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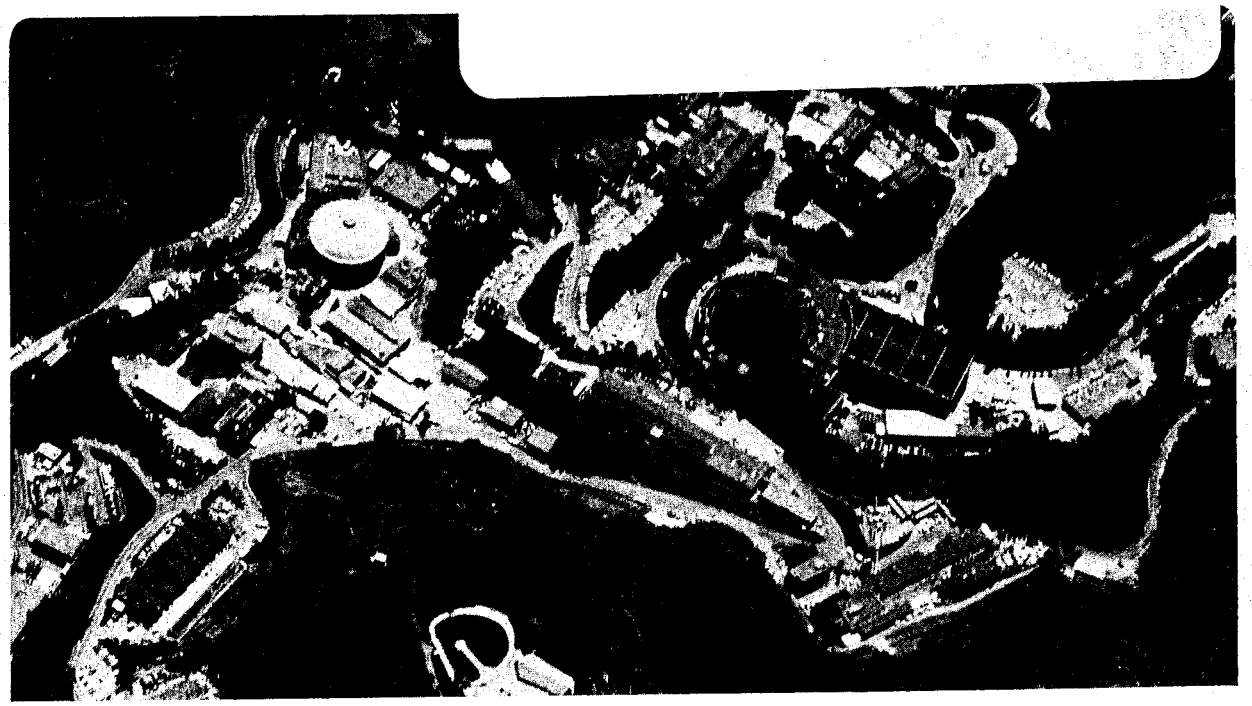

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A LARGE L-BAND RECTANGULAR CORRUGATED HORN

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Abstract—This paper describes a lightweight, corrugated-horn antenna, constructed from sheet metal. Over a 1.3–1.7 GHz operating band, its half-power beamwidth is approximately 20° in the E-plane and varies from 17° to 13° in the H-plane. Quarter-wave choke slots at the aperture help to reduce the E-plane sidelobes below −55 dB at angles greater than 90°, while the H-plane sidelobes lie in that range both with and without choke slots. Return loss throughout the operating band is −25 dB or below. Critical dimensions are provided, together with useful guidelines for designing similar antennas.

I. INTRODUCTION

We have developed a large (≈ 2-meter-long), lightweight horn antenna with low sidelobes for measurements of the cosmic background radiation temperature near 1.4 GHz. The antenna, a rectangular horn with corrugations on its E-plane walls, is made primarily from aluminum sheet for lightness and ease of fabrication. This design has several significant advantages over the conical corrugated horns used at higher frequencies [1,2]. First, the horn is much lighter than a machined corrugated horn of comparable size. Second, the antenna is relatively simple to construct, and does not require any special machining facilities other than a sheet-metal break of sufficient width. Horns of this sort are especially convenient for prototype development, since characteristics such as the slot width can be readily varied. Third, the horn can be easily broken down into panels for transport. In common with conical corrugated horns, it has low sidelobe levels and a good input match.

