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1967-47

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X-Band
Cylindrical Lens Antenna

26 October 1967

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LINCOLN LABORATORY

X-BAND CYLINDRICAL LENS ANTENNA

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Group 61

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Abstract

This report describes a low-silhouette X-band circularly polarized airborne antenna. The antenna system consists of a solid polyethylene cylindrical lens and a circular polarization transducer illuminated by a line source.

Accepted for the Air Force
Franklin C. Hudson,
Chief, Lincoln Laboratory Office

X-Band Cylindrical Lens Antenna

I. INTRODUCTION

In connection with a program to investigate, design and improve antennas for use in satellite communication systems, Lincoln Laboratory has developed an X-band airborne antenna which has a low silhouette and the following characteristics:

1. Essentially complete coverage of the hemisphere above the horizontal plane of the aircraft.
2. Power gain ≈ 31 db.
3. Power handling capability > 10 kw.
4. Circularly polarized with transmit and receive signals orthogonally polarized.
5. Produces tracking error signals in the azimuthal plane of scan.
6. Two operating frequency bands (bandwidth ≈ 50 Mcps) separated by approximately 600 Mcps.

The antenna system consists of a solid polyethylene cylindrical lens and a circular polarization (CP) transducer illuminated by a line source. The 48-inch by 0.9-inch line source consists of a pair of orthogonally polarized waveguide slotted arrays combined in a parallel-plate assembly which in turn illuminates the lens. One array, operating at the transmit frequency (f_t) is an end fed, non-resonant, narrow-wall slotted waveguide array with the E-field parallel to the broad walls of the parallel-plate assembly. The receive

frequency (f_r) array is formed by center feeding a broad-wall slotted waveguide non-resonant array whose radiated E-field is perpendicular to the broad walls of the parallel-plate assembly. The receive signals propagate from the lens to the parallel-plate region and then past the narrow wall transmit array to the receive array.

II. DESCRIPTION OF ANTENNA

For dual-frequency operation separated by 600 Mcps in a waveguide slotted array, the following problems must be considered. In a slotted waveguide array the radiation pattern beam peak will shift away from the normal to the line source by approximately one-half degree for a one percent change in frequency with no beam squint present when the slot spacing is one-half guide wavelength ($\lambda_g/2$). If a single waveguide array were used with simultaneous operation at f_r and f_t , there could result a sizable separation between the transmit and receive beams. To avoid this problem separate waveguide arrays for each of the two frequencies were combined in the parallel-plate assembly with the f_t array appropriately squinted to allow the transmit and receive beam peaks to coincide. The choice of using a non-resonant array as opposed to an array with slot spacing of a half wavelength was made to avoid a narrow bandwidth impedance match which would be necessary in a resonant array. A slot spacing was used which placed the operational frequency sufficiently away from the resonant frequency to obtain low VSWR's but still close enough to the resonant frequency to minimize the beam squint. A uniform array

illumination allowing for a tolerable terminating load loss of five percent was used as the design criterion.¹ The waveguide size used for both arrays is WR-112 with the slots machined in the broad wall for the f_r array and slotted in the narrow wall for the f_t array. A one-degree beam squint was measured for both arrays. Because of the one-degree beam squint the transmit array has been positioned at an angle to bring both the transmit and receive beams into coincidence. The presence of the transmit array presents a high voltage standing wave ratio (VSWR) to the receive array; however, this has been minimized by increasing the external width of the transmit waveguide array to achieve the proper phase relationship so that the reflections from both surfaces will cancel. The broad-wall receive array looks into an E-plane bifurcated parallel-plate junction formed by the narrow-wall array and the parallel-plate assembly. In this way symmetry is achieved preventing the excitation of higher order modes and subsequent radiation pattern and gain degradation. The parallel-plate length changes from 1-1/4 inch to 0.9 inch at the f_t slotted aperture. Bolted to this parallel-plate assembly is a flared section about 7 inches deep with a 9-inch by 48-inch aperture. This section also holds the polyethylene lens assembly and the polarizer at the correct focal distance from the parallel-plate line source. A drawing of this assembly is shown in Fig. 1 and a photograph of the antenna is shown in Fig. 2.

A polarizer consisting of an array of vanes oriented at 45° transforms the left-hand circularly polarized receive signal to the linear which is necessary

for the operation of the receive array. The polarizer also transforms the transmit array linearly polarized signal to a right-hand circular transmitted wave. A waveguide folded E-plane hybrid is used to combine two identical broad-wall slotted arrays to obtain sum and difference error patterns at the receive frequency.

III. DIELECTRIC LENS

In an operational antenna it would be desirable to use teflon as a material for the lens because of its low transmission loss and ability to withstand high temperature. Polyethylene was used for the development model because it is more readily available at a lower cost than teflon with no significant sacrifice of the electrical characteristics. The lens was designed using geometrical optics and is a hyperbolic cylinder with a maximum lens thickness of 2.662 inch. The flare angle of 60° was chosen to obtain a reasonably short focal length about equal to the height of the lens for the purpose of minimizing the swept volume. The dielectric lens corrects phase errors of approximately $3/4$ wavelength which exist in the flared section of the antenna. Figure 3 is a photograph of the dielectric lens.

IV. CIRCULAR POLARIZER

Transformation from the linearly to the circularly polarized waves is performed at the antenna aperture. An array of vanes oriented 45° to the incident linear polarization transforms the incident wave into a circularly polarized wave in the following manner. Resolving the incident field into

orthogonal components, parallel and perpendicular to the vanes, and considering the time delay in propagating through the vanes one of the component vectors is delayed in time by a phase angle dependent upon the vanes spacing and depth. When this differential time phase relationship is approximately 90° and the component field vectors are of equal amplitude the output wave is circularly polarized. In this manner the transmit signal becomes right-hand circularly polarized and the left-hand circularly polarized² receive signal is converted into linearly polarized signals. Figure 3 depicts the polarizer and includes the vane dimensions.

