FAA-73-26

REPORT NO. FAA-RD-74-25

CALCULATED AND SCALE MODEL EXPERIMENTALLY MEASURED SCATTERING FROM METALLIC STRUCTURES IN INSTRUMENT LANDING SYSTEM

G. Chin
L. Jordan
D. Kahn
S. Morin

MARCH 1974
INTERIM REPORT

Prepared for

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
SYSTEMS RESEARCH AND DEVELOPMENT SERVICE
Washington DC 20591

NOTICE

Technical Report Documentation Page

1. Report No. FAA-RD-74-25	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle CALCULATED AND SCALE MODEL EXPERIMENTALLY MEASURED SCATTERING FROM METALLIC STRUCTURES IN INSTRUMENT LANDING SYSTEM		5. Report Date March 1974
		6. Performing Organization Code
7. Author(s) G. Chin, L. Jordan, D. Kahn, S. Morin		8. Performing Organization Report No. DOT-TSC-FAA-73-28
9. Performing Organization Name and Address Department of Transportation Transportation Systems Center Kendall Square Cambridge MA 02142		10. Work Unit No. (TRAIS) R4129/FA407
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington DC 20591		13. Type of Report and Period Covered Interim Report Jan - June 1973
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Comparison is made of theoretically calculated and experimentally determined scattering from metallic tilted rectangles and vertical cylindrical scatterers. The scattering was experimentally measured in a scale model range at the Watertown Arsenal, Watertown, MA. The theoretically calculated scattering effects were obtained from the Transportation Systems Center, (TSC), physical optics model for ILS scattering. Reasonably good agreement was found between theoretically calculated and experimentally measured received power patterns.

17. Key Words ILS, Scattering Theory, Scattering Scale Model Experiment, Metallic Tilted Rectangle, Vertical Cylinder		18. Distribution Statement DOCUMENT IS AVAILABLE TO THE PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22151.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 34	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

PREFACE

The work described in this report was performed by staff members of the Electromagnetics Technology Division. This program on scattering in Instrument Landing Systems is sponsored by the Systems Research and Development Service of the Federal Aviation Administration in the Department of Transportation.

The experimental tests were carried out by Robert M. Weigand and Francis J. La Russa, staff members of the Electromagnetics Technology Division. The tests were performed at facilities of the U. S. Army Watertown Arsenal (Watertown, MA).

We gratefully acknowledge the help received from Mr. Alex Robb and Mr. David Newsom of Kentron Hawaii, LTD. Cambridge, MA for their programming work on this project.

CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONT'D)

1. INTRODUCTION

Experimental tests were performed by R. M. Weigand and F. J. La Russa, staff members of the Electromagnetics Technology Division on the scattering of electromagnetic waves to determine the suitability of Building #311 of the U. S. Army Watertown Arsenal (Watertown, MA) for use as an instrument landing system scale model range. The description of the experimental conditions and results used in this report is derived from their report[1] and their subsequent additional experimental work undertaken at our request. This additional experimental work was needed for obtaining experimental scattering results which could be compared with the theoretical predictions of the Transportation Systems Center (TSC) Instrument Landing System (ILS) performance prediction model. The purpose of this report is to present such experimental and theoretical comparisons.

As a part of the present ILS scattering study project, mathematical-physical models have been developed to compute the scattering from various geometrical objects.[2] For the purpose of comparison we have computed a set of theoretical receiver power curves corresponding to the set of experimentally measured curves obtained at the Watertown Arsenal range.

2. REVIEW OF THE EXPERIMENTAL WORK AND CONDITIONS AT WATERTOWN ARSENAL (REFERENCE 1)

Measurements were made of the receiver power induced by the direct and the scattered fields from both environmental objects at the test site (heating system, exterior walls, testing room and structural I beams causing undesirable reflections) and certain large scattering objects deliberately placed in the field of the transmitting antenna. Figure 2-1 shows the location of the test range which is the area covered with aluminum sheets.

A 100 to 1 scaling of the glide slope range was employed. The 330 MHz glide slope frequency (wavelength equaled 2.9822 feet) was scaled to 33 GHz.

After experimental tests showed that the environmental objects caused some scattering to the receiver point, "Eccosorb CH" absorbers were placed on the side and end of the range to a height of two feet, as shown in Figure 2-1.

The transmitter consisted of a Hewlett Packard Sweep Oscillator Model 8690B with Model 8697A plug in. The oscillator was operated in the CW mode. The receiver consisted of one of several horn antennas clamped to a carriage which travels on a long I beam perpendicular to the center line of the range.

Because of the superposition of the wave field from the transmitting antenna and that from the antenna image the vertical receiver antenna pattern at a constant range consisted of a series of peaks and minima. Figure 2-2 shows schematically the vertical radiation pattern from an antenna located above a reflecting ground plane. In the actual experiment the transmitting antenna was located four inches above the ground plane. This resulted in a vertical pattern having a first peak approximately at 1.25° above the ground plane and subsequent peaks at 2.5° intervals beyond this - see Figure 2-2. Minima are located midway between peaks at 2.5° intervals and multiples thereof.

