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DEVELOPMENT OF A 611 MHZ FEED FOR A 9-METER REFLECTOR

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Summary

A 2X2 array of fan-dipoles is designed as a feed for an existing 9.14 meter diameter reflector. Baffles (conducting fences) were utilized to reduce mutual coupling between dipoles and to improve the feed radiation pattern in the H-plane. Significant strut scattering effects were noted in the secondary patterns of the reflector antenna.

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Introduction

A four-element dipole array is designed as a feed to illuminate a nine-meter diameter paraboloidal reflector at 611 MHz to be used with a UHF radiometer for measuring the sky background radiation. The reflector is installed on a 2-axis pedestal located near building 1299 and was originally configured as a cassegrain antenna to be used as a missile-tracking ground station. For the present application, the subreflector was removed, the feed opening in the center of the main reflector replaced by a flat conducting plate, and the antenna configured as a direct-fed paraboloid.

Description

The geometry of the reflector is shown in figure 1. The ratio of the focal-length to diameter is 0.417; therefore, the feed pattern angular illumination is $\pm 62^{\circ}$. In order to achieve high beam-efficiency, as required for radiometric measurements, the antenna must be designed for low-sidelobes; therefore, the illumination of the reflector must be highly tapered at the edge. An edge taper between -20dB and -25dB was selected for the feed design, which should produce a reflector radiation pattern sidelobe level of -40dB or lower in the absence of aperture blockage. However, the presence of the feed and struts in front of the reflector can produce significant electromagnetic scattering which will result in increased sidelobes.

A photograph of the feed is shown in figure 2. The feed is a 2X2 array of fan-dipoles excited in-phase by a 4-way power divider network mounted on the backside of the array as shown in figure 3. The pertinent dimensions of the final array design are illustrated in figure 4. The baffles on two edges and between elements were included as an integral part of the design to control the pattern shape and to aid in impedance matching due to reduced interelement coupling. The radiating element is a fan-dipole tuned to 611 MHz at the first resonance and matched to a 50-ohm coax input. The fan-dipole was selected since enough parts were already available for the array assembly and the basic design data had already been generated earlier during the development of a broad-band version of the half-wave fan-dipole [1]. Some adjustment in the element design was necessary to obtain a good impedance match within the 608-614 MHz band for the 4-element array. The final dimensions of the dipole element are shown in figure 5. The electromagnetic effects of the polystyrene supports for the dipole elements (shown in figure 2) were found earlier to be insignificant.

Design

The basic array geometry (i.e. element spacing) of the 2X2 array was established by array pattern calculations for linear dipole elements located over an infinite conducting ground plane. The principal plane patterns for a 2X2 array of linear dipoles can be calculated from

E-plane:

$$E_\theta = \sec\theta\,[\cos(\pi L \sin\theta) - \cos(\pi L)] \cdot \sin(2\pi H \cos\theta)\,\cos(\pi S \sin\theta) \,/\, (1 - \cos(\pi L)) \qquad (1)$$

H-plane:

$$E_\phi = \sin(2\pi H \cos\theta)\,\cos(\pi S \sin\theta) \qquad (2)$$

where L is the length of the dipole, H is the height of the dipole above the ground plane, and S is the dipole spacing (all dimensions specified in wavelengths). Using equations 1 and 2, the element spacing was varied in order to achieve the desired reflector illumination. The calculated patterns of a 2X2 array of linear dipoles is shown in figure 6 for element spacings of 0.50λ in the E-plane and 0.55λ in the H-plane. These equations and calculations are not intended to accurately model the radiation patterns for an array of fan-dipoles, but are intended to be used as an initial starting point for the emperical design of the fan-dipole array; although, the main beam (i.e. the reflector illumination function) should not differ greatly from these calculations.

The fan-dipoles were initially tuned to the desired band using existing data and then final tuning was accomplished by trimming the individual dipole arms of each element in the array with the other three elements terminated in 50 ohms. The input voltage-standing-wave-ratio (VSWR) for each element of the array is shown by the dashed curve in figure 7. The solid curve in figure 7 shows the input VSWR of the array with the four elements combined through the power divider network.

Since the initial array design did not contain baffles or other techniques for reduction of mutual coupling, the VSWR increase within the design band is attributed to array coupling effects. The measurements in figure 8 confirm the existence of coupling levels of sufficient magnitude to cause a significant array mismatch. Baffles (conducting fences) centered between the array elements were empirically designed to reduce the interelement coupling, as verified by the measurements in figure 9. The effect of the fences upon the input VSWR is shown in figure 10. The presence of the fences cause the individual elements to be tuned to a lower frequency; however, the combined array VSWR within the resonant band of the dipoles shows an improvement due to reduction of interelement mutual coupling.

Before retuning the dipoles to the desired frequency band, radiation patterns of the array with cross-baffles were measured. These patterns are shown in figure 11. The E-plane pattern of the feed array indicates a very highly tapered reflector illumination with very low spillover and back-radiation; however, the H-plane feed pattern requires some improvement in order to achieve the desired reflector illumination. The H-plane feed pattern improvement was accomplished by installing baffles (conducting fences) on two edges of the ground plane and optimizing the baffle spacing to obtain the feed radiation patterns shown in figure 12.

With the cross-baffles and H-plane edge-baffles installed, an attempt was made to tune the array to the 608-614 MHz band by shortening the dipole elements. The VSWR results are shown in figure 13. Further improvement in the array impedance matching would require additional empirical iteration of the dipole height (length of balun) and dipole length. Lack of time did not allow further design iterations.

Reflector Radiation Patterns

The radiation pattern in the far-field of an aperture can be calculated from the Fourier transform of the tangential electric field distribution in the aperture. The θ and ϕ components of the radiation fields for the aperture are computed from

$$E_\theta = j\beta \frac{e^{-j\beta r}}{2\pi r} \left[P_x \cos\phi + P_y \sin\phi\right] \quad (3)$$

$$E_\phi = j\beta \frac{e^{-j\beta r}}{2\pi r} \left[P_y \cos\phi - P_x \sin\phi\right] \quad (4)$$

where P_x and P_y are defined as

$$P_x = \iint_{S_a} E_{ax}(x,y)\, e^{j\beta(x \sin\theta \cos\phi + y \sin\theta \sin\phi)}\, dx\, dy$$

$$P_y = \iint_{S_a} E_{ay}(x,y)\, e^{j\beta(x \sin\theta \cos\phi + y \sin\theta \sin\phi)}\, dx\, dy$$

In equations 3 and 4, E_{ax} and E_{ay} are the x,y components of the aperture electric field which, for a reflector, is obtained by the geometrical optics projection of the feed radiation pattern off the reflector surface onto a plane perpendicular to the z-axis of the reflector. S_a is the projected area of the reflector, (r,θ,ϕ) are the usual spherical coordinates of the far-field observation point, and $\beta=2\pi/\lambda$ where λ is the wavelength at the operating frequency. Equations 3 and 4 give very good results, provided that there are no objects (such as feed and struts) in front of the reflector to cause electromagnetic scattering. However, calculations using equations 3 and 4 can be supplemented with the Geometrical Theory of Diffraction [2,3] to account for the effects of feed and strut scattering.

A reflector antenna computer code [4] was used to perform radiation pattern calculations for the geometry of figure 1 using the feed illumination patterns of figure 12. The calculated radiation patterns in figure 14 for the unblocked aperture show very low sidelobes; however, when the feed and strut scattering effects were included, the sidelobes increased to -32dB in the E-plane and the 45°-plane and to -22dB in the H-plane, as shown in figure 15. Upon examination of the scatter patterns of figures 16 and 17 for the feed and struts, it was determined that the major contribution to high sidelobes in the H-plane is due to strut scatter; whereas, sidelobe levels in the E-plane and 45°-plane were primarily due to scatter from the feed. Rotation of the feed 45° with-respect-to the struts would result in strut scatter patterns as shown in figure 18 and reflector radiation patterns as shown in figure 19. Thus the preferred configuration is one in which the feed is polarized 45° with-respect-to the strut projections in the aperture plane.

Conclusions

A 611 MHz 2X2 array of fan-dipoles has been designed as a feed for an existing 9-meter reflector. It was demonstrated that conducting baffles could be used to reduce interelement mutual coupling (thus aiding in the input impedance matching) and to reduce sidelobes in the H-plane of the feed pattern. Calculated results for reflector radiation patterns show sidelobes of -22dB to -26dB due to strut scattering.

References

[1] Bailey, M. C.: "Broad-Band Half-Wave Dipole," IEEE Transactions on Antennas and Propagation, Vol. AP-32, April 1984, pp. 410-412.

[2] Kouyoumjian, R. G. and Pathak, P. H.: "A Uniform Geometrical Theory of Diffraction for an Edge in a Perfectly Conducting Surface," Proc. IEEE, Vol. 62, pp. 1448-1461, 1974.

[3] Pathak, P. H. and Kouyoumjian, R. G.: "An Analysis of the Radiation from Apertures in Curved Surfaces by the Geometrical Theory of Diffraction," Proc. IEEE, Vol. 62, pp. 1438-1447, 1974.

[4] Rudduck, R. C. and Chang, Y. C.: "Numerical Electromagnetic Code - Reflector Antenna Code NEC-REF(VERSION 2) Part I: User's Manual," Ohio State University Technical Report 712242-16 (713742), December 1982.