This paper describes the design of the antenna and reports the results of our pattern and reflection measurements.

II. THEORY

In contrast to the large body of work published on the theory and design of conical corrugated horns, relatively little has been written about rectangular corrugated horns. Some of the first such horns are described in a paper by Lawrie and Peters [3], who pioneered this field. The theory of wave propagation in E-plane corrugated waveguide is discussed in some detail by Baldwin and McInnes [4]. The parametric study of the properties of corrugated surfaces by Metzer and Peters [5] provides useful insights into the effects of ridge thickness, corrugation density, and surface resistivity. Work by these authors and others has been summarized by Clarricoats and Olver [6]. Studies have shown that E-plane corrugated horns have substantially lower sidelobes than do smooth-wall horns of similar size, in some cases comparable to those of conical corrugated horns. They also suggest that resistive losses may be lower than those of smooth-wall horns.

Corrugated horns are generally designed with two objectives: to achieve an antenna pattern with low sidelobes and to optimise the input match. One achieves these goals primarily by adjusting the depths of the corrugation slots to provide the desired field characteristics. Slots one-quarter wave deep at the aperture cause the aperture-plane electric field to taper smoothly to zero at both the E-and H-plane walls; slots one-half wave in depth give rise to a field that matches the field in uncorrugated rectangular guide, for a good match at the horn throat.

One must be careful to launch only the desired mode or modes in the corrugated horn. Most commonly, this is the HE_{12} rectangular mode (in the notation of [6]), whose transverse electric field component tapers smoothly to zero at the H-plane walls and also decreases smoothly toward the E-plane walls. In general, the presence of other modes causes higher sidelobe levels and a more irregular and more frequency-dependent radiation pattern. Among these undesired modes

is the HE_{11} slow-wave mode, whose field increases to a maximum at the E-plane walls, as well as various higher-order modes.

One can understand the effect of corrugations on the field behavior by considering an E-plane corrugated rectangular waveguide (Fig. 1), whose properties resemble those of corrugated horns with moderate flare angles. The slots in the E-plane walls act as shorted segments of rectangular waveguide of length s, branching off from the main guide. Within a slot, waves are assumed to propagate in the TE_{10} mode. (Note that the electric field within the slot is in the z direction, perpendicular to the ridges.) The TE_{10} guide wavelength in the slot is λ_s,[1] given by the equation

$$\lambda_s = \left(\frac{1}{\lambda^2} - \frac{1}{4a^2}\right)^{-1/2},$$

where λ is the free-space wavelength. Reflections from the metal surface at the base of the slot create standing waves.

Boundary conditions for the allowed modes in the main guide are set by the requirements that the field components be continuous at the E-plane walls ($y = \pm b/2$), and that E_y vanish at the smooth H-plane walls. If the slot depth s is equal to $\lambda_s/4$, E_y and H_x vanish at $y = \pm b/2$, although a small E_x component remains. In the HE_{12} mode, E_y decreases monotonically to zero at both the E- and H-plane walls, yielding a radiation pattern with a well-defined peak and low sidelobes, whereas the value of E_y for higher-order modes may go through several maxima and minima before vanishing at the walls. If $s = \lambda_s/2$, the standing-wave condition at $y = \pm b/2$ forces E_x to vanish, creating boundary conditions equivalent to a conductive wall. In this case, the fields of the HE modes resemble those of the TE modes in uncorrugated waveguide. In particular, the HE_{12} field distribution resembles that of the TE_{10} mode in uncorrugated guide of width a and height b.