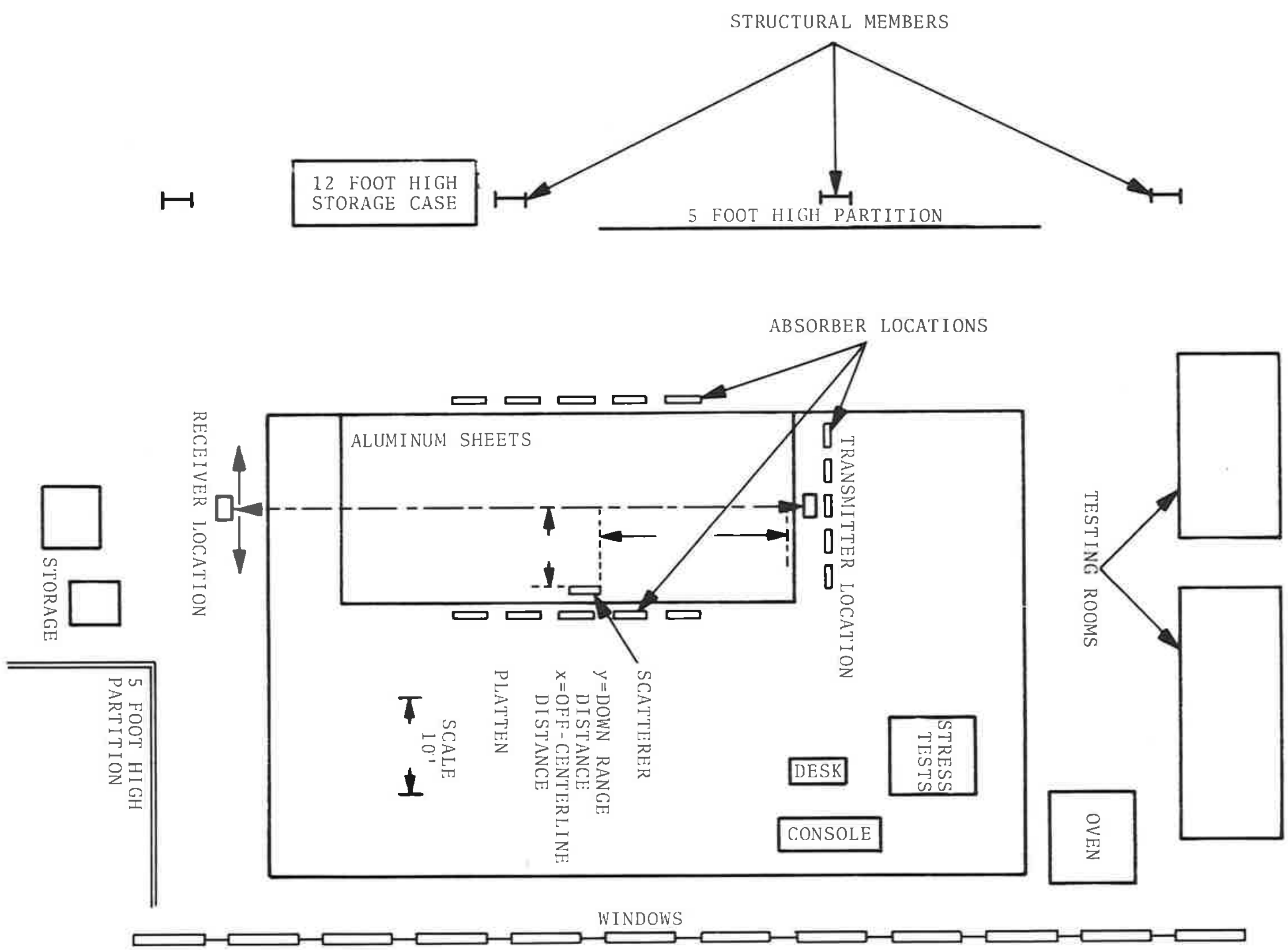


Figure 2-1. Test Range and Environment in Watertown Arsenal Building #311 (After Weigand and La Russa, Reference 1)

from the transmitter to the receiver (see Figure 2-4). The point of view is as looking from the transmitter down range.

The slight irregularities of the curve in Figure 2-2 were caused by environmental scattering. The gentle roll - off toward the edge of the pattern seen in Figure 2-3 is because both the transmitting and the receiving antenna have a similar horizontal gain pattern. The pattern is not symmetrical with respect to the center line. There is a prominent portion peaking at 1.5° to the left of the center direction. In the mathematical model developed to simulate scattering from various objects the horizontal gain pattern is taken as symmetrical with respect to the center line. The over all theoretical pattern without scatterers was adjusted so as to fit the empirical curve given in Figure 2-3.

Figure 2-5 shows the measured received power (when no targets were present) at the first minimum (19 5/8 inches) above the ground at a range of 36 feet. The range was the same for all the measurements presented in this report.