The polarizer was designed to produce circular polarization at the center frequency and then its performance was measured at the transmit and receive frequencies. Measurements were performed on a 2000-foot-long ground level test range using a rotating linearly polarized feed as the transmitter. A series of measurements were made to separate polarization measurement errors from the data. The antenna under test was left in a fixed position in the plane of polarization while the transmit polarization was rotated in the same plane to obtain the angular position that produced the maximum field. The test antenna was then shifted in 45° steps in the polarization plane where each time the linear transmit orientation angle resulting in the maximum field at the test antenna was obtained. The angular orientations of the maximum field at the test antenna were referenced to the long dimension of the antenna for both transmit and receive cases. A method for representing the data on an

impedance chart is described elsewhere.³ The data is plotted on a Smith chart and is shown in Figs. 4 and 5.

The radial displacement of the plotted points is proportional to the axial ratio of the circular polarization transducer modified by measurement errors. The spread of the plotted points enclosed in circle A approximates the external effects on the ellipticity of the polarizer. It can be seen that the ellipticity of the polarizer is 1.1 db for the RHCP transmit signal and 1.15 db for the LHCP receive signal. This appears to be the optimum configuration for obtaining the best CP signal at both frequencies.

V. ANTENNA PATTERNS AND GAIN MEASUREMENTS

Linearly polarized antenna patterns were taken at the Lincoln Laboratory 2000-foot range test facility and a set of these patterns are shown. Antenna patterns 1 through 6 are linearly polarized and patterns 7 through 11 are circularly polarized patterns of both the receive and transmit modes of operation. The circularly polarized patterns include the polarization measurement errors while the accompanying table of measurements shows the polarizer ellipticity obtained as described above.

The gain measurements are referenced to an isotropic radiator with matched polarization and are listed in the accompanying table. The load loss is that part of the input power which is dissipated in the load terminating each array. Final data is presented in the following table.

Table of Measurements

	<u>Receive (f_r)</u>	<u>Transmit (f_r)</u>
Gain	31.0 db	30.7 db
Polarization Axial Ratio	1.15 db	1.10 db
HPBW* E-plane	8.1	1.5
H-plane	1.8	11.2
Load Loss	0.1 db	0.9 db
VSWR	1.65	1.44

Although both arrays were designed for uniform illumination, the performance of the receive array indicates that an appreciable taper does exist. If this array were redesigned to yield a more nearly uniform illumination the gain of f_r should be increased to about 32 db. Initially, the transmit array had a gain of 32.3 db, a HPBW of 10.8 and a load loss of less than 0.1 db. Subsequent changes in the configuration, which improved the overall characteristics of the antenna have resulted in the increased load loss, wider HPBW and lower gain as listed in the table. By readjusting the slot design to couple more energy out of the narrow-wall waveguide and by readjusting the lens position, the performance could be improved to obtain the values initially measured.

Although the development antenna was not designed to handle 10 kw of power, it is considered that a straightforward modification would permit the antenna to operate under all specified conditions satisfactorily.

* These beamwidths were measured without the polarizer in place.

VI. CONCLUSION

A circularly polarized X-band antenna consistent with the design objectives has been constructed and tested. An antenna of this design inside a radome and mounted on top of an aircraft could be mechanically scanned to provide at least hemispherical coverage down to the horizontal plane of the aircraft. The low silhouette rectangular configuration is more suitable than the more conventional paraboloid because the aspect ratio can be arranged to obtain a greater radiating aperture in a given radome.

ACKNOWLEDGMENT

The author wishes to thank Mr. L. J. Ricardi for his many helpful suggestions.

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2. J. D. Kraus, Antennas, (McGraw-Hill, New York, 1950).
3. V.H. Rumsey, G.A. Deschamps, M.L. Kales, J.I. Bohnert, "Techniques for Handling Elliptically Polarized Waves with Special Reference to Antennas," Proc. IRE 39, No. 5, 533-566 (1951).

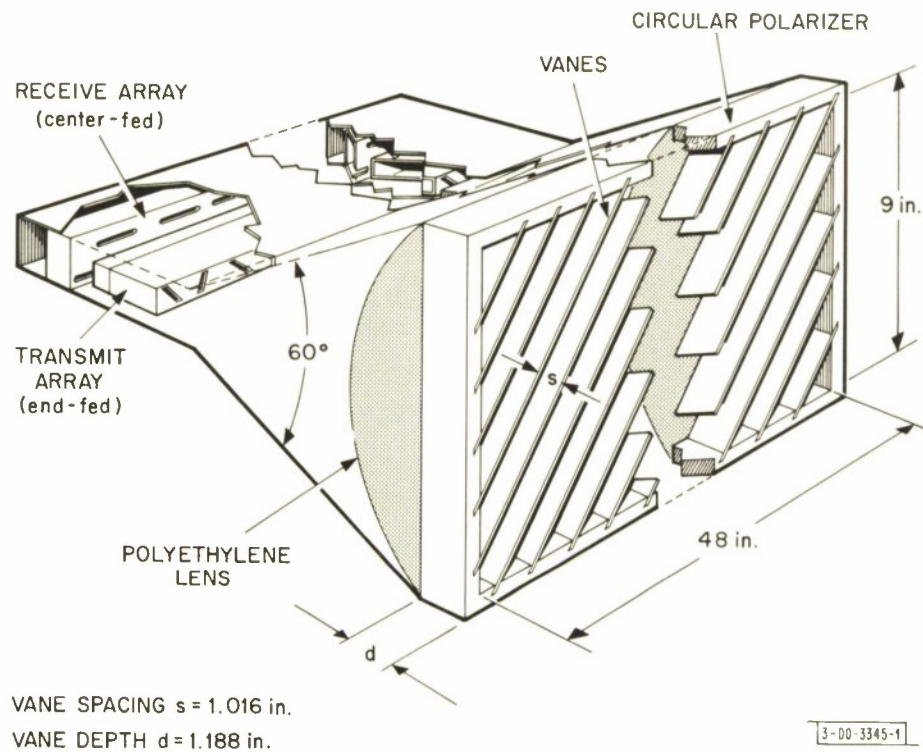


Fig. 1. X-band cylindrical lens antenna.