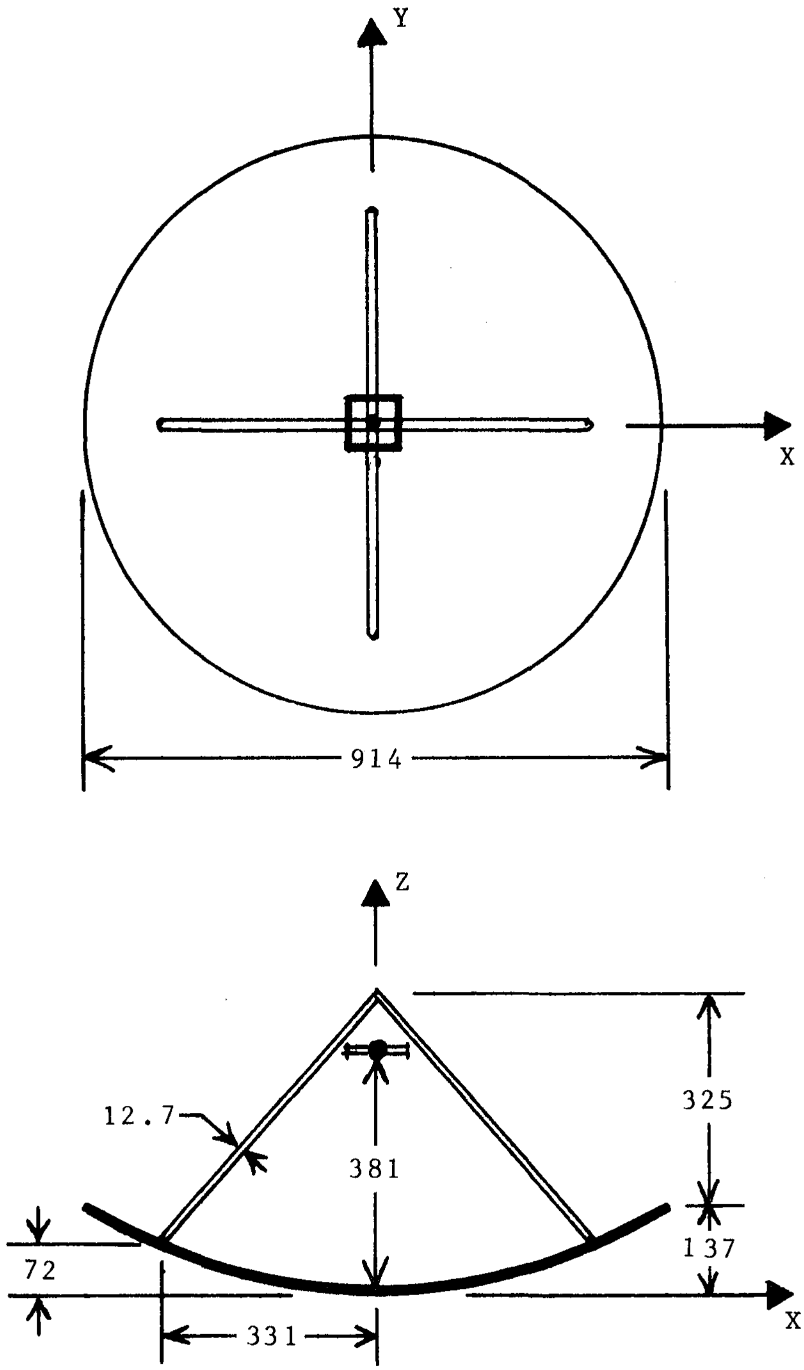

Figure 1. Geometry of 9-meter paraboloidal reflector (dimensions in centimeters).

Figure 2. Photograph of 611 MHz feed.

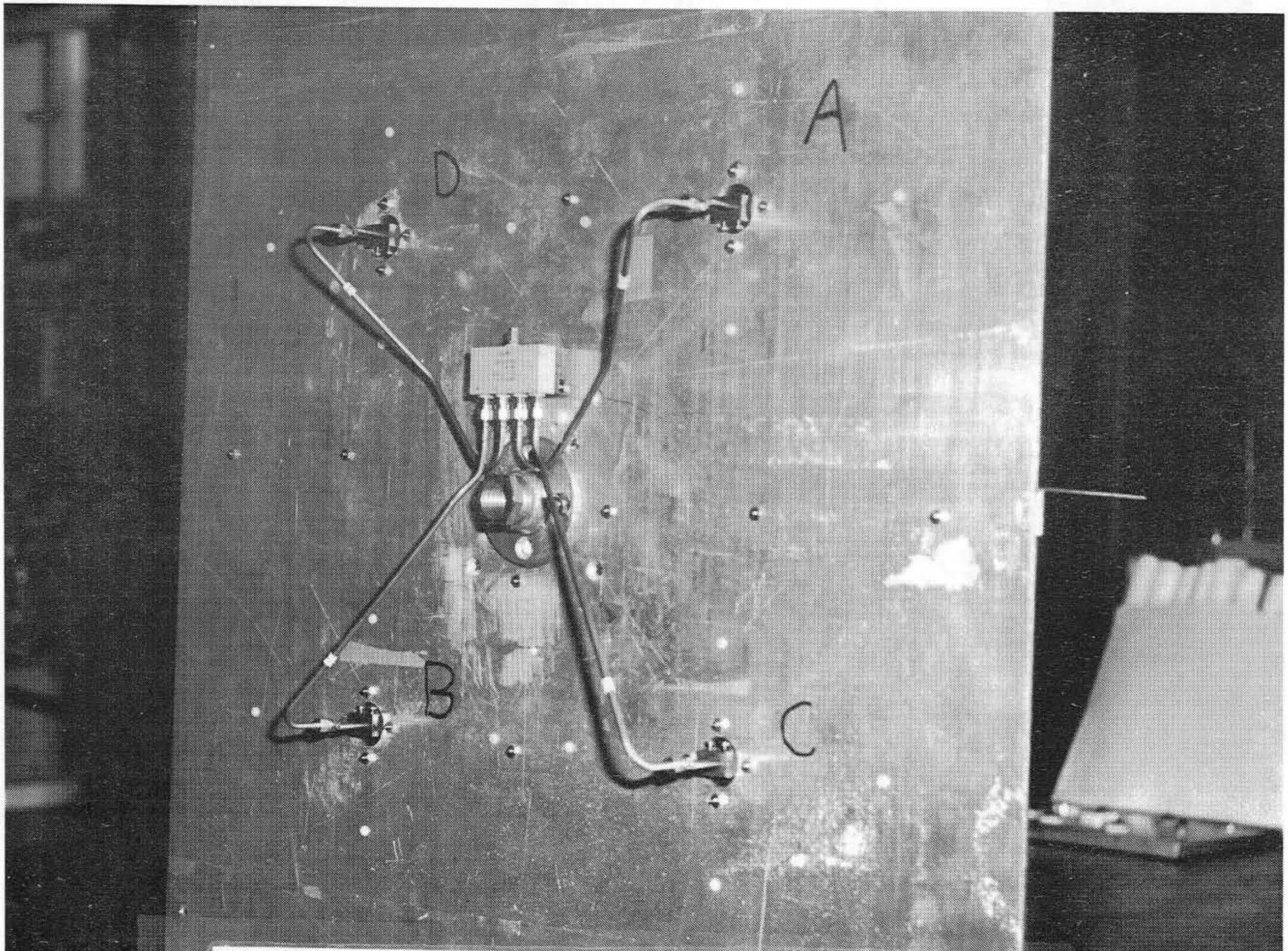

Figure 3. Power divider network for 611 MHz feed.

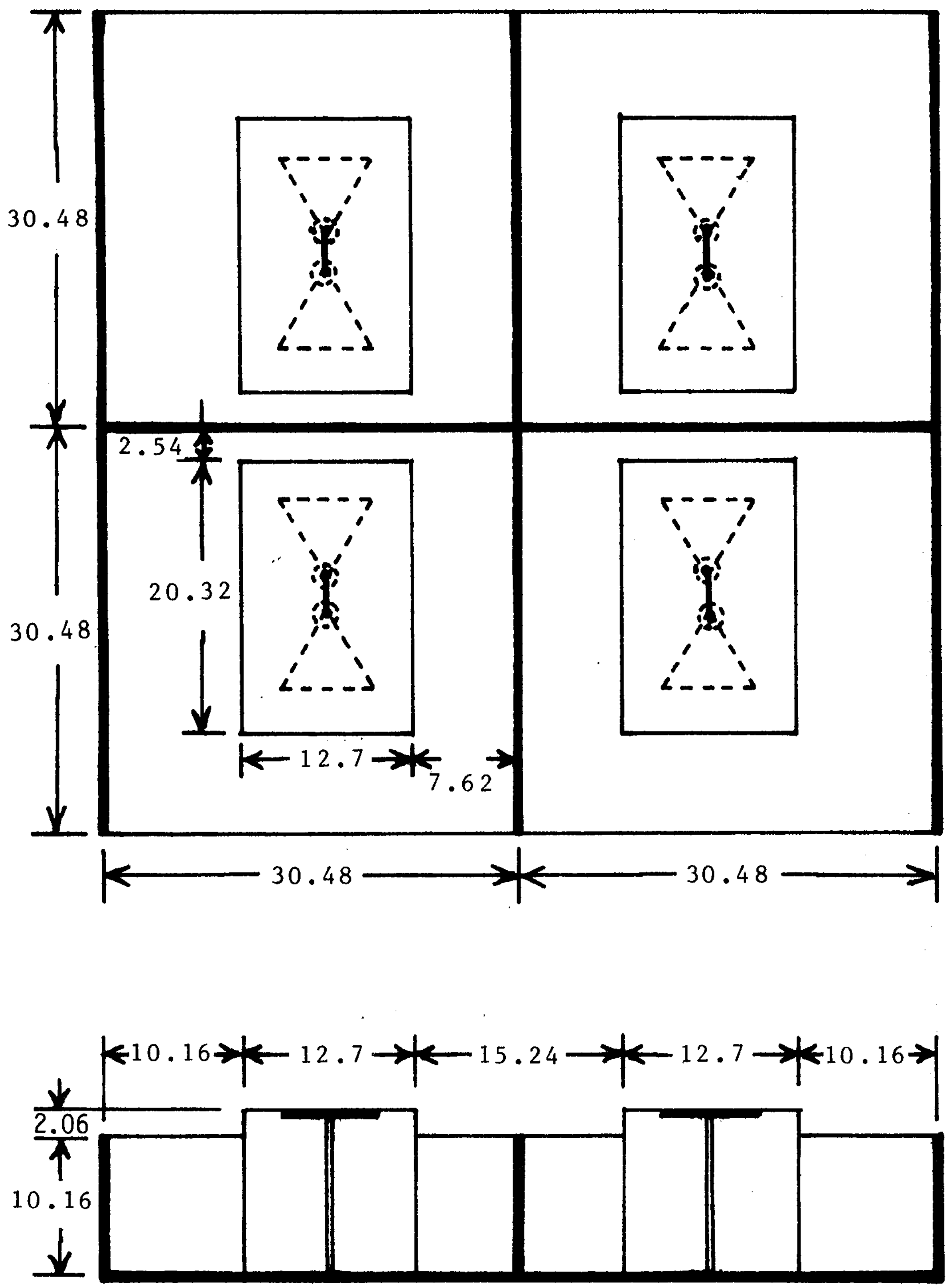

Figure 4. Dimensional drawing of 2X2 array with baffles (dimensions in centimeters).