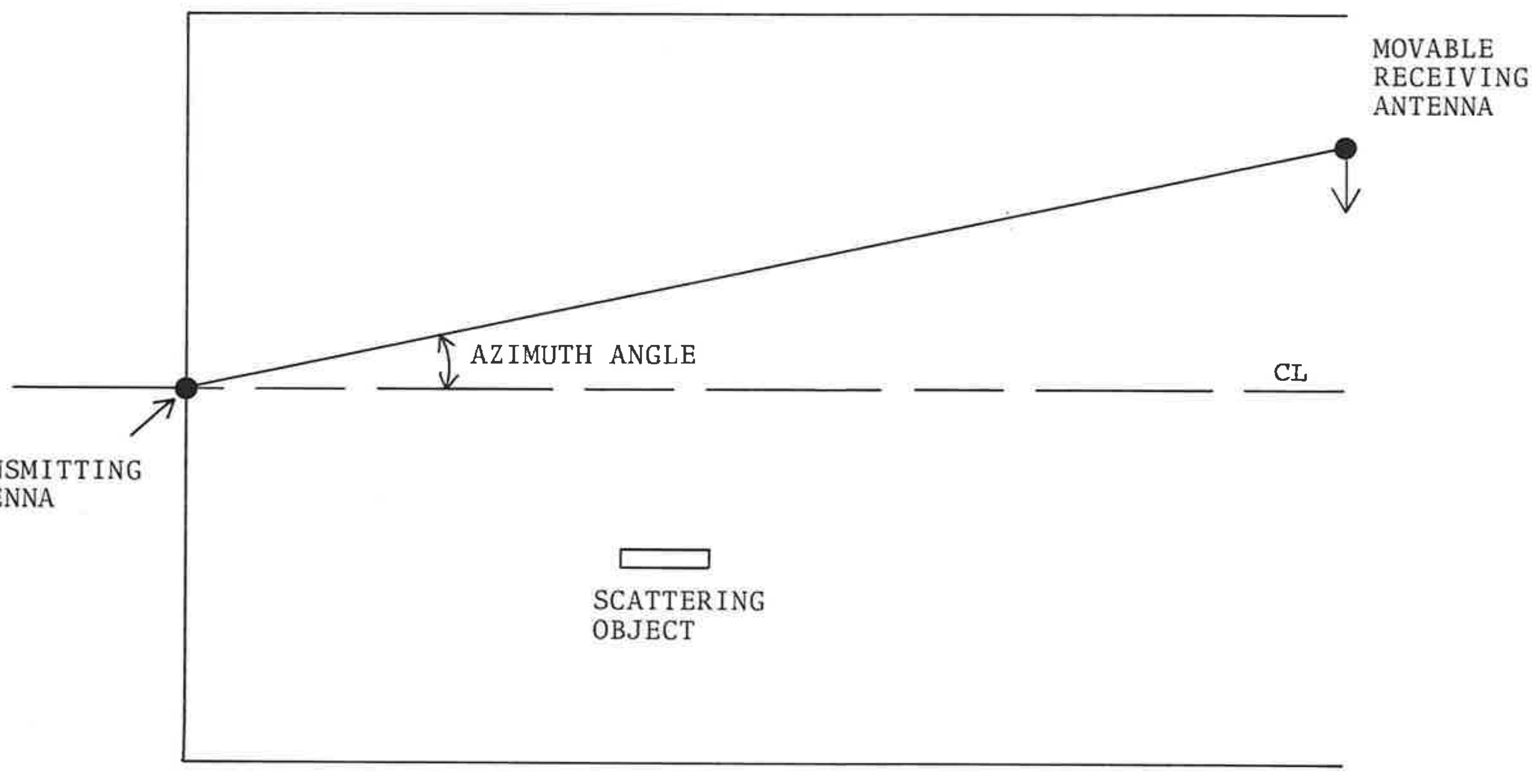


Figure 2-4. Diagram Showing Details for Range Figure in Figure 3-1a and Subsequent Figures. (CL is the Center Line Down the Range from the Transmitter; the Receiver is Moved Perpendicular to the Center Line.)