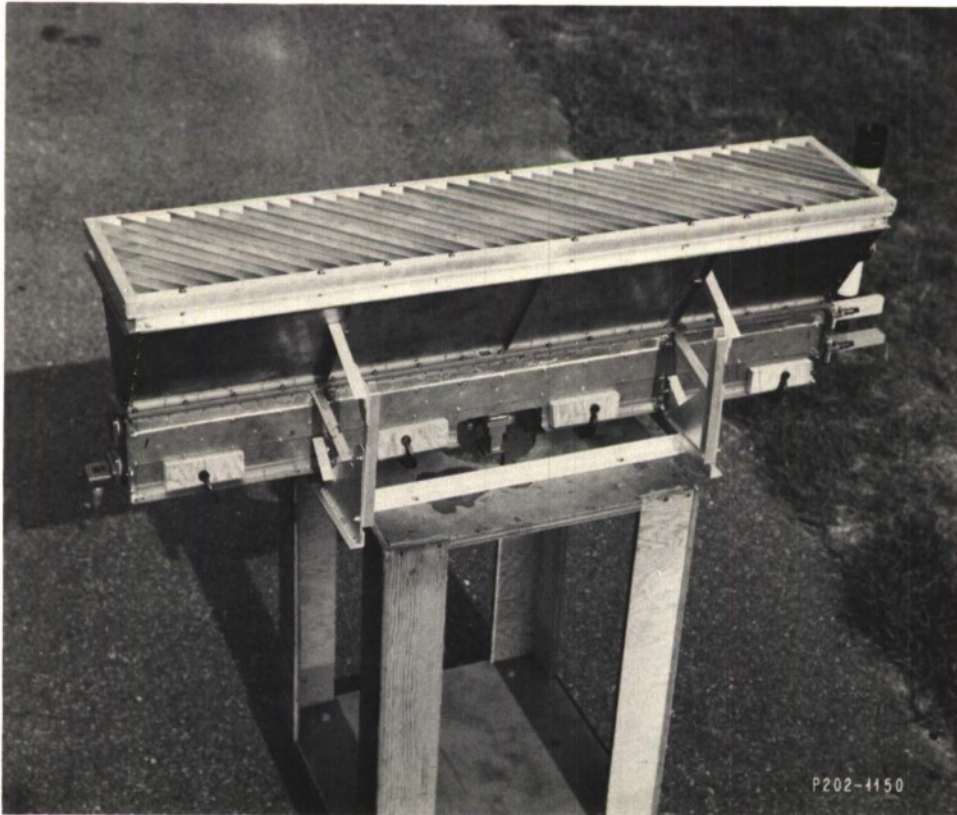


Fig. 2. X-band cylindrical lens antenna.

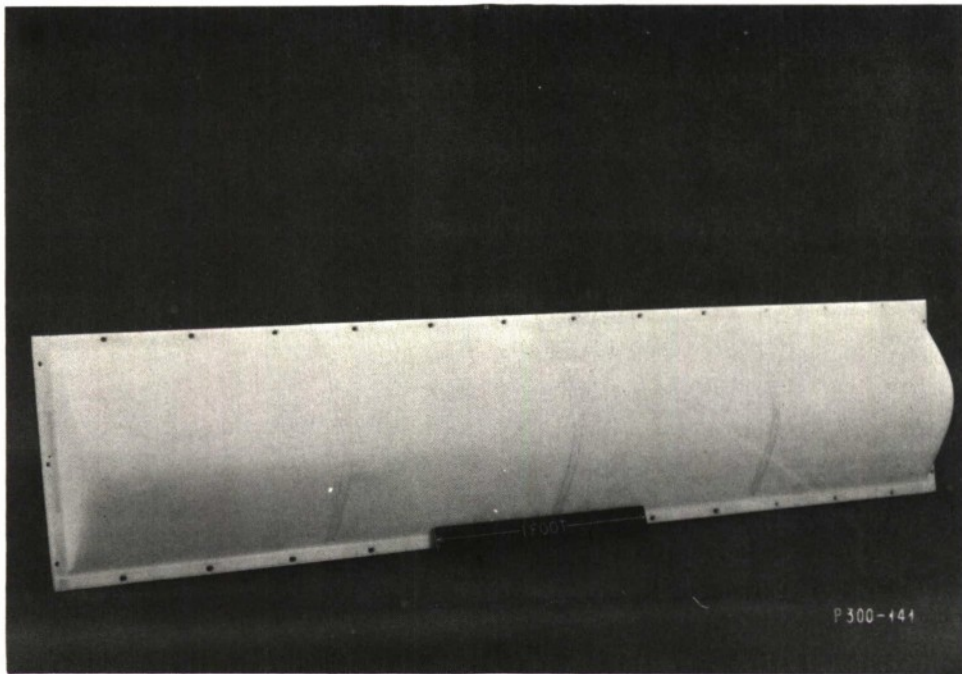


Fig. 3. Polyethylene cylindrical lens.