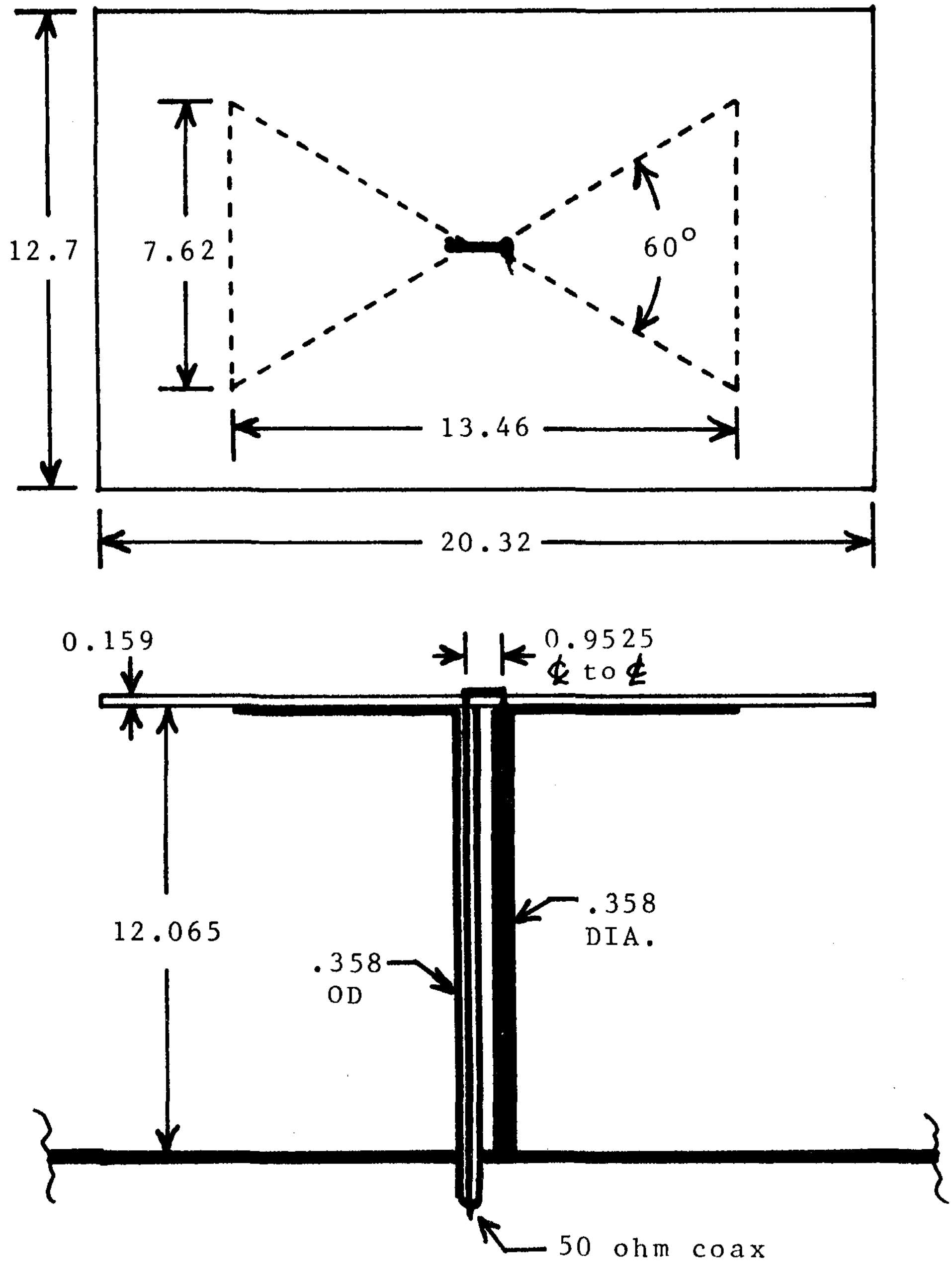

Figure 5. Detail dimensions of final dipole design (dimensions in centimeters).

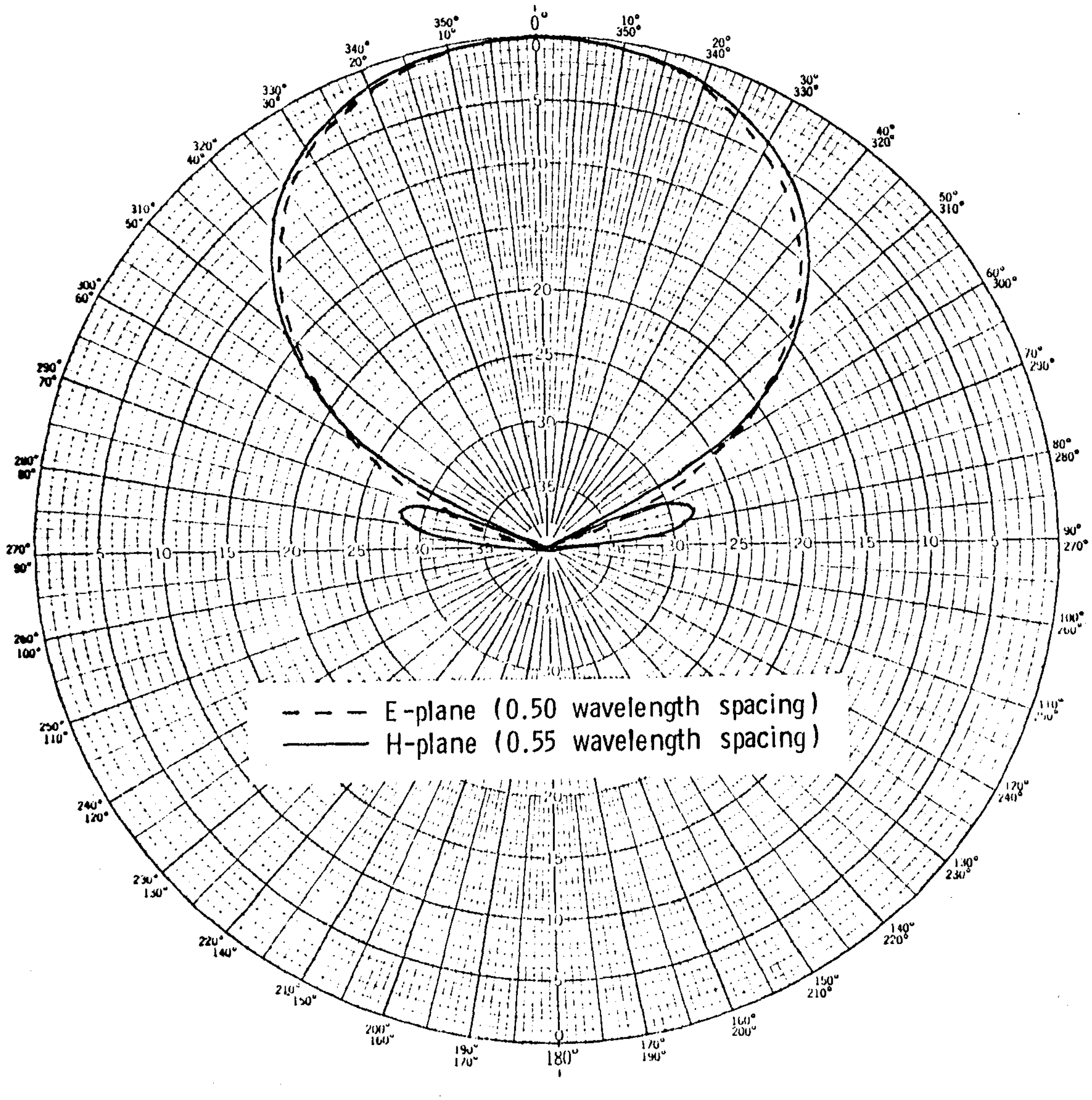

Figure 6. Calculated radiation patterns for 2X2 array of linear dipoles located over an infinite conducting ground plane (dipole length = 0.3 wavelengths, dipole height = 0.25 wavelengths).