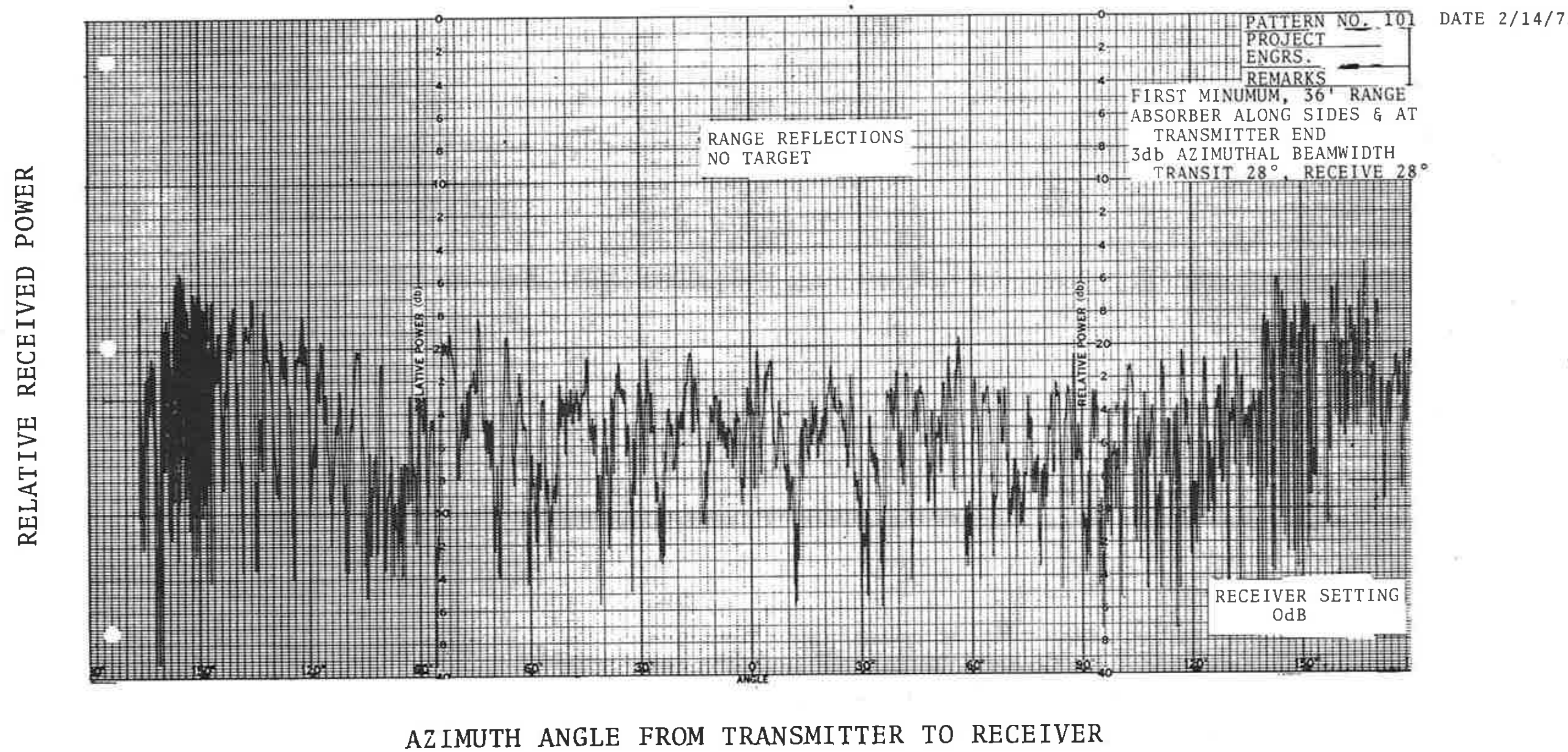


Figure 2-5. Measured Received Power with Antenna at First Minimum - No Target, 36' Range

3. COMPARISON OF MEASURED RECEIVED POWER WITH THEORETICALLY COMPUTED RECEIVED POWER FOR VARIOUS SCATTERERS

In this section we consider the experimentally measured and the theoretically calculated received power patterns when various large scattering objects were placed in the range.

3.1 TILTED RECTANGULAR SCATTERER

Figure 3-1a shows the measured received power at the second lobe peak above the ground for a rectangular metal scatterer, 17 inches high, 72 inches long, tilted 1° from the vertical. The top edge was tilted away from the center line; the lower edge was in contact with the ground. In full scale, the rectangle would be 142 feet high and 600 feet long. The rectangle (made of aluminum) was located with its length parallel to the center line and 6 feet from it. The midpoint of the rectangle was 18 feet down range from the antenna as shown in Figure 3-1a.

A theoretical program was developed at TSC to calculate the Fraunhofer scattering from an elevated, slanted, perfectly conducting rectangular slab. The development was reported in Section 4.4 of Reference 2. The calculation is restricted to the case when

$$\frac{\pi \rho^2}{\lambda r'} \quad \text{and} \quad \frac{\pi \rho^2}{\lambda R'} << 1 \qquad (1A)$$

where ρ is the distance from the mid-point of the lower edge to the opposite corner of the slab, λ is the radiation wavelength, r' is the distance from the antenna to the slab and R' is the distance from the slab to the observation point. The above restriction limits the size of the slab. To obtain the scattering from the 142 feet x 600 feet rectangle one must analytically consider the slab to be composed of smaller sub-slabs. The scattering from the large slab is then the sum of the scattering from the sub-slabs.