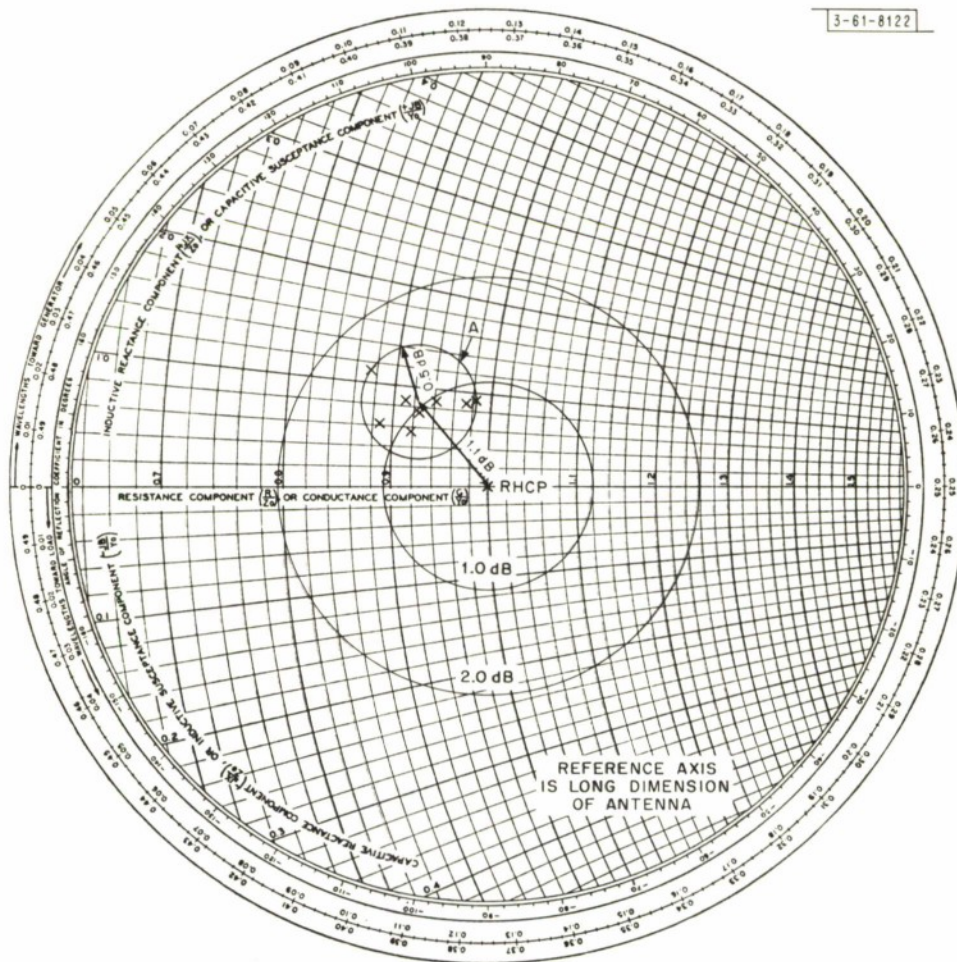


Fig. 4. Polarizer data for f_t array.

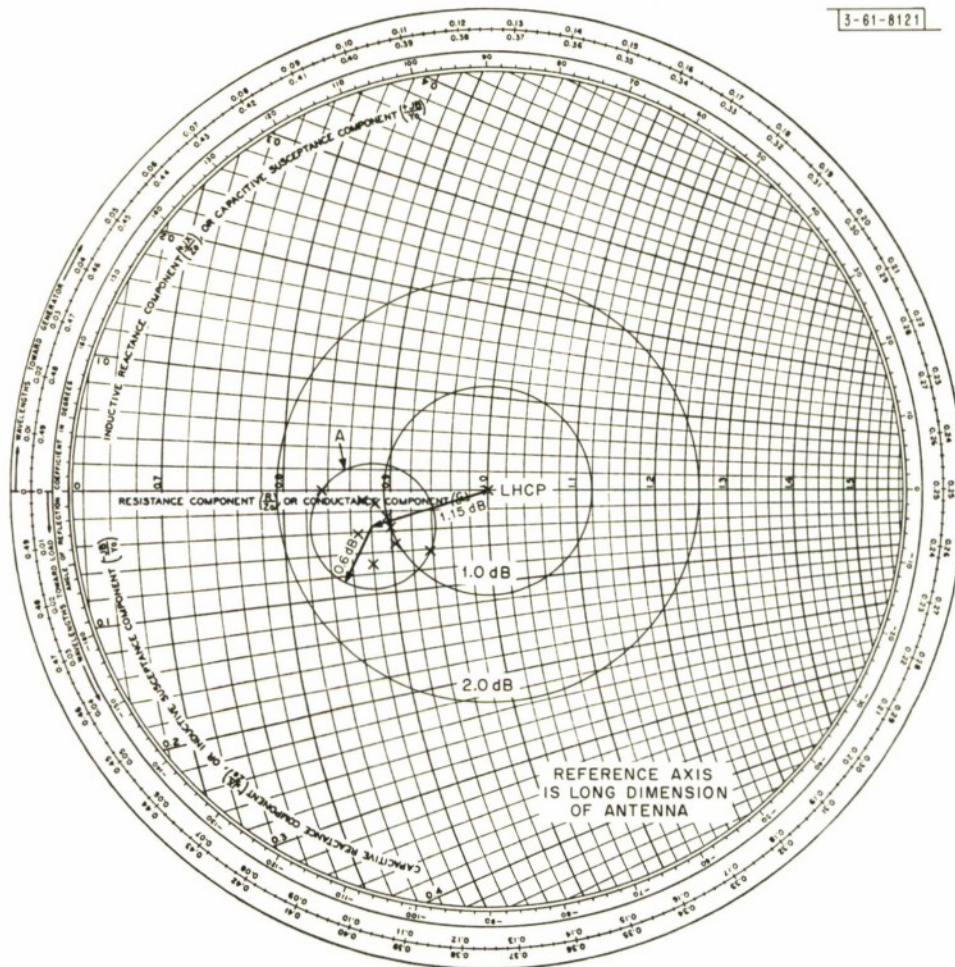
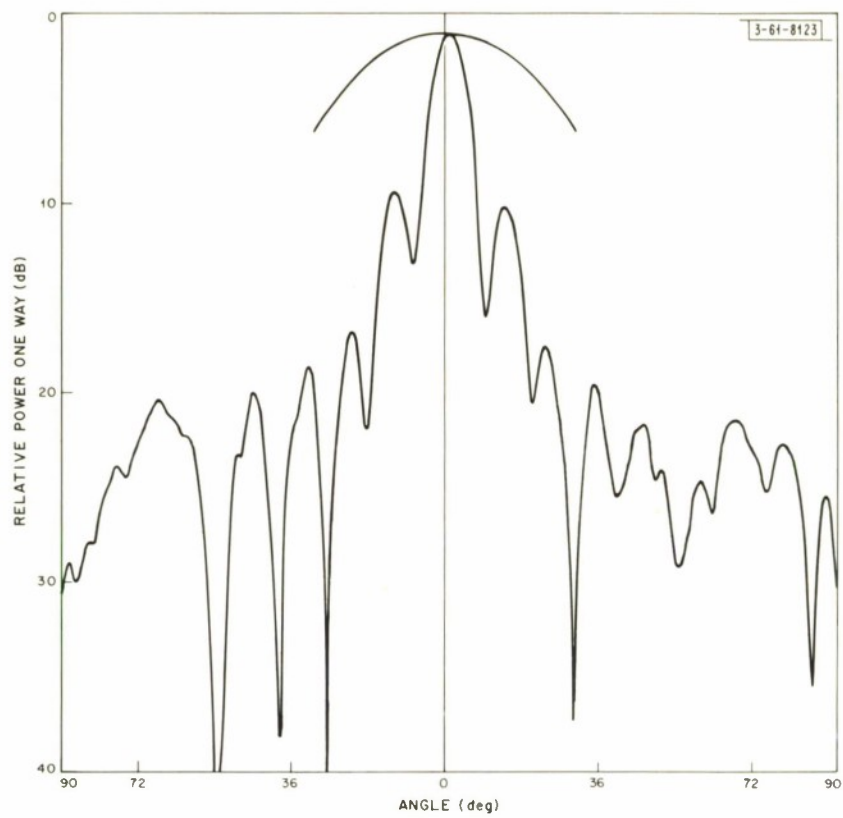
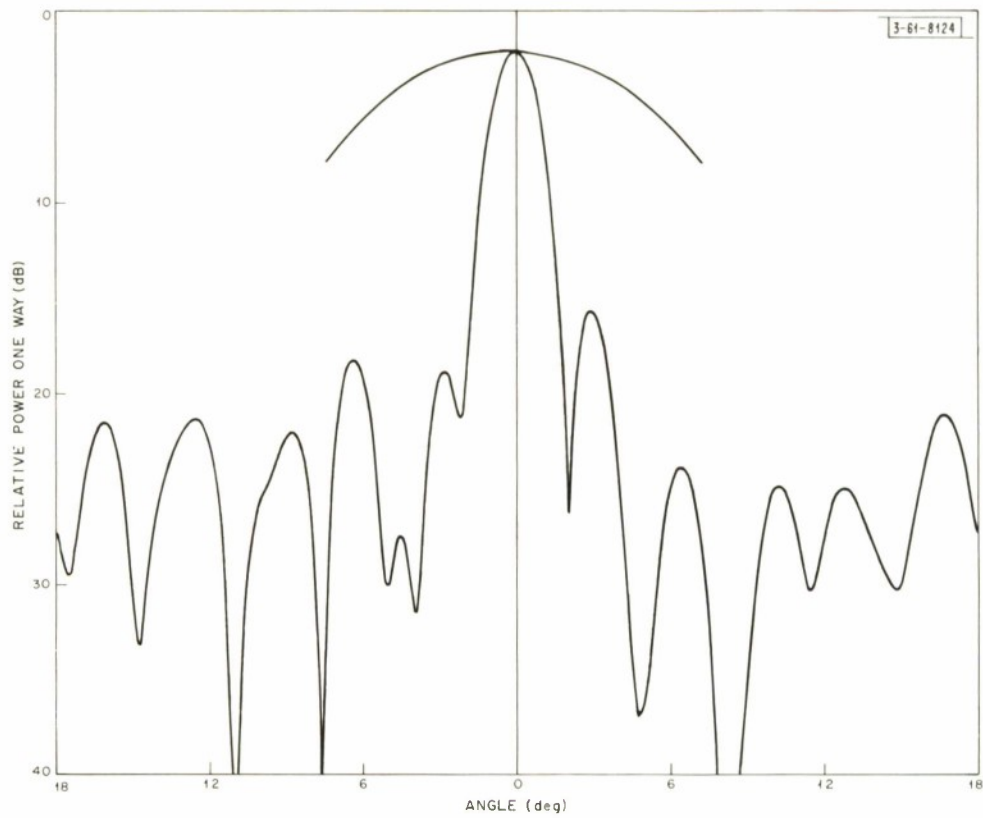