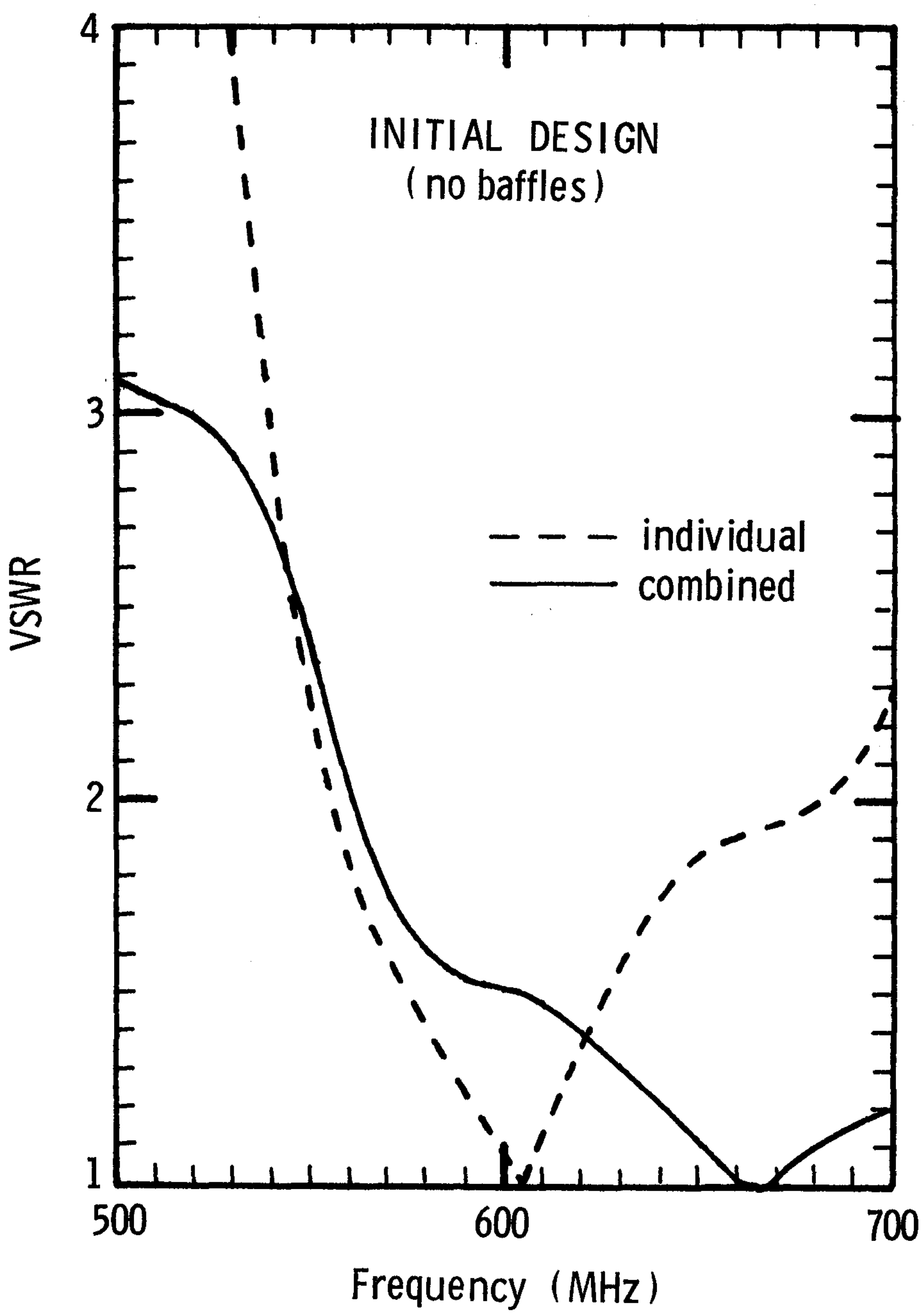

Figure 7. Measured VSWR for 2X2 array without baffles.

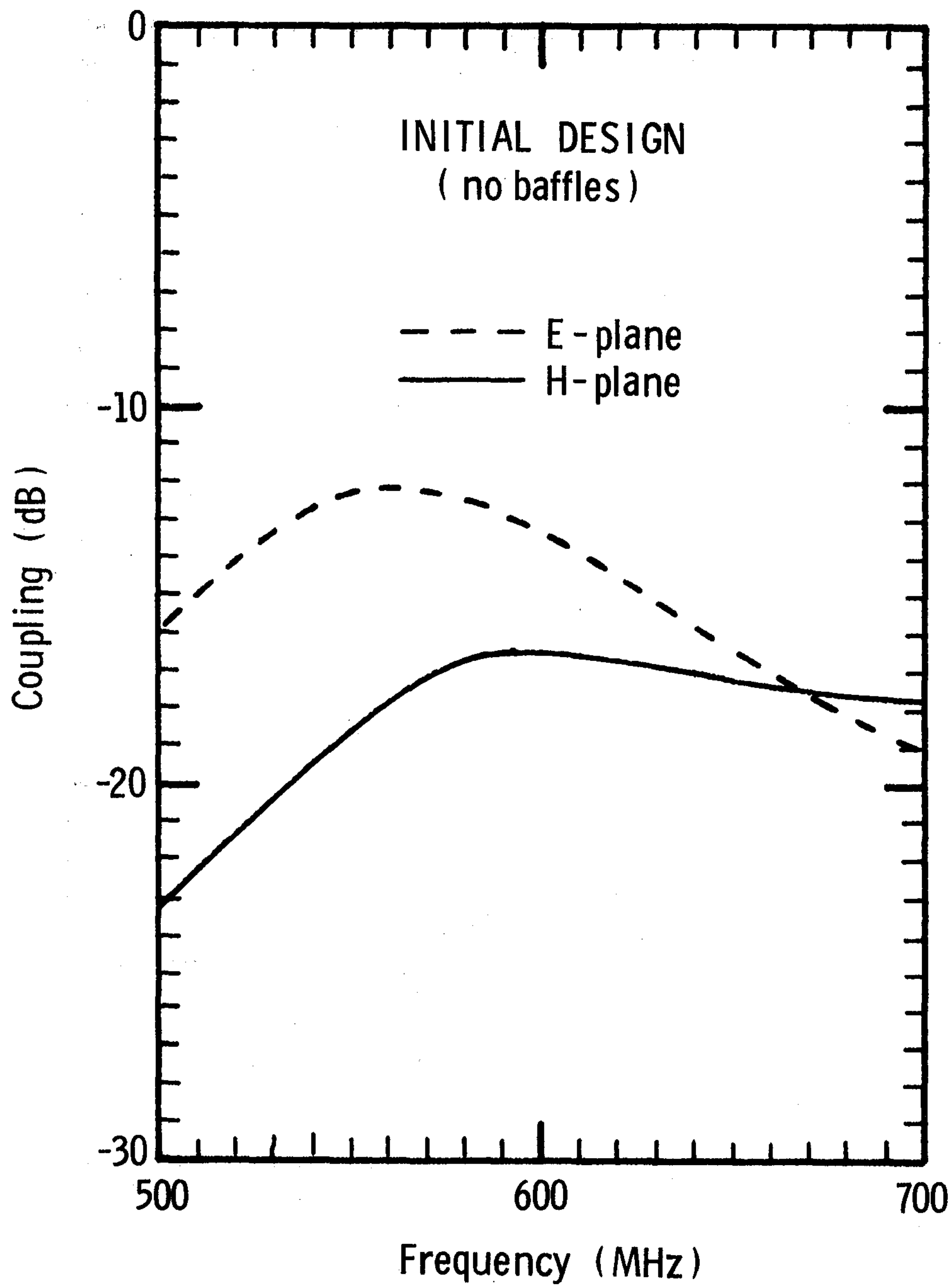

Figure 8. Measured interelement coupling for 2X2 array without baffles.

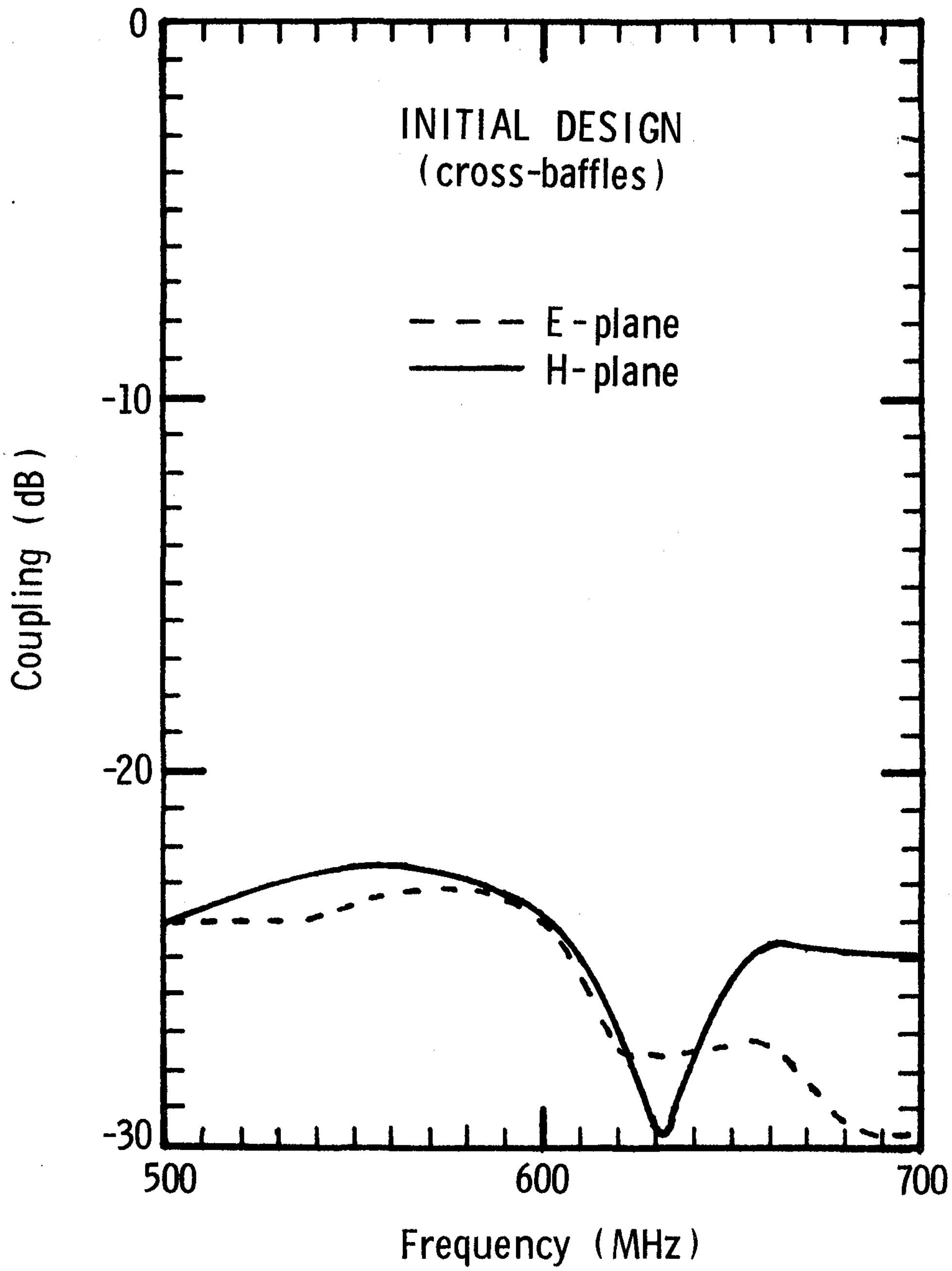

Figure 9. Measured interelement coupling for 2X2 array with cross-baffles.