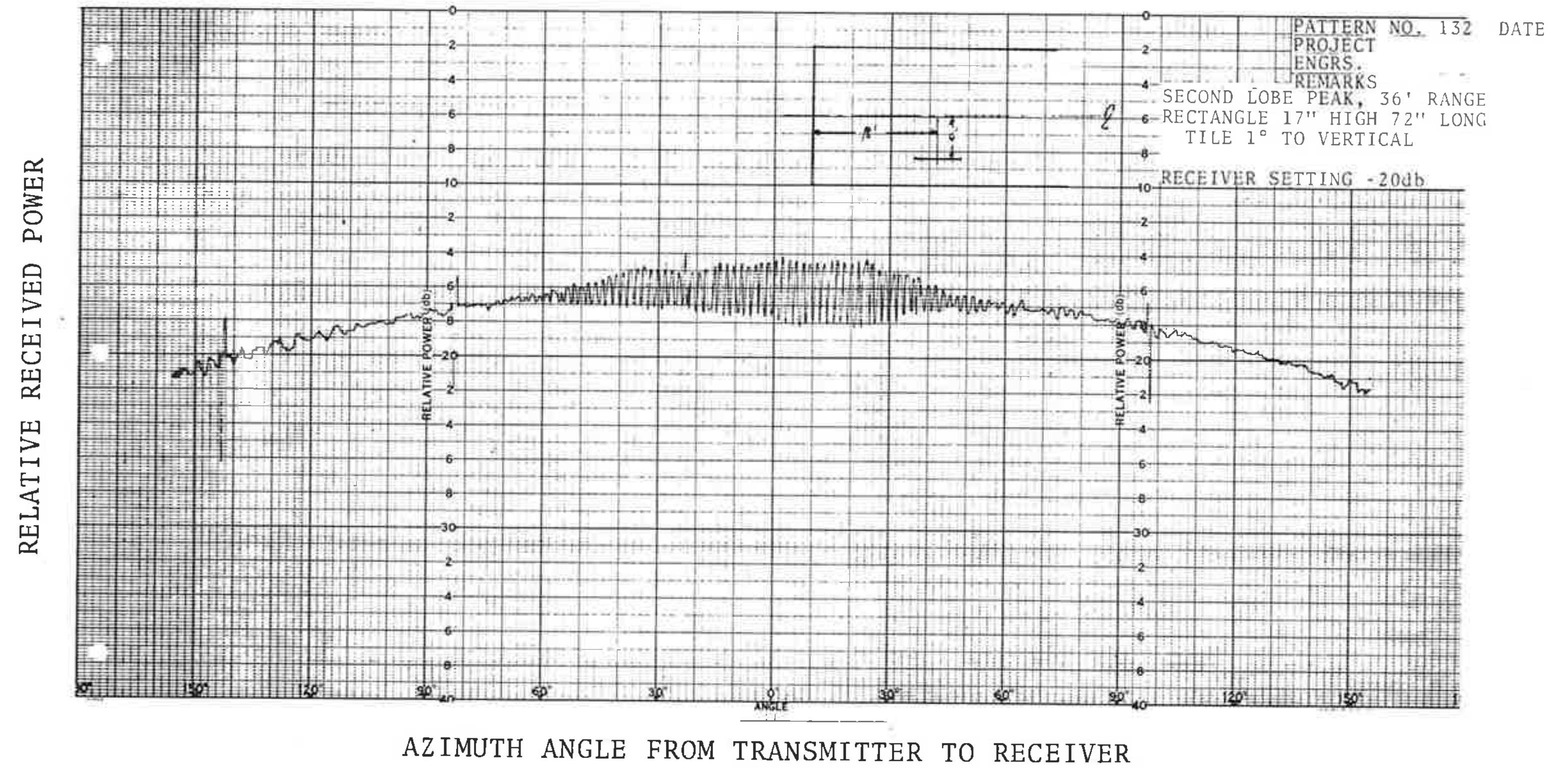


Figure 3-1a. Measured Received Power Aluminum Rectangle Scatterer

The rectangle shown in Figure 3-1a was first divided (in the computation) into four horizontal strips; the computer program then automatically sub-divided the strips in the horizontal direction so as to satisfy the restriction given in Equation 1A.

Since the model in Reference 2 assumed that the horizontal gain of the receiver was uniform while the experimental transmitter and the receiver both had non-uniform gains, factors for these gains were included in the computation program for the direct wave, the incident wave on the scatterer and the wave from the scatterer to the receiver. The received power is expressed by

$$20\text{Log}_{10}\ (V_d + V_s)\ \text{dB}$$

where V_d is the voltage at the receiver induced by the direct wave and V_s is that induced by the scattered wave. The figures show the relative power in a dB scale (so that absolute numerical values have no meaning in the figures).

Figure 3-1b shows the calculated received power at the second lobe peak for the rectangular scatterer (tilted 1°) shown in Figure 3-1a. The peak to peak amplitude of the fluctuation is a measure of the power induced by the scattering.

Figure 3-2a shows the measured received power at the second lobe peak when the previously mentioned rectangle was tilted 15° from the vertical. The corresponding calculated received power is shown in Figure 3-2b. In comparison with the case when there was a 1° tilt the amplitude of the fluctuation is diminished; also the region of maximum amplitude is shifted toward the right from the center line (looking from the transmitter). The figures show reasonable agreement between the measured and the calculated received power with regard to fluctuation amplitude, envelope shape and angular location peak values.

Figure 3-3a shows the measured received power at the first minimum for the same rectangle tilted 1° from the vertical. In

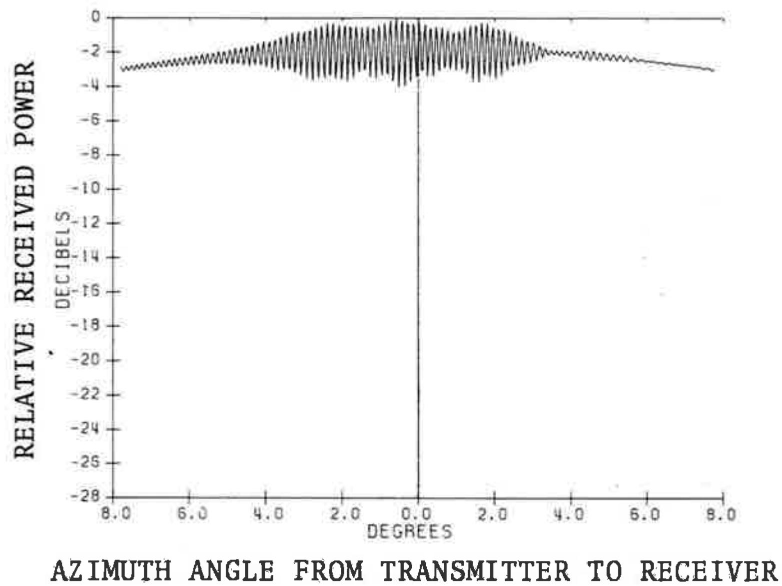
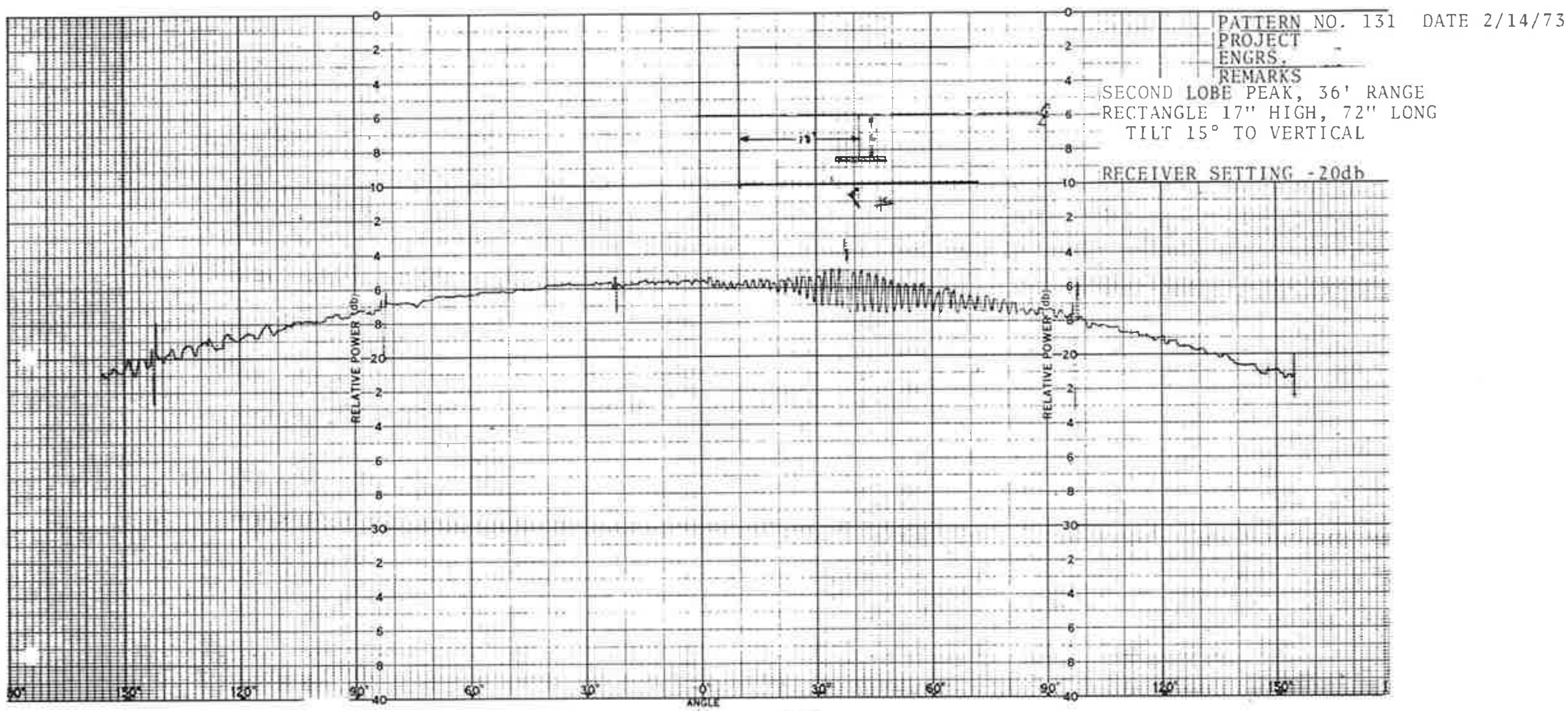


