to that expected from previously tested rectangular horns constructed with different techniques. The HPBW increases by $\sim 4^0$ at $\pm 10\%$ of the 2.0 GHz center frequency in both the E and H planes.

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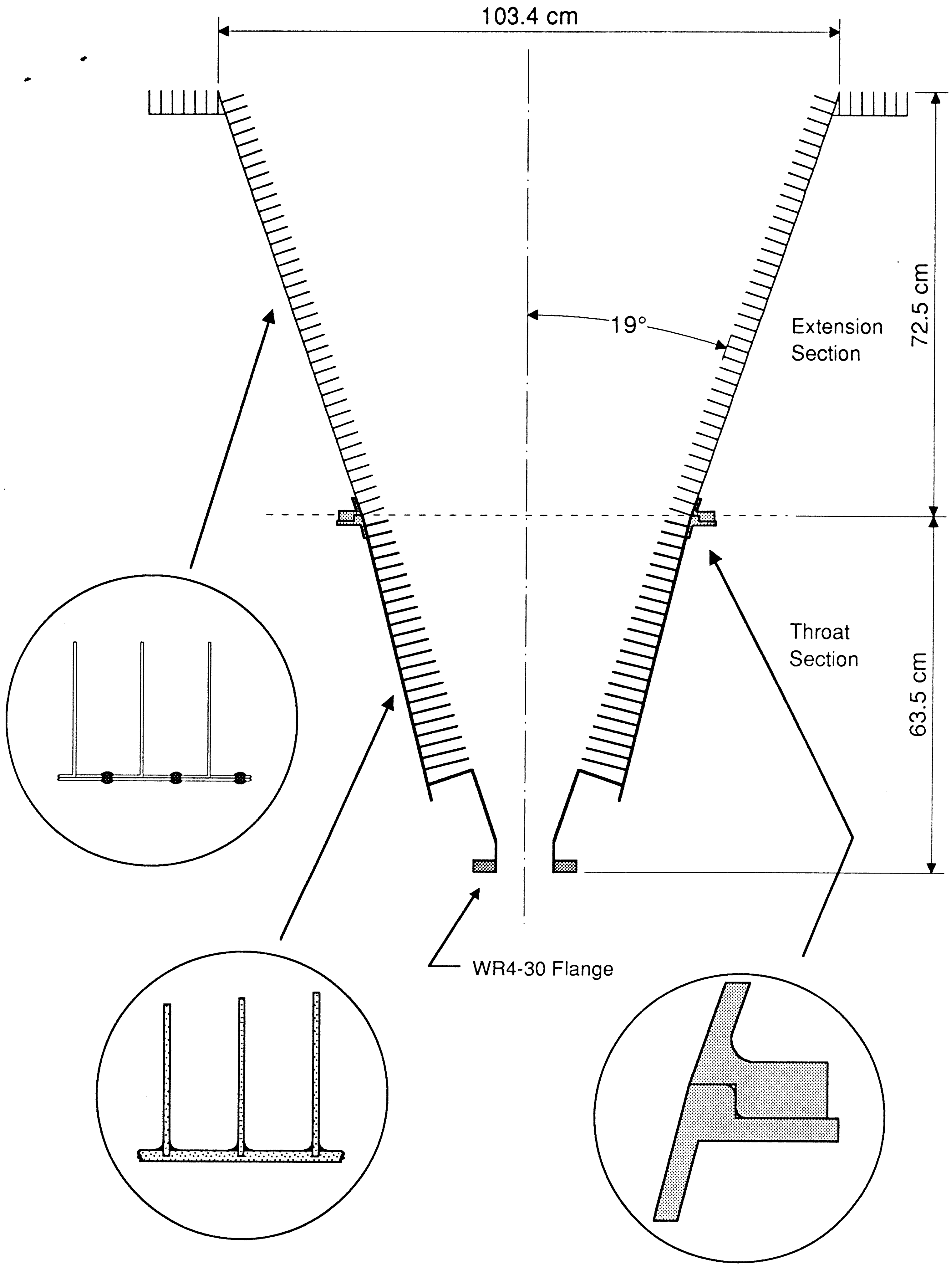
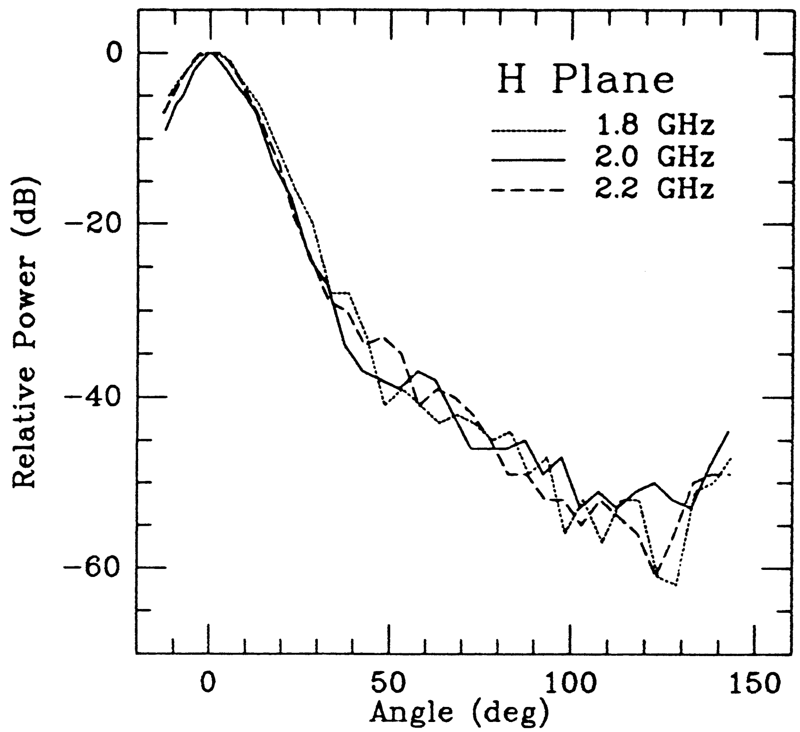
Caption to figures