The low-frequency cut-off for the HE_{12} mode occurs when $\lambda_s = 2s + b$. To avoid excessive reflection at the transition from smooth to corrugated walls, one can include a short section of flared smooth-wall waveguide at the horn throat in order to lower the HE_{12} cut-off frequency at the onset of corrugations. For good match over a moderate bandwidth, the HE_{12} cut-off frequency should be at least 20–30% below the minimum operating frequency. Reflections are further reduced if the first slot is made approximately $\lambda_s/2$ deep and the subsequent slot depths are gradually decreased to $\lambda_s/4$. An alternative form of smooth-to-corrugated transition—a gradual taper in the slot depths from 0 to $\lambda_s/4$—is ruled out because it also launches the HE_{11} slow-wave mode, which can propagate when $s \leq \lambda_s/4$. This mode is especially undesirable because the strong field at the E-plane walls causes high sidelobes.

III. ANTENNA DESIGN AND CONSTRUCTION

The antenna, shown in Fig. 2, can be divided for the purpose of description into four regions:
1) The smooth-wall throat section;
2) The intermediate corrugated section, whose slot depths taper from approximately $\lambda_s/2$ near the throat to $\lambda_s/4$ at the wide end;
3) The corrugated extension;
4) The quarter-wave traps at the mouth of the horn.

WR-650 waveguide at the throat (16.5 cm by 8.3 cm cross-section) flares out into the 16-cm-long smooth-walled section of the horn. Both the E- and H-plane walls have a 19° semi-flare angle; their ultimate dimensions are 27 cm and 19 cm, respectively. This expanded section of smooth-walled guide lowers the HE_{12} cut-off frequency at the entrance to the corrugated section to approximately 980 MHz.

The intermediate corrugated section, 38 cm in length, serves as a transition from the smooth-walled section near the throat to the large section that comprises the main body of the horn. The two E-plane walls of this section contain corrugations whose ridge tops are coplanar with the walls

[1] This is denoted λ_g in the notation of [4] and [6].

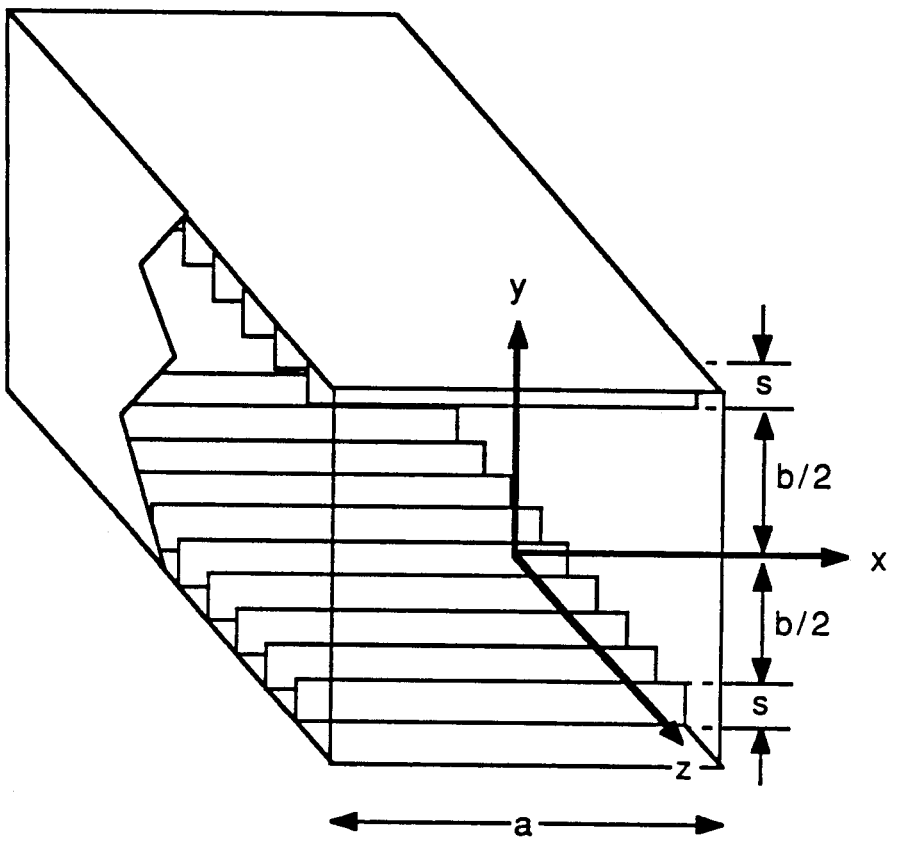

Figure 1: E-plane corrugated rectangular waveguide.