Figure 3-1b. Calculated Received Power at Second Lobe Peak for Case Shown in Figure 3-1a

RELATIVE RECEIVED POWER



AZIMUTH ANGLE FROM TRANSMITTER TO RECEIVER

Figure 3-2a. Measured Received Power at Second Lobe Peak, Aluminum Rectangle Scatterer, 17" High, 72" Long, Tilted 15° from Vertical

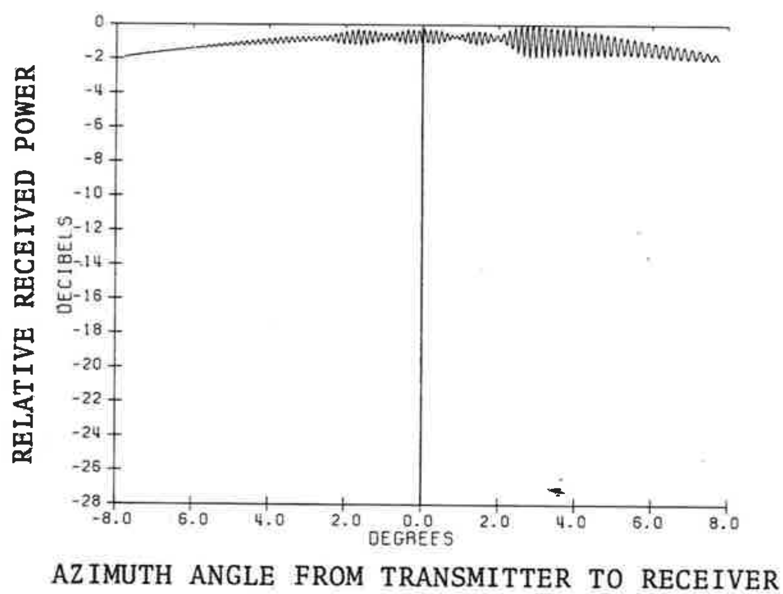


Figure 3-2b. Calculated Received Power at Second Lobe Peak for Case Shown in Figure 3-2a