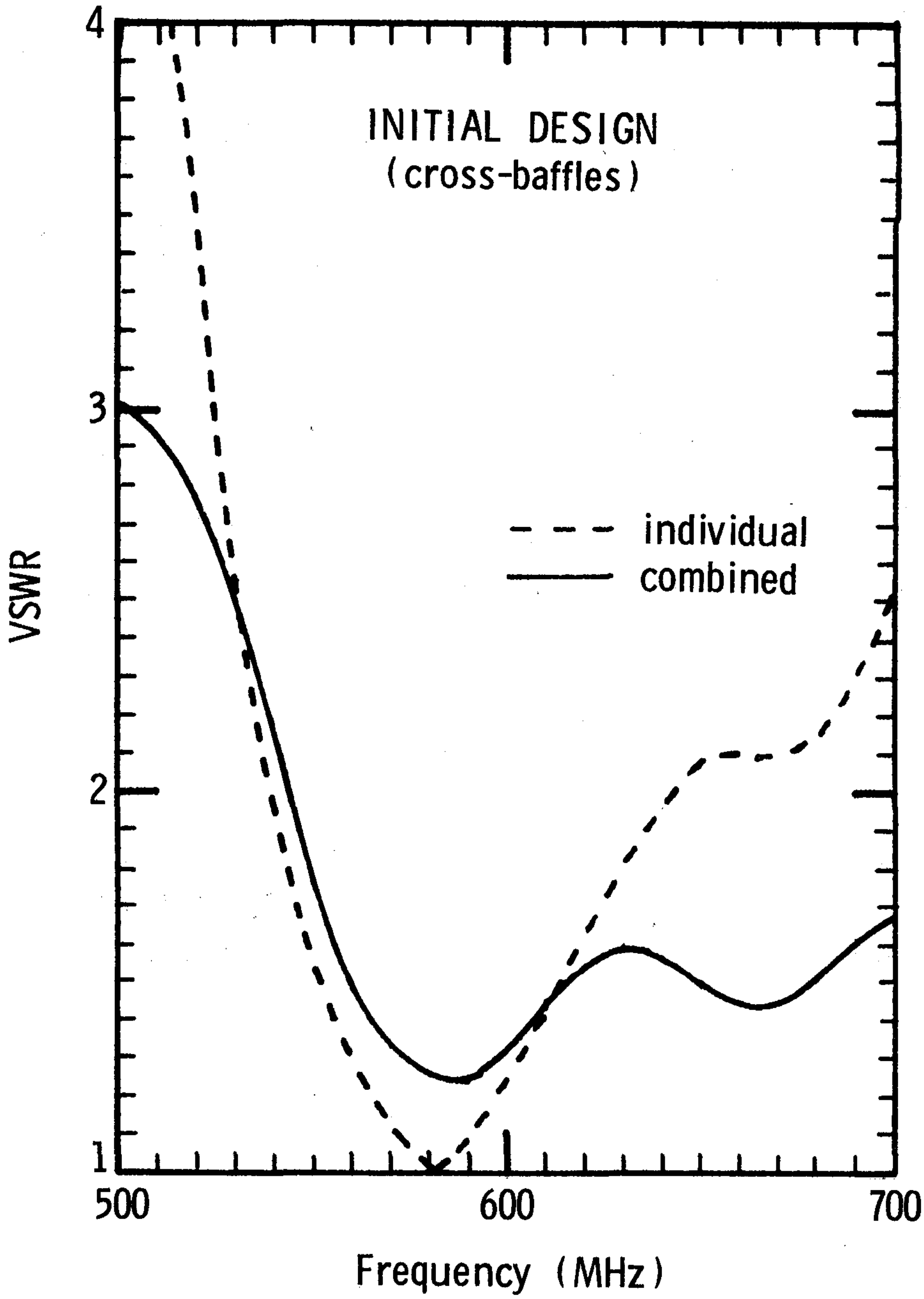

Figure 10. Measured VSWR for 2X2 array with cross-baffles before final dipole tuning.

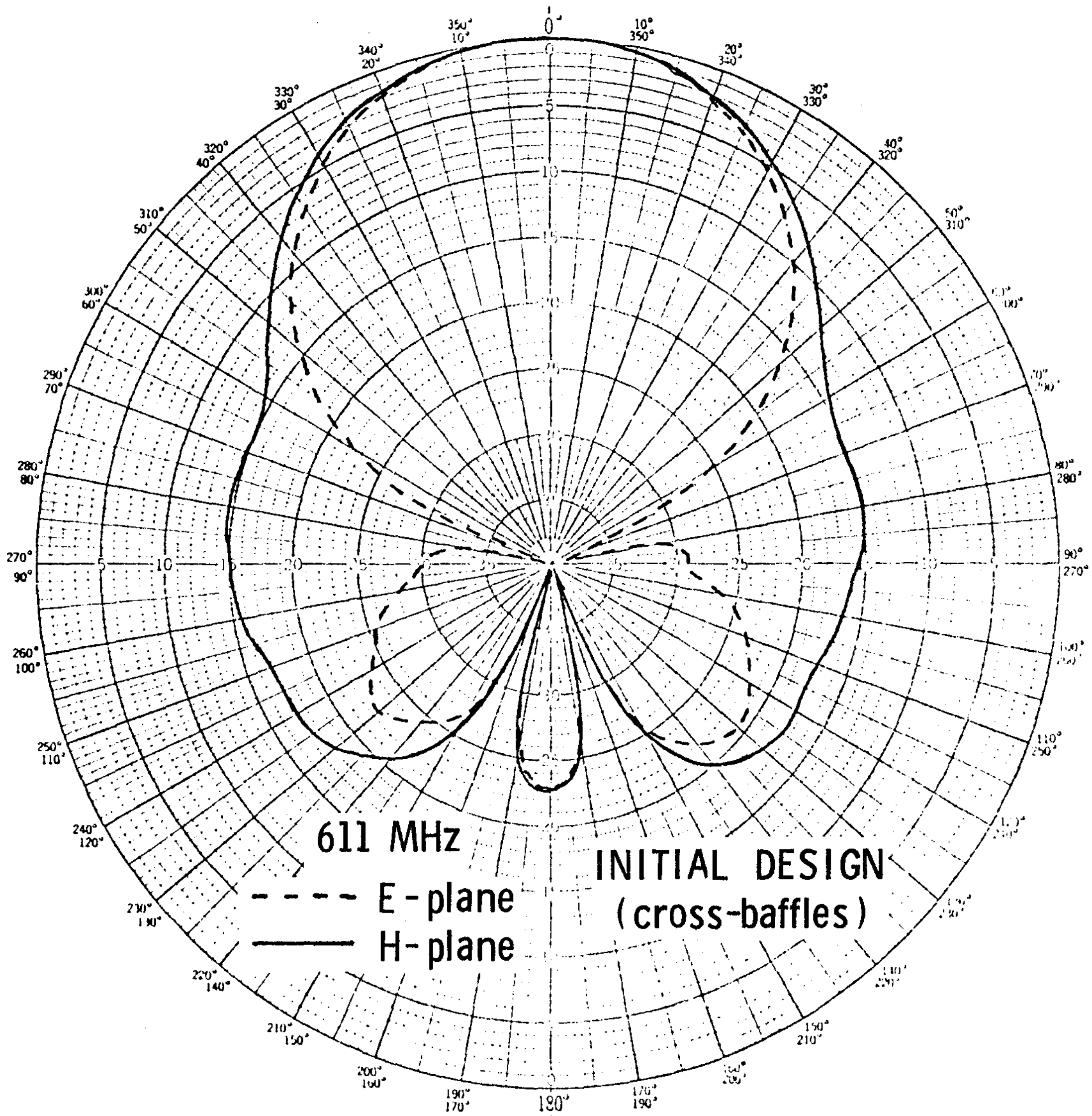

Figure 11. Measured radiation patterns of 2X2 array with cross-baffles.