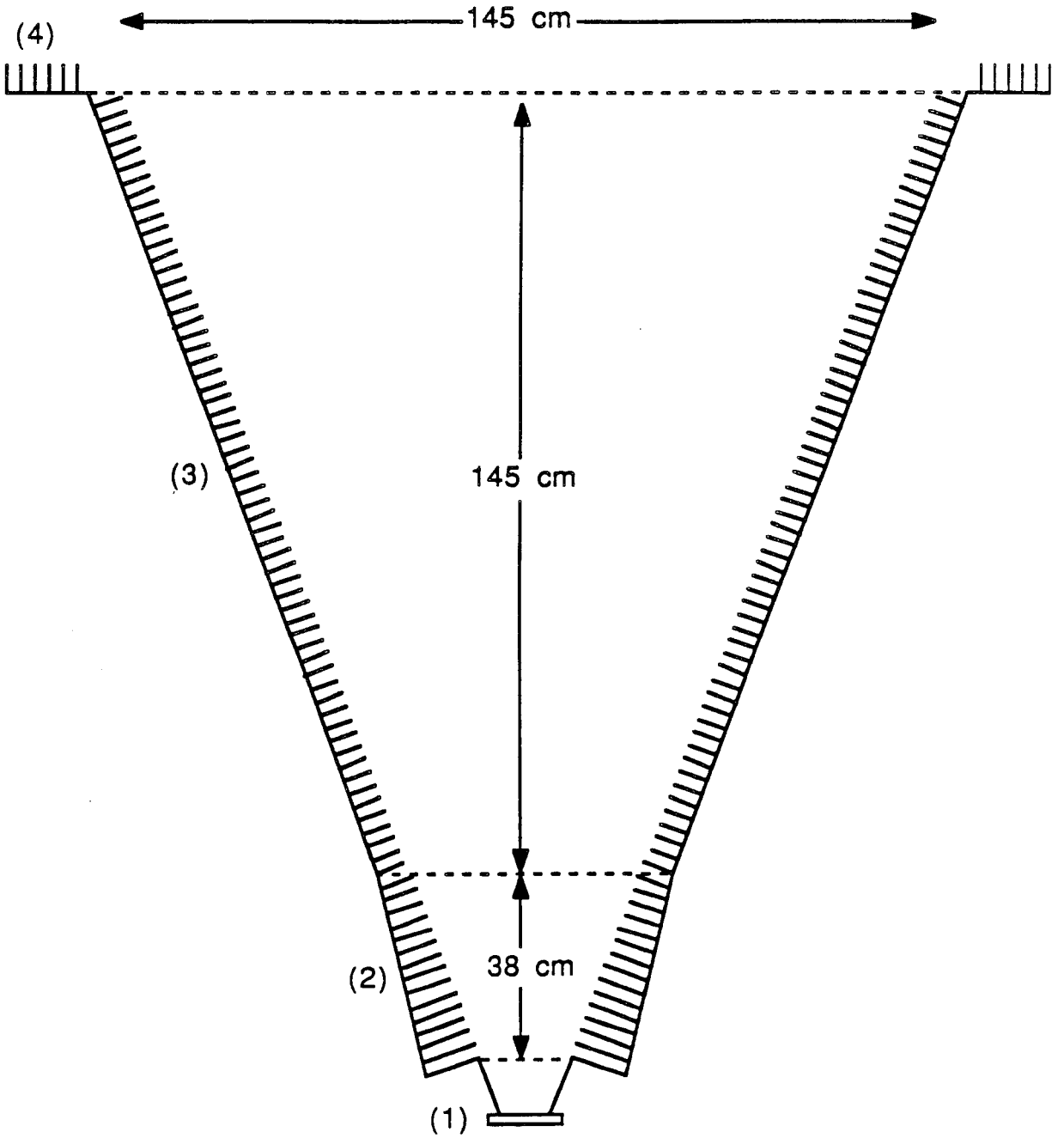

Figure 2: *H*-plane cutaway view of rectangular corrugated horn.

of the smooth-walled section. The smooth H-plane walls continue, unbroken, from the previous section. Both the E- and H-plane surfaces continue the 19° flare of the smooth section. The first slot is 9.1 cm in depth, approximately $\lambda_g/2$ at 1.74 GHz. The next 15 slots taper smoothly to a depth of 5.2 cm, approximately $\lambda_g/4$, at the far end of the section. The corrugations are spaced at 2.5-cm intervals. Their density (approximately 7 to 9 corrugations per wavelength) yields acceptably low reflection without excessive resistive loss [5].