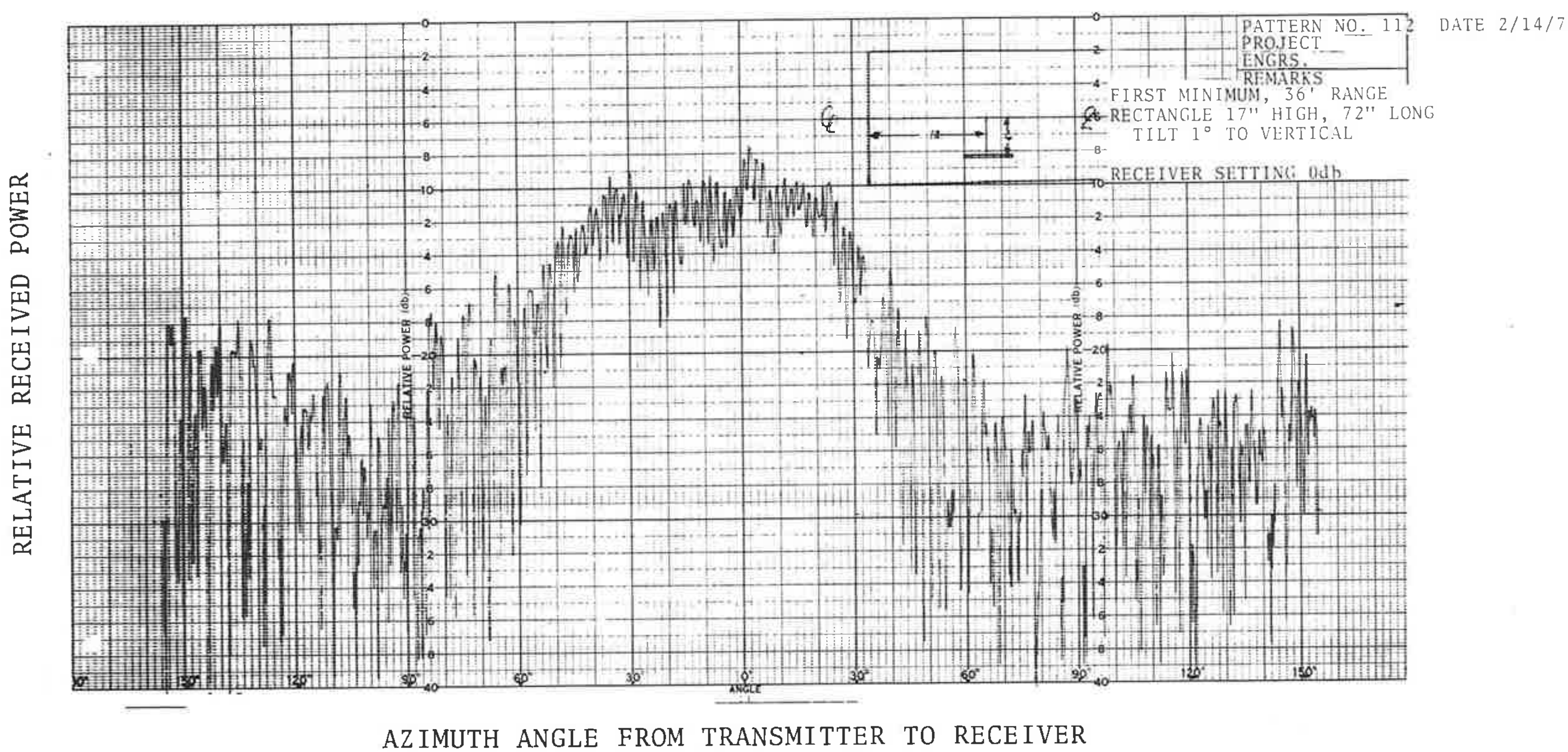


Figure 3-3a. Measured Received Power at First Minimum , Aluminum Rectangle Scatterer, 17" High, 72" Long, Tilted 1° from Vertical

this minimum the primary induced voltage is caused by the scattered wave from the rectangle. Figure 3-3b shows the corresponding calculated received power for the same observation height. The relative strength of the peak above the background is about the same for both the experimental and the calculated curves. The calculated curve, however, has a narrower peak region as compared with the peak of the experimental curve. When the rectangle had a tilt of 15° from the vertical there were no noticable changes in the measured and calculated curves from that when there was no scatterer. Apparently the main body of energy is reflected in a direction higher than the observation point.

3.2 VERTICAL CYLINDRICAL SCATTERER

Figure 3-4a shows the measured received power at the second lobe peak for an aluminum cylindrical scatterer (with a vertical axis) 3 3/8 inches in diameter and 24 1/8 inches high. In the full scale this would be a cylinder 28.125 feet in diameter and 201.04 feet in height. A theoretical program was developed at TSC to calculate the scattering from a perfectly conducting cylindrical section elevated above a perfectly conducting ground plane.[3] With the restriction that the ratio of the cylinder diameter to the radiation wavelength to much greater than one we used Kirchoff's approximation - approximating the tangential component of the total magnetic field on the cylinder surface by twice the tangetial component of the incident magnetic field on the side illuminated according to geometric optics and approximating the very small field on the shadow side by a null field. Also, the mathematical model is restricted to the case

$$\tau = \frac{\pi\rho^2}{\lambda R'} \ll 1 \qquad (1B)$$

where ρ is now one half the size of the scatterer, R' is the distance from the transmitter to the scatterer or from the observation point to the scatterer, and λ is the radiation

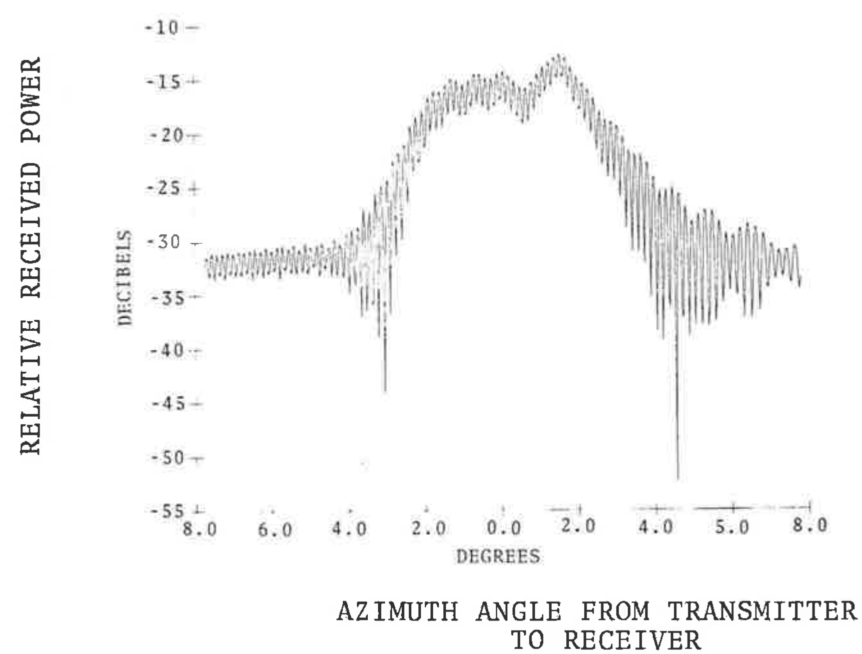


Figure 3-3b. Calculated Received Power at First Minimum for Case Shown in Figure 3-3a.