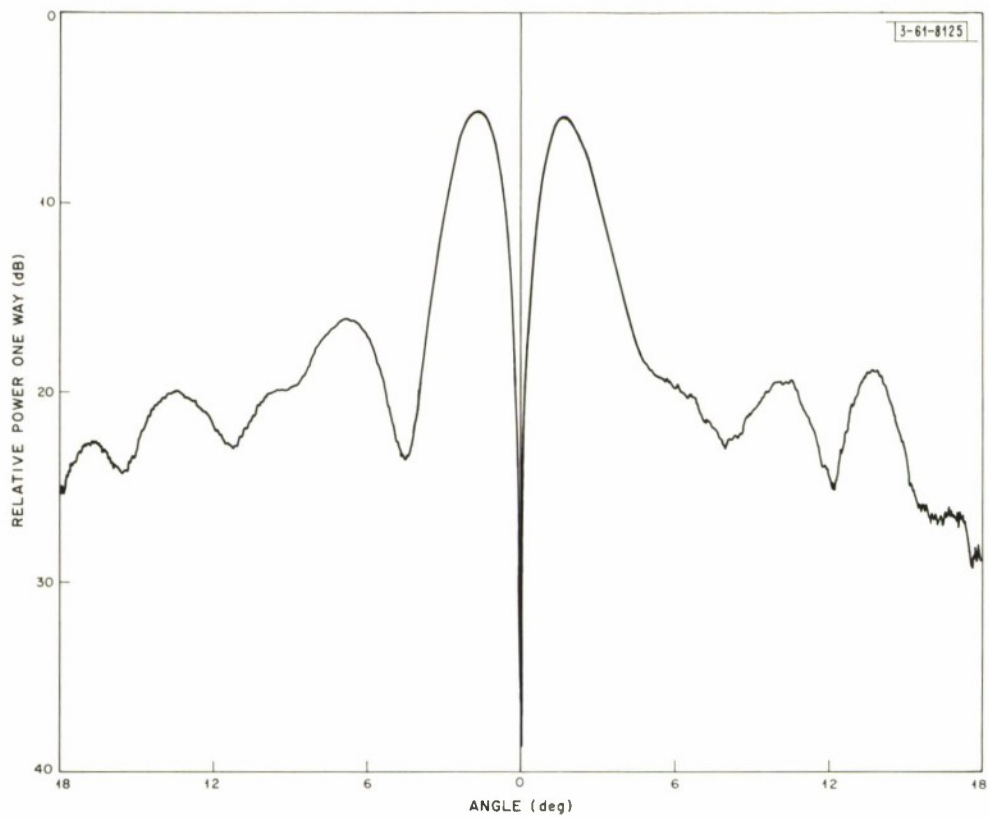
Fig. 5. Polarizer data for f_r array.



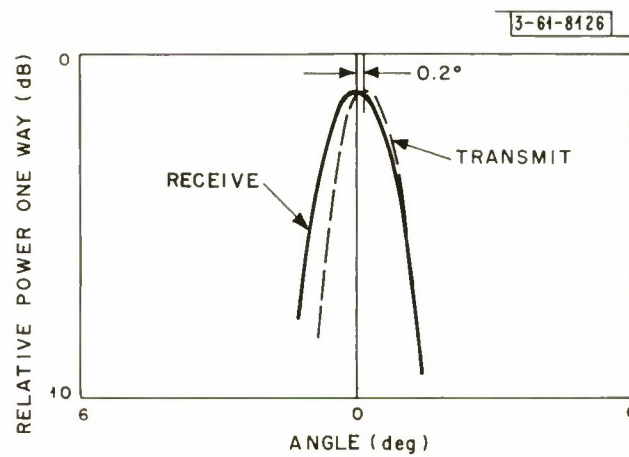
Antenna Pattern 1. Linearly polarized E-plane, f_r .