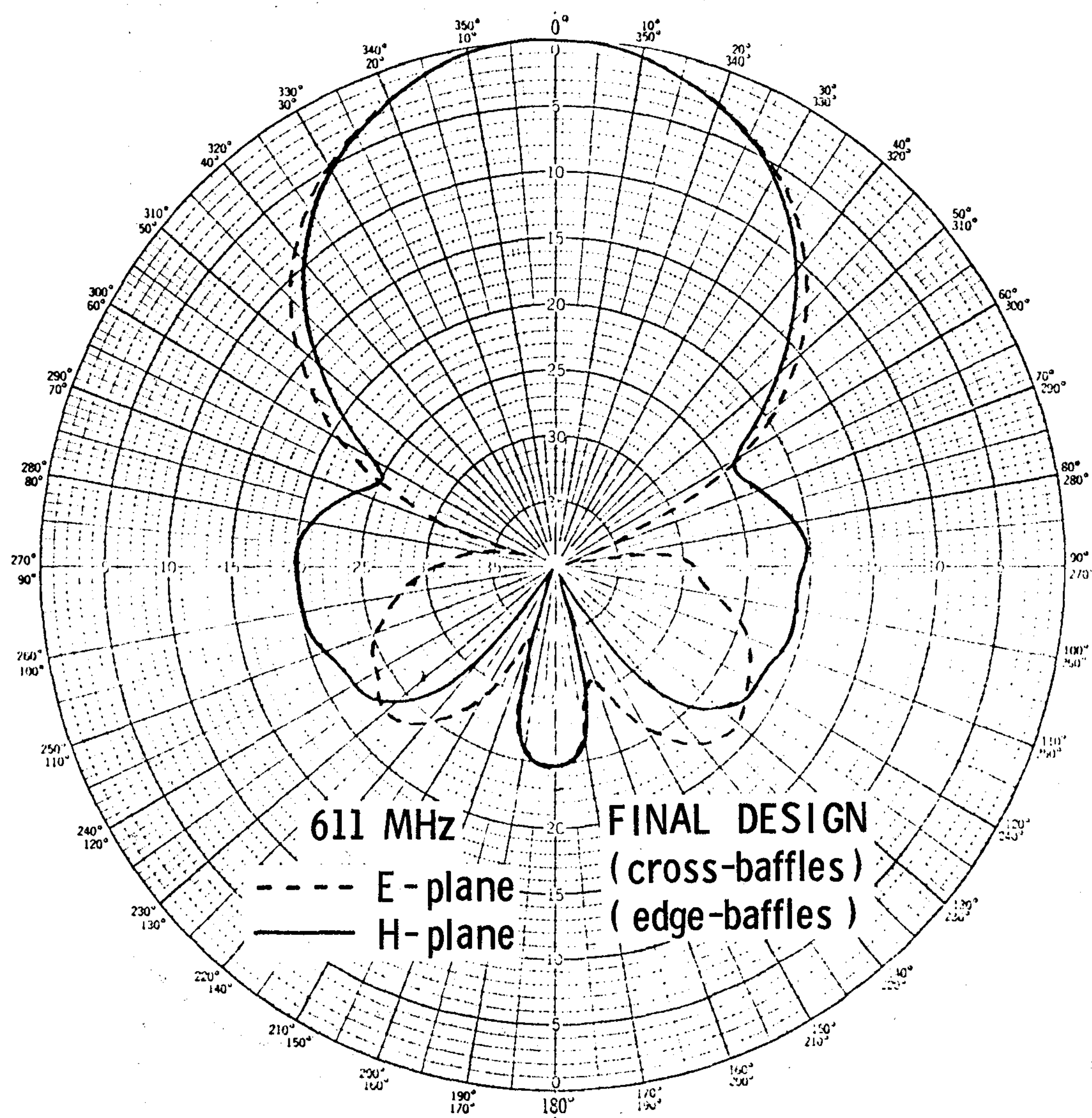

Figure 12. Measured radiation patterns of 2X2 array with cross-baffles and edge-baffles.

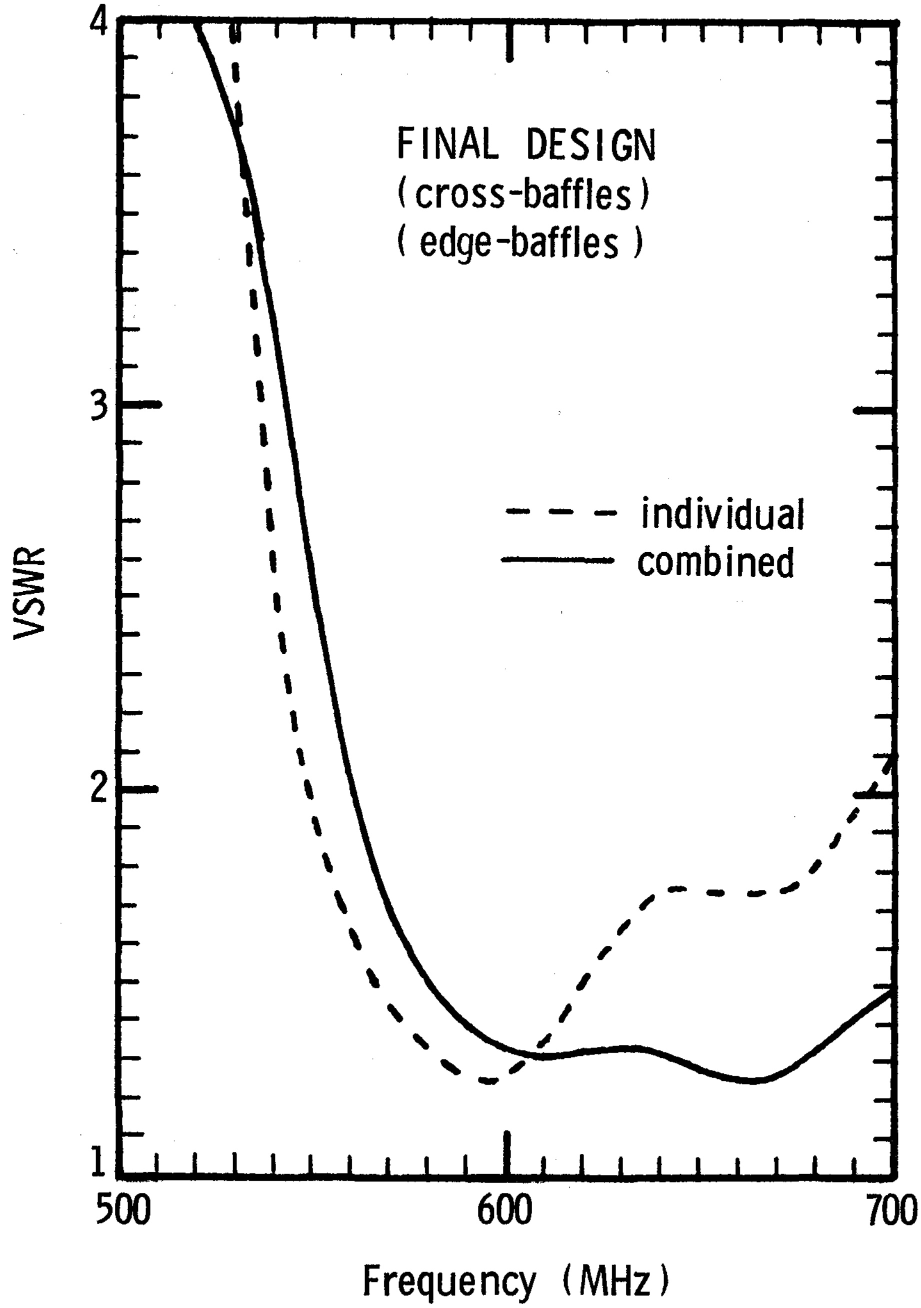

Figure 13. Measured VSWR for 2X2 array with cross-baffles and edge-baffles after final dipole tuning.

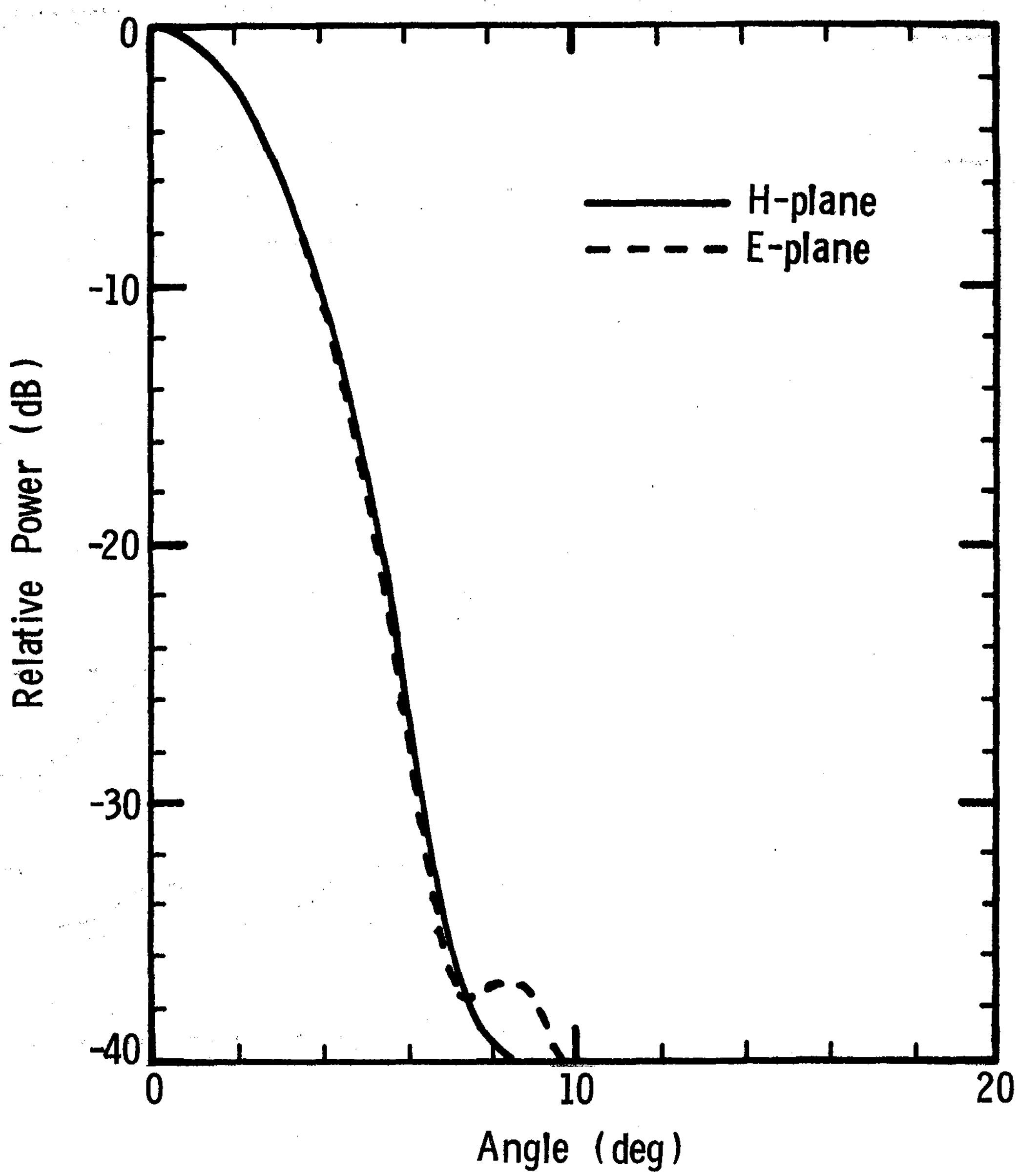

Figure 14. Calculated reflector radiation patterns at 611 MHz using feed patterns of figure 11.