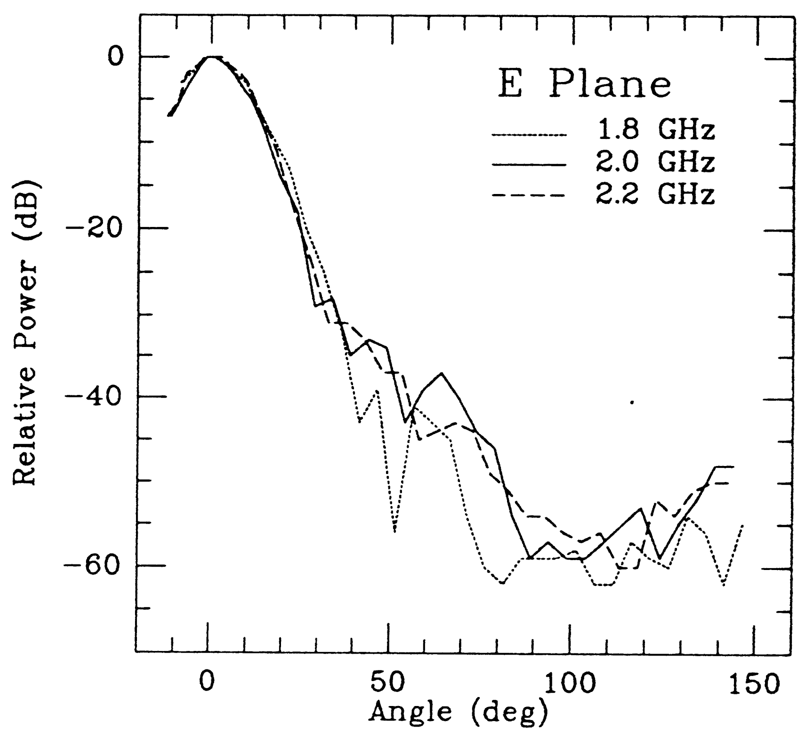
Fig. 1 - Schematic of the E-plane walls profile. The two insets on the left show the construction techniques for the extension section and for the throat section; the inset on the right shows the mating flanges between the two sections.

Fig. 2 - Measured radiation patterns for the full antenna at three test frequencies. a) H-plane; b) E-plane.



103.4 cm
19°
Extension
Section
72.5 cm
Throat
Section
63.5 cm
WR4-30 Flange


H Plane
1.8 GHz
2.0 GHz
2.2 GHz
Relative Power (dB)
0
−20
−40
−60
0
50
100
150
Angle (deg)


E Plane
1.8 GHz
2.0 GHz
2.2 GHz
Relative Power (dB)
0
−20
−40
−60
0
50
100
150
Angle (deg)