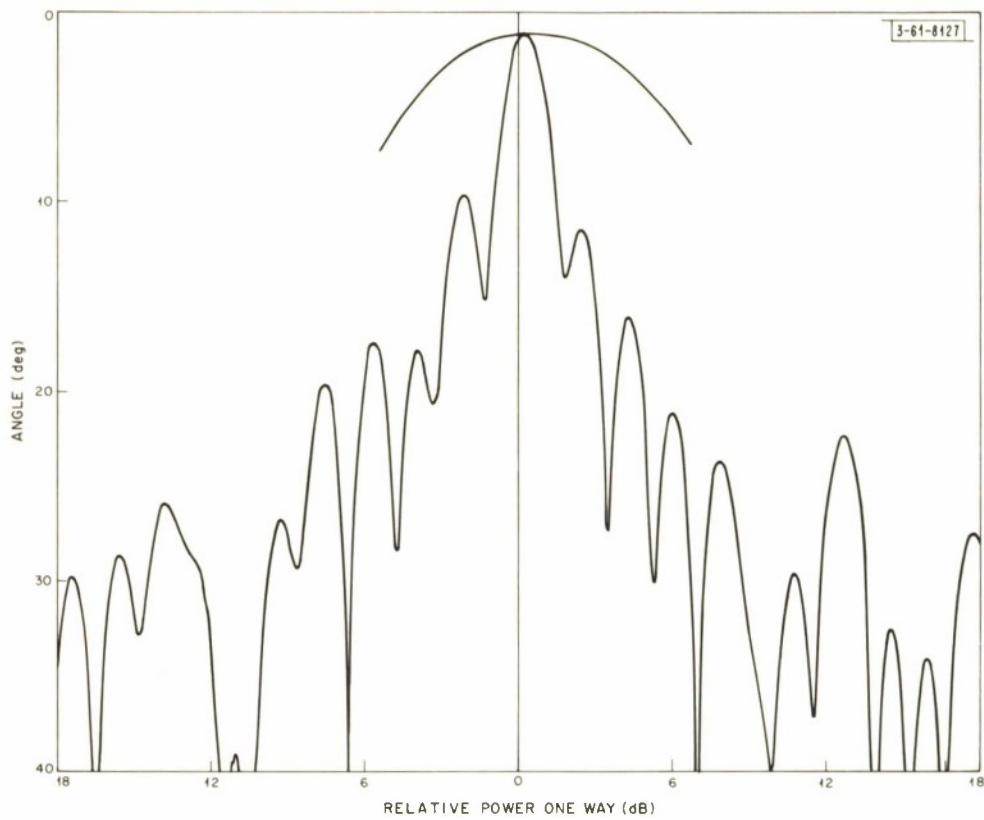
Antenna Pattern 2. Linearly polarized H-plane, f_r sum arm.



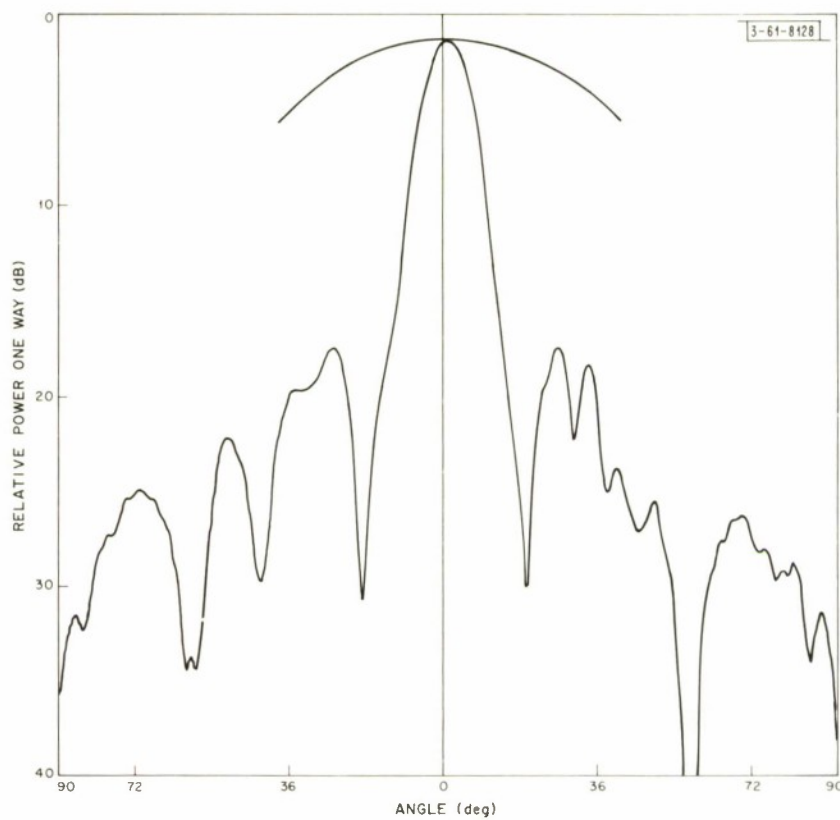
Antenna Pattern 3. Linearly polarized H-plane, f_r difference arm.