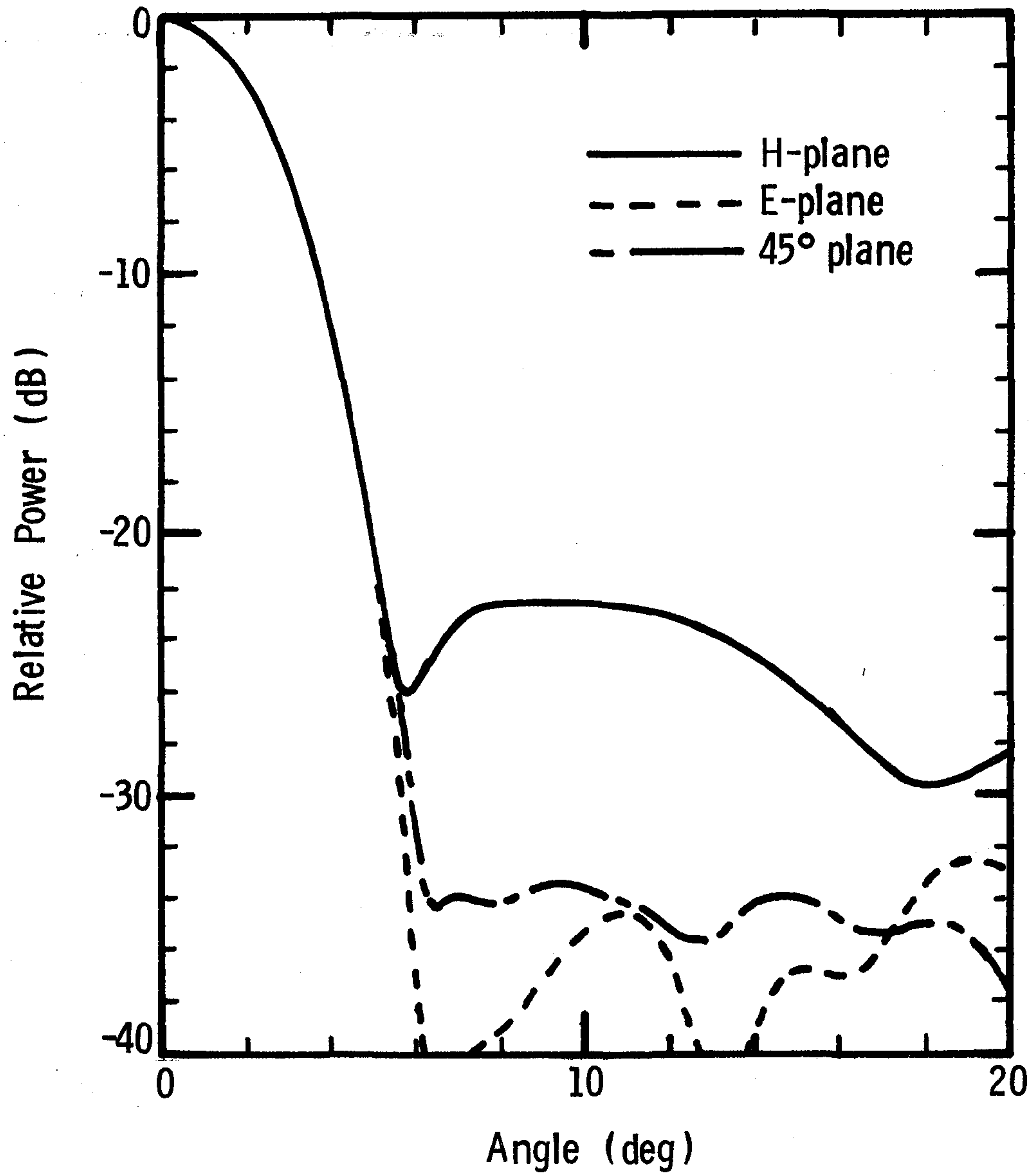

Figure 15. Calculated reflector radiation patterns at 611 MHz including feed and strut scattering effects.

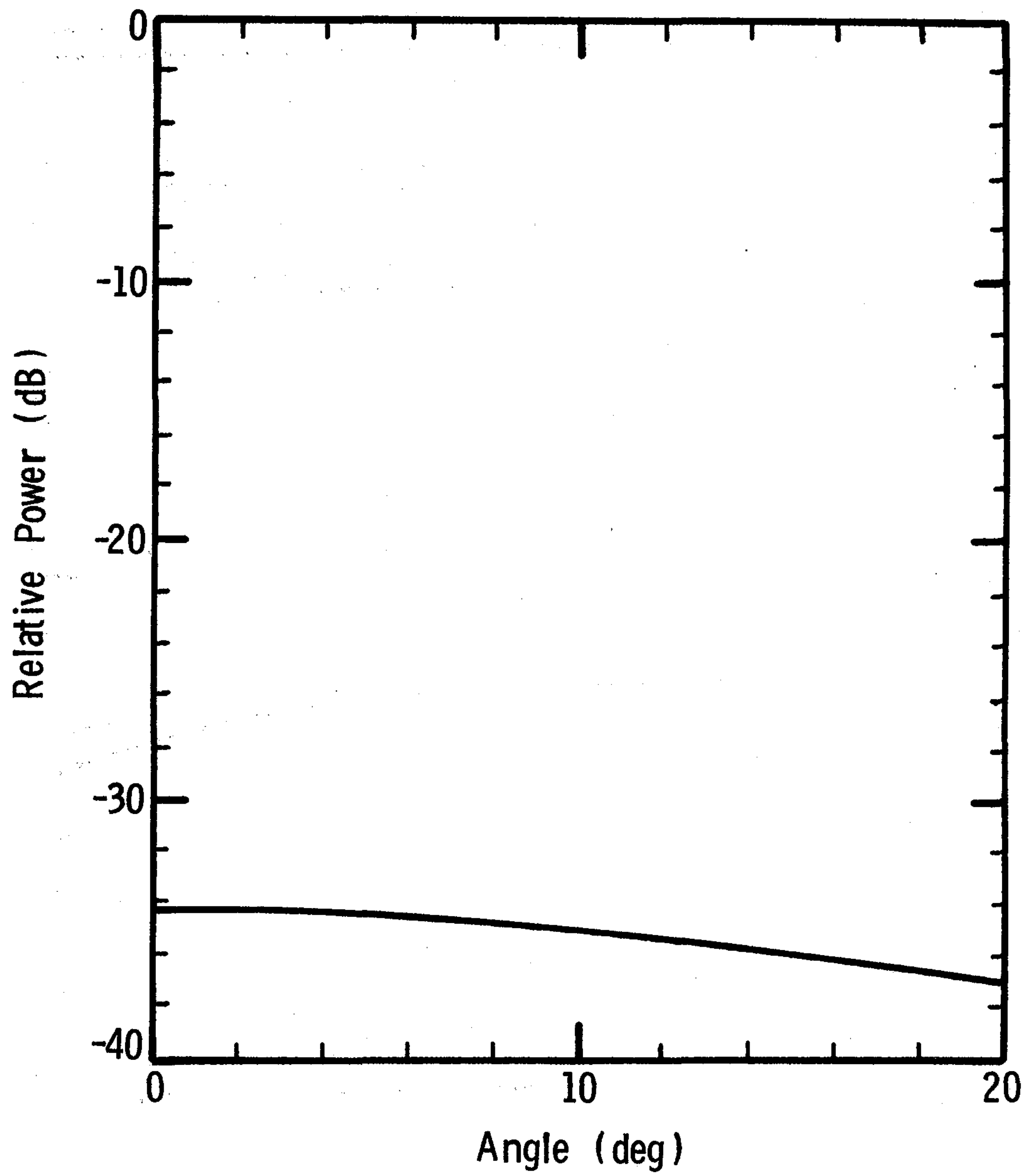

Figure 16. Calculated scatter pattern for feed blockage.