The ridges are made from strips of 0.8-mm aluminum sheet for reduced weight, ease of construction, and low ohmic loss. The strips are bent at right angles along their lengths and bolted to a flat aluminum backing sheet. The E-plane backing sheets open at a 13.5° semi-flare angle in order to provide the taper in the slot depth. Lengths of aluminum angle running along the edges of the pyramid stiffen the structure and provide attachment surfaces for the E- and H-plane walls. The walls are braced externally, and the E-plane ridges provide added stiffness. At their wide end, the E-plane walls are 53 cm across, while the maximum width of the H-plane walls is 45 cm.

The extension is a continuation of the previous corrugated section, with the same 19° semi-flare angle and a slot depth of 5.2 cm throughout the 145-cm length of the section. The dimensions of horn mouth are 149 cm by 145 cm. The choice of opening angle and aperture dimensions causes the phase to vary by more than 180° across the aperture, for a beam pattern whose main lobe is wider than that of a diffraction-limited horn but less frequency-dependent.

To further reduce the sidelobe and backlobe response, we have installed quarter-wave-deep choke slots in the aperture plane around the periphery of the horn, a technique that has been shown to work well for circular antennas [7, 8]. Along each edge of the aperture are five slots, each one 5.2 cm deep and 2.5 cm wide, made also of folded sheet metal bolted to a backing sheet. No attempt has been made to optimize either the number or the width of these slots, since the design used here provides sufficient backlobe suppression for our needs.

IV. REFLECTION

The return loss of the horn, measured by means of a slotted line, is plotted in Fig. 3. Between 1.3 and 1.7 GHz, the return loss is −25 dB or lower. Removal of the antenna extension increases the reflected signal by ~1 dB or less, an indication not only of the fact that very little reflection occurs within the extension but also of the good match between the mouth of the intermediate corrugated section and free space.

V. RADIATION PATTERN

We have measured the antenna's radiation pattern on a roof-top test range, with a 24-m separation between the source antenna and the test antenna. Scattering from near-field objects in the test range prevents accurate measurements at angles greater than ~150°, but measurements of other rectangular corrugated horns indicate that the response from 150° to 180° is likely to be similar to the pattern between 90° and 150° [3]. To evaluate the contribution from the quarter-wave choke slots at the aperture, we have performed measurements both with and without them. Figure 4 shows the E-and H-plane patterns at 1.3, 1.5, and 1.7 GHz. The shape of the E-plane main lobe is quite similar at all three frequencies, with a half-power beamwidth that varies from 21° at 1.3 GHz to 18° at 1.7 GHz. The antenna response between 90° and 150° is below −55 dB with the choke slots in place and below −50 dB without them. The unexpectedly high sidelobes at 1.7 GHz may be evidence of a secondary mode at this frequency.

The H-plane main lobe is narrower and somewhat more frequency-dependent than its E-plane counterpart. The half-power beamwidth varies from 17° at 1.3 GHz to 13° at 1.7 GHz. The H-plane sidelobes show structure at the −55 to −60 dB level from 90° to 150°. The relatively high sidelobes at 1.7 GHz again suggest the presence of a secondary mode. The patterns are approximately what one would expect from an aperture field with a cosine distribution in the E- and H-planes, and a phase error given by the dimensions of the antenna.