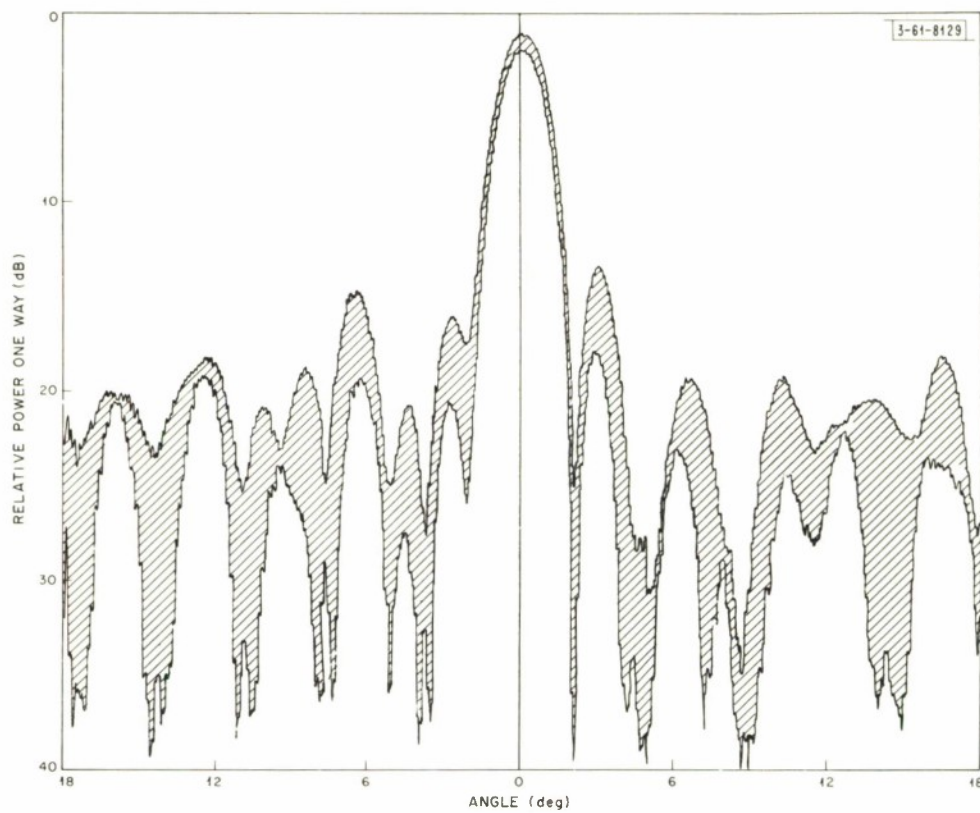
Antenna Pattern 4. Comparison of f_t and f_r beam positions.



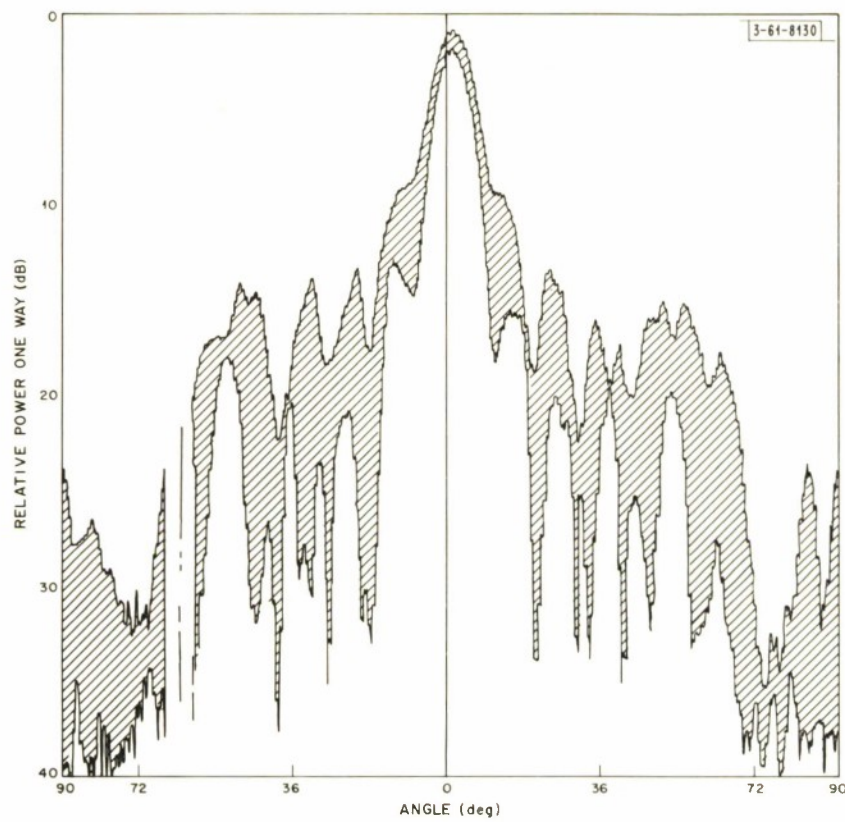
Antenna Pattern 5. Linearly polarized E-plane, f_t .



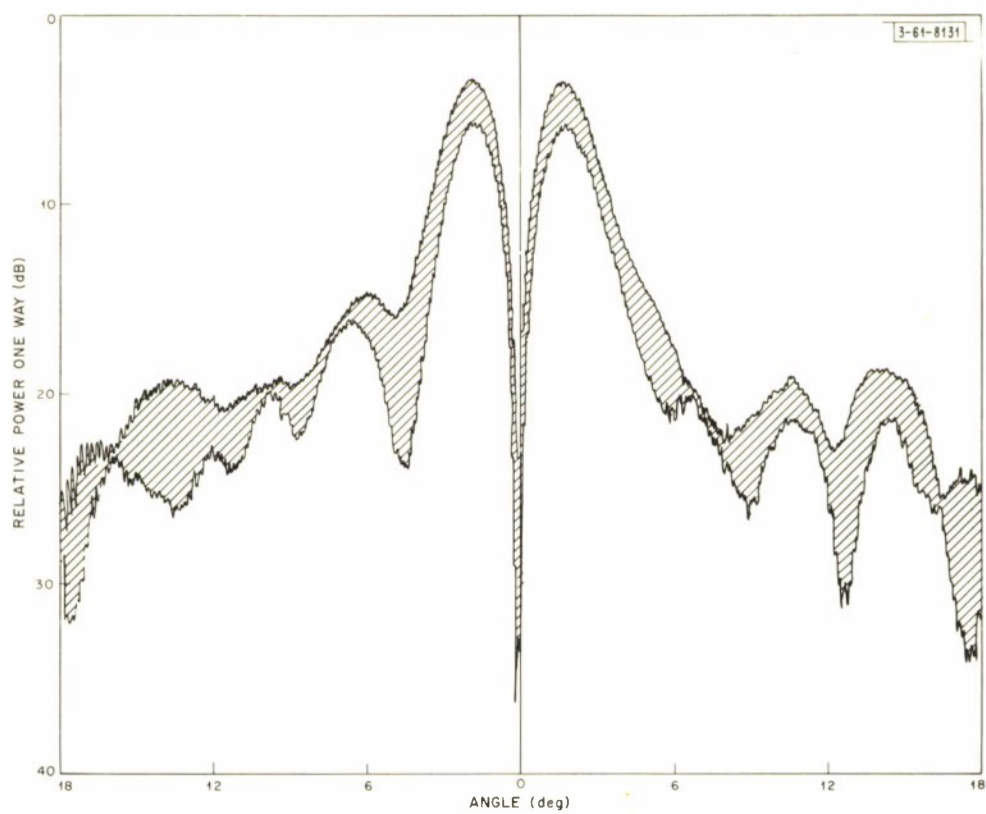
Antenna Pattern 6. Linearly polarized H-plane, f_t .