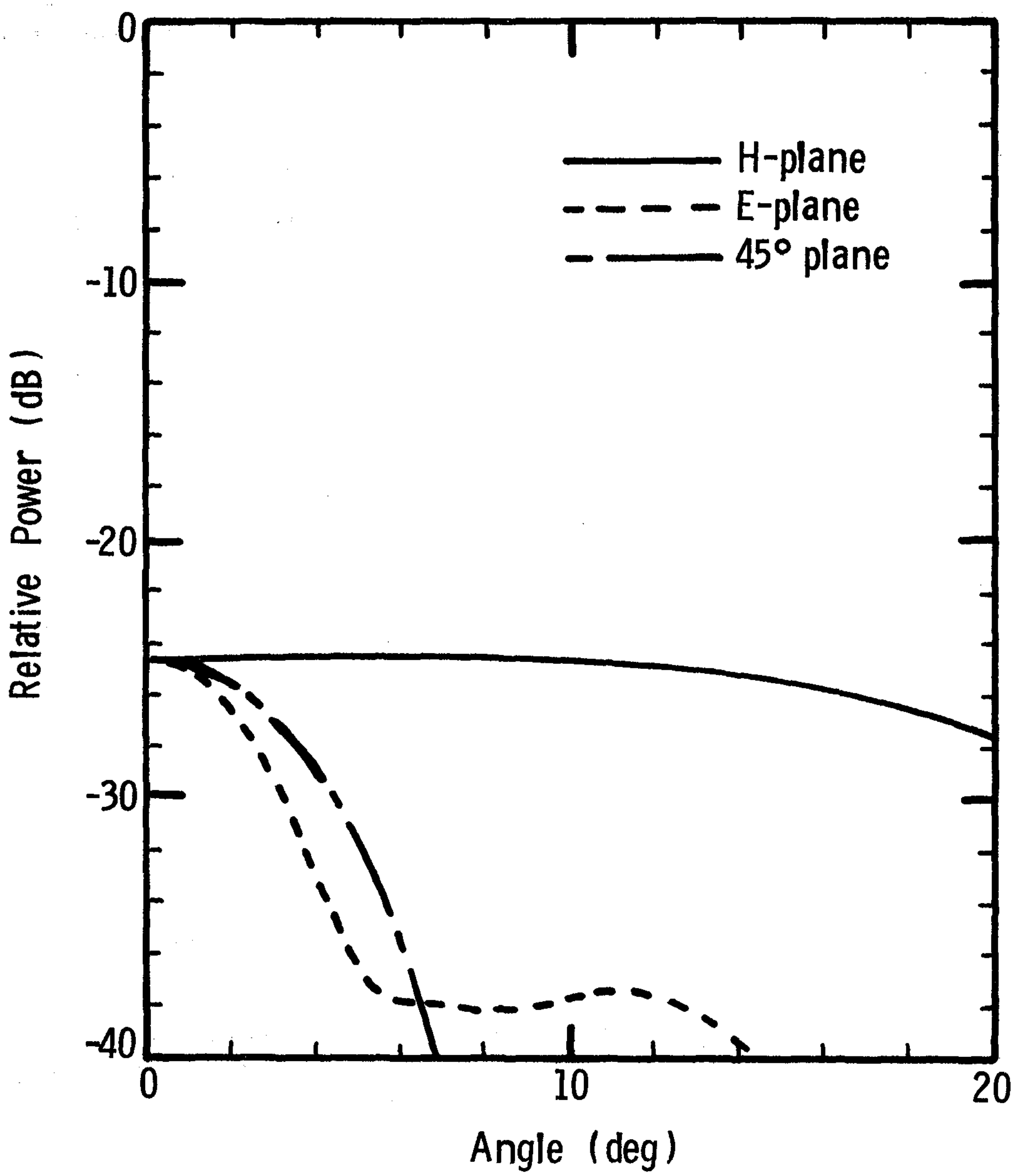

Figure 17. Calculated scatter patterns for struts.

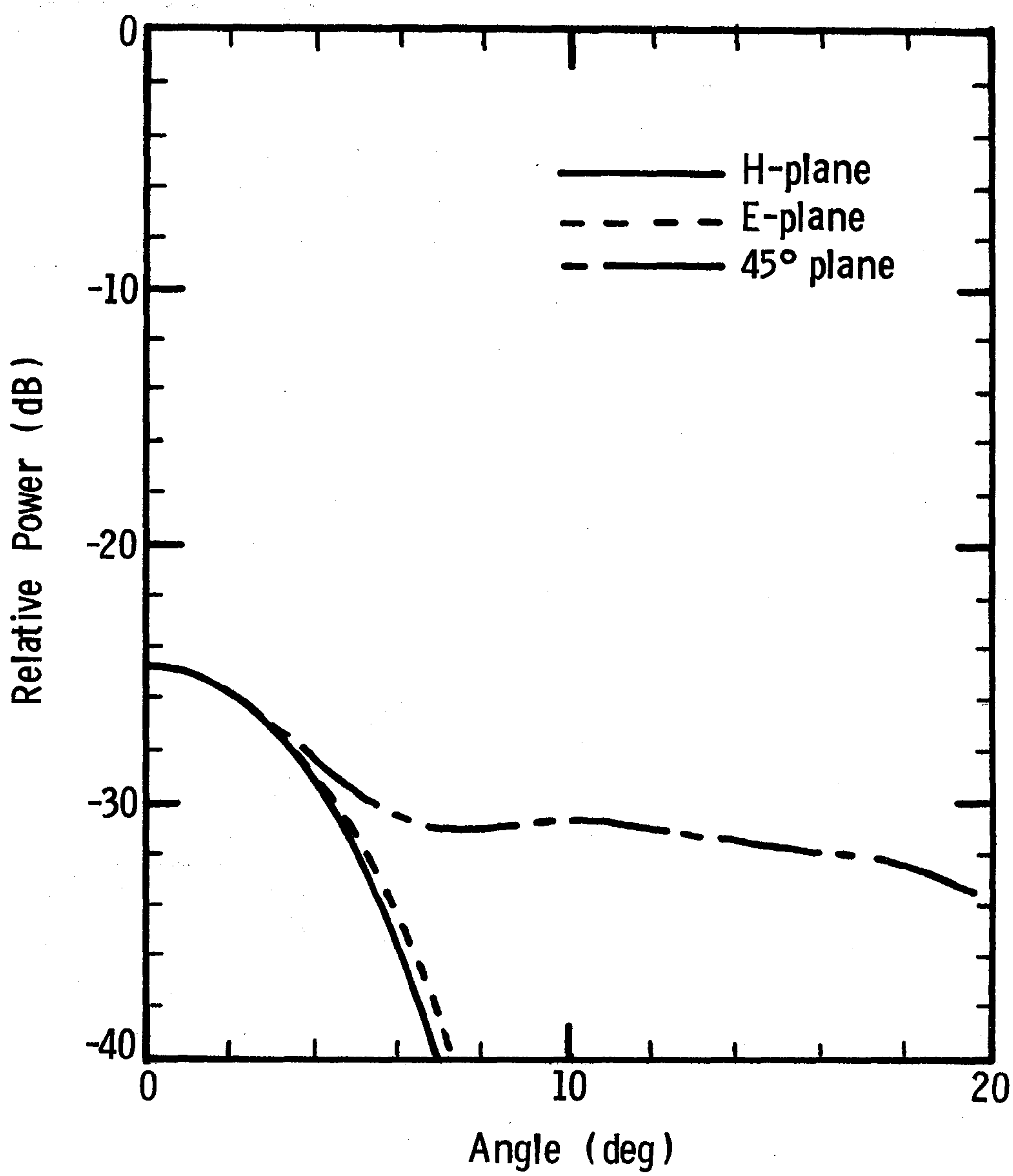

Figure 18. Calculated scatter patterns for struts with feed polarized 45° to strut projections in aperture plane.

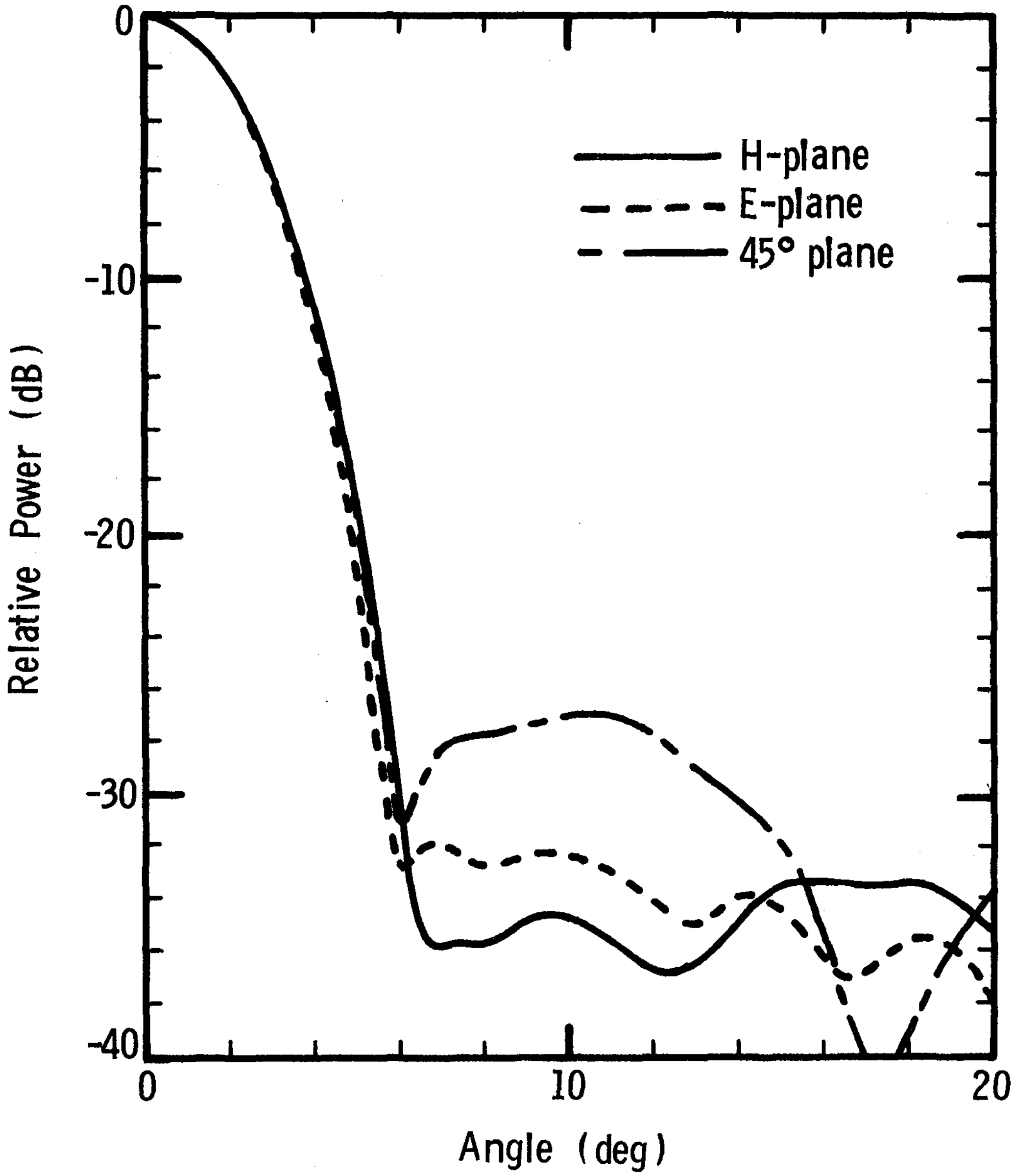

Figure 19. Calculated reflector radiation patterns at 611 MHz including feed and strut scattering effects with feed polarized 45° to strut projections in aperture plane.

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16. Abstract

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