The effect of the quarter-wave choke slots is shown in Fig. 4. The E-plane antenna response

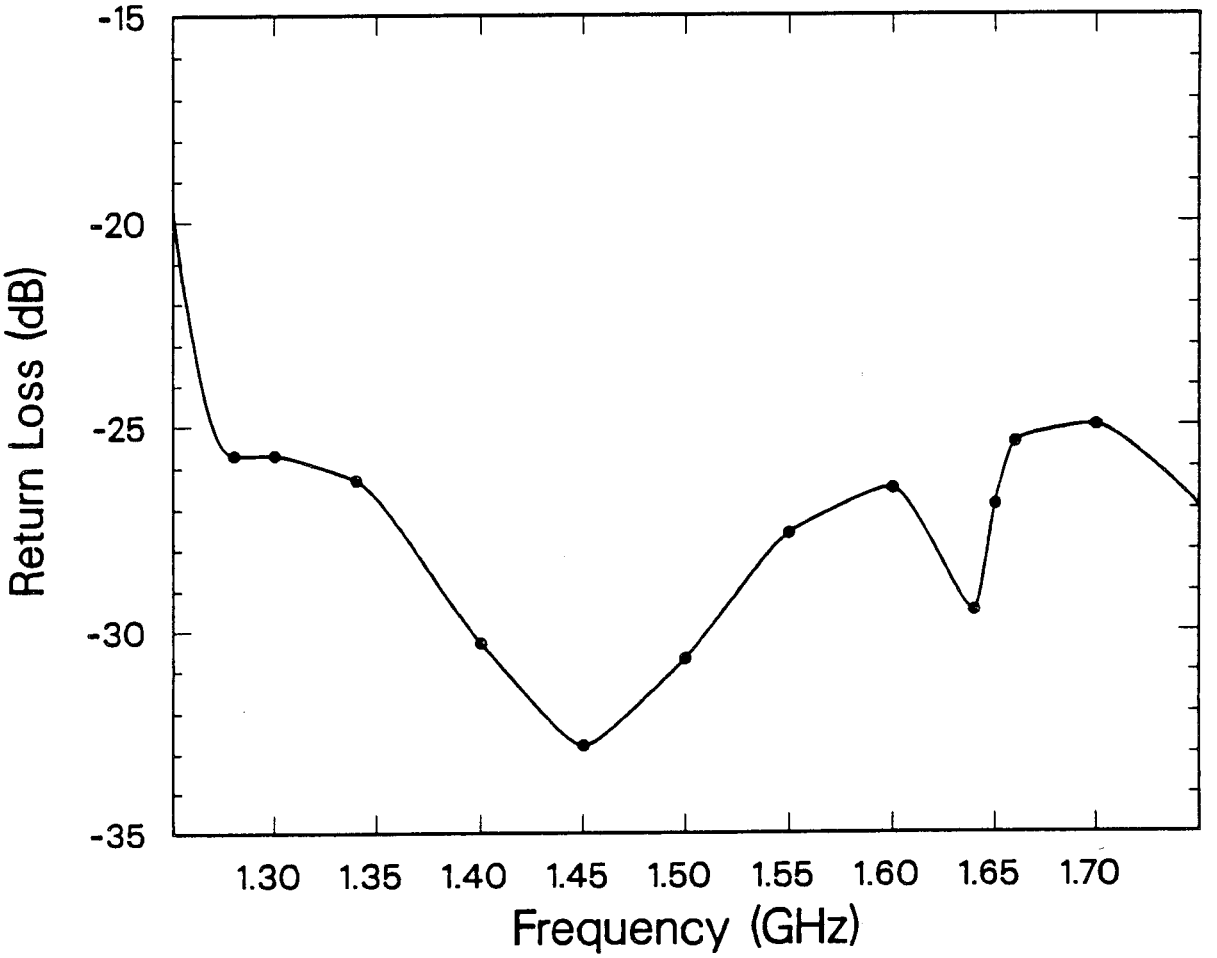

Figure 3: Corrugated antenna return loss. Points indicate measured values.