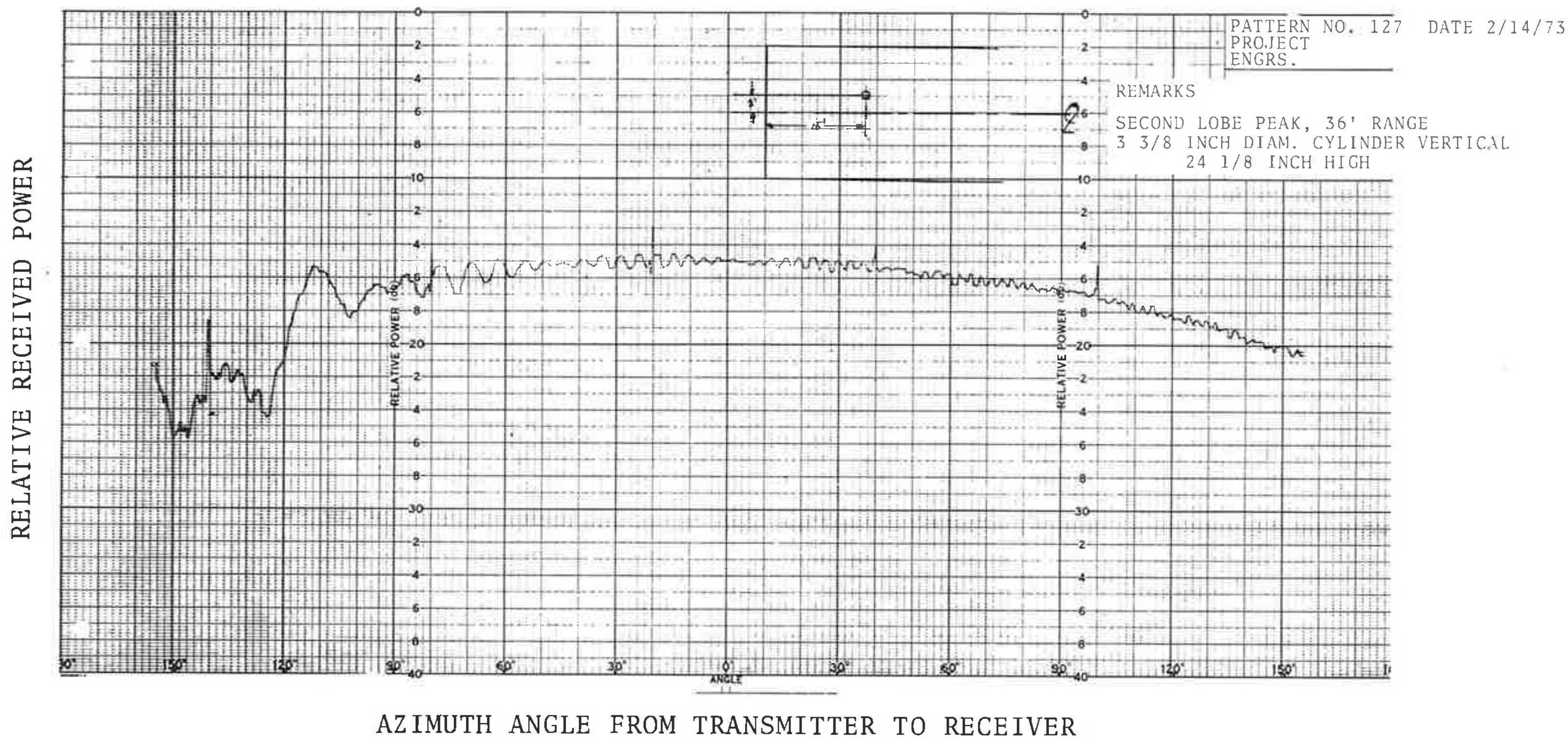


Figure 3-4a. Measured Received Power at Second Lobe Peak, Aluminum Vertical Cylinder Scatterer, 3 3/8" Diameter, 24 1/8" High

wavelength. For the present case λ = 3 feet and R' $\cong$ 1500 feet full scale. When τ = 1/5, ρ = 17.3 feet and when τ = 1/4, ρ = 19.3 feet. The cylinder in Figure 3-4a has a radius 14 feet full scale. We divided the vertical extent of the cylinder into four sections of about 50 feet each. The computer program was then applied to each section and the total scattering is the sum of the components. Figure 3-4b shows the calculated received power at the second lobe peak for the case shown in Figure 3-4a. As can be seen the amplitudes are closely matched and the fluctuation envelopes for the experimental and theoretical curves occur at the same places. The dip in power on the left corresponds to the geometric shadow of the cylinder.

Figure 3-5a shows the measured received power at the second lobe peak for a thicker vertical copper cylindrical scatterer, 11 1/8 inches diameter and 23 15/16 inches high. Full scale, this would be a cylinder with a 46.35 feet radius and 199.48 feet height. Although in this case Equation 1B is not satisfied (τ = 1.5) we nonetheless used the previously described program to calculate the scattering. Figure 3-5b shows the calculated received power at the second lobe peak for the case shown in Figure 3-5a. One result of overstepping the phase criterion (Equation 1B) is that the dip in power in the geometric shadow (on the left) is not so large in the theoretical pattern in comparison to the dip in the experimental pattern. In the central portion, however, the theoretical and experimental patterns compare favorably.

At the first minimum there were no noticeable changes in the measured and calculated curves (caused by the vertical cylinder of the two mentioned diameters) from the case of no scatterer.