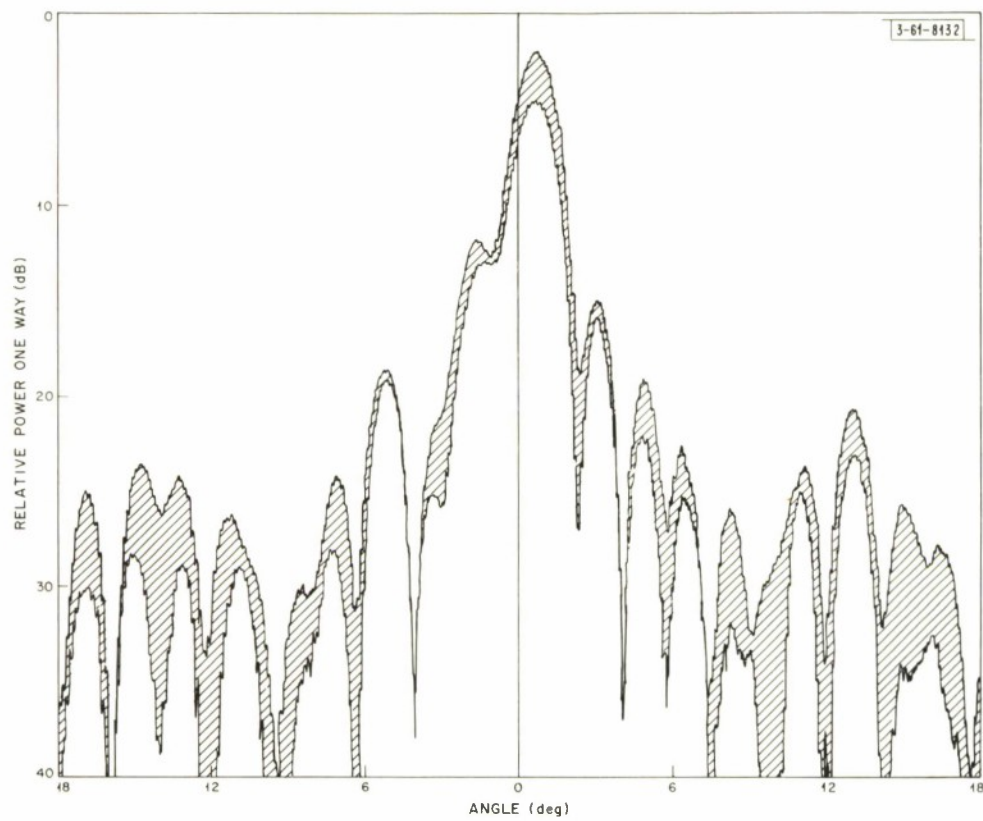
Antenna Pattern 7. Circularly polarized array patterns, f_r sum arm.



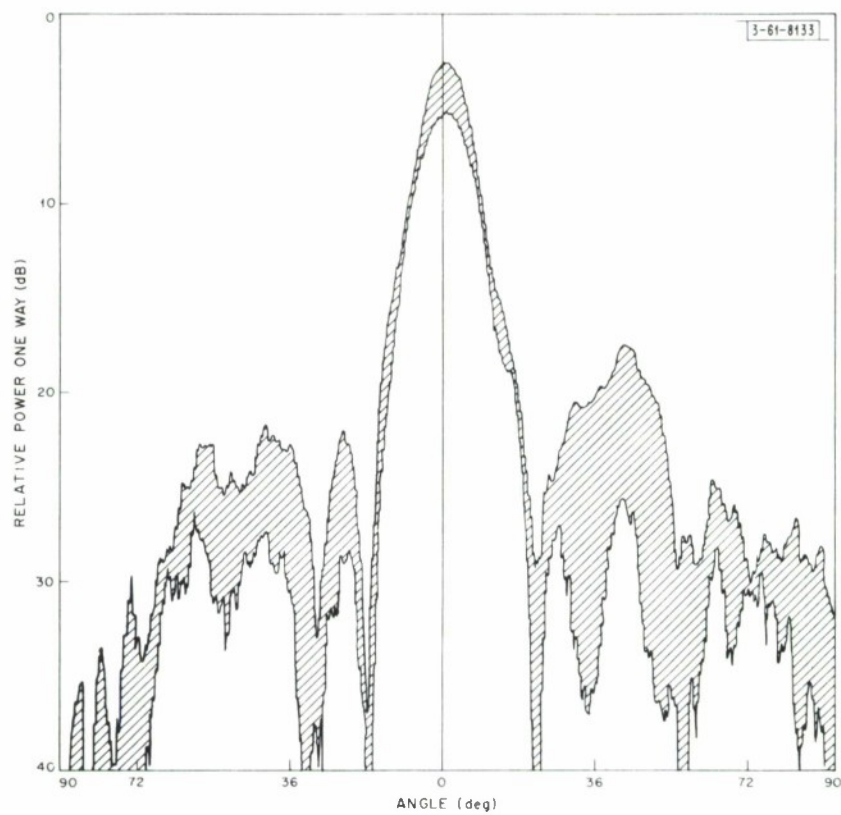
Antenna Pattern 8. Circularly polarized lens pattern, f_r .



Antenna Pattern 9. Circularly polarized array pattern, f_r difference arm.



Antenna Pattern 10. Circularly polarized array pattern, f_t .



Antenna Pattern 11. Circularly polarized lens pattern, f_t .