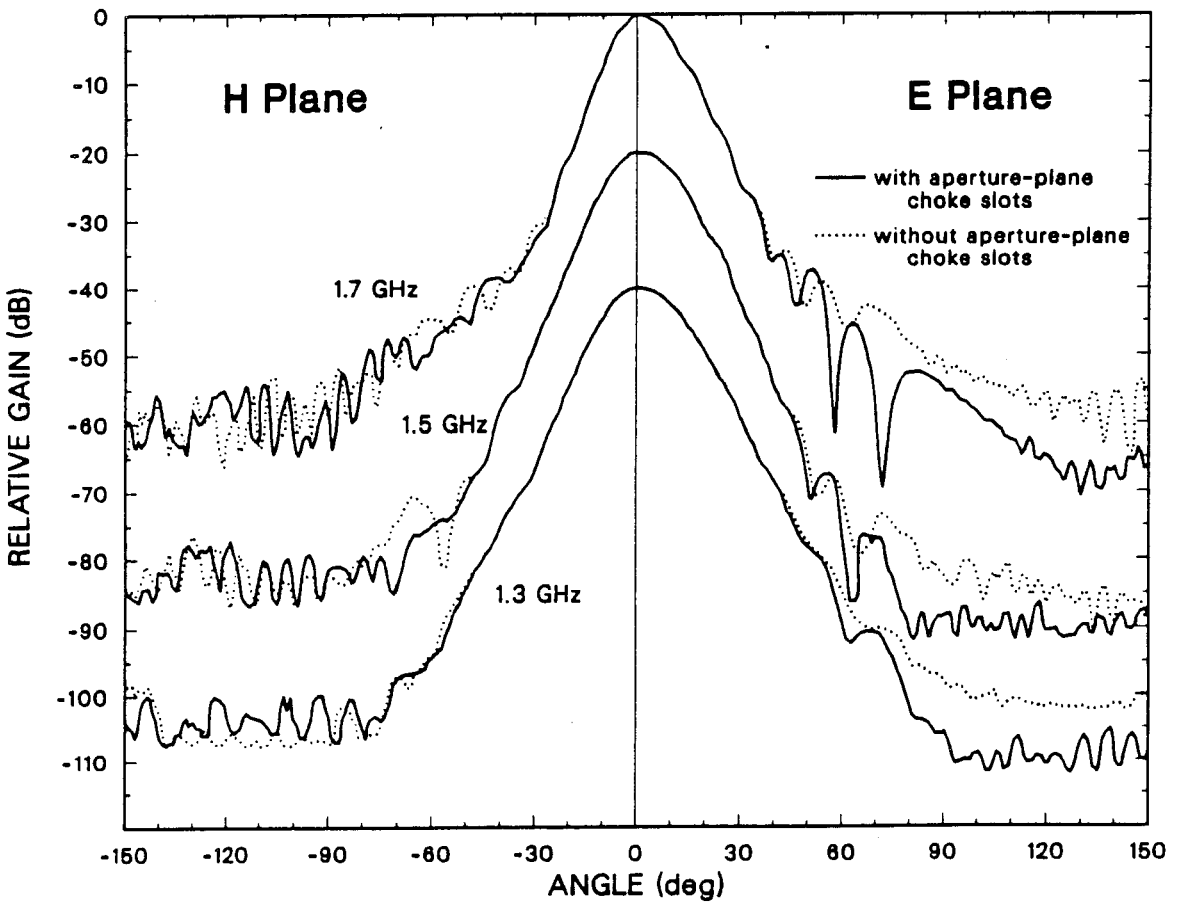

Figure 4: Measured E- and H-plane patterns for rectangular corrugated horn. Successive patterns offset by 20 dB.

at angles greater than ~75° is reduced by as much as 10 dB. The *H*-plane choke slots have no significant effect; sidelobe and backlobe levels are virtually the same with and without them.

Scattering by objects in the test range prevented us from making accurate far-field measurements of the cross-polarized response, although we were able to make rough measurements of the response in the aperture plane. The ratio of co-polarized to cross-polarized response measured at the aperture varied from <10 dB near the *H*-plane walls to >35 dB near the center of the aperture.

VI. CONCLUSIONS

We have shown that rectangular corrugated horn antennas with good sidelobe suppression over at least a 25% bandwidth can be made from sheet metal, using simple techniques. Quarter-wave choke slots at the aperture flange, also fabricated from sheet metal, provide another 5 to 10 dB of sidelobe and backlobe suppression in the *E*-plane; greater backlobe suppression may be obtainable with a different choice of slot width and number. The techniques described here permit one to build corrugated horns to operate in a frequency range where such horns constructed by conventional techniques would not be practical.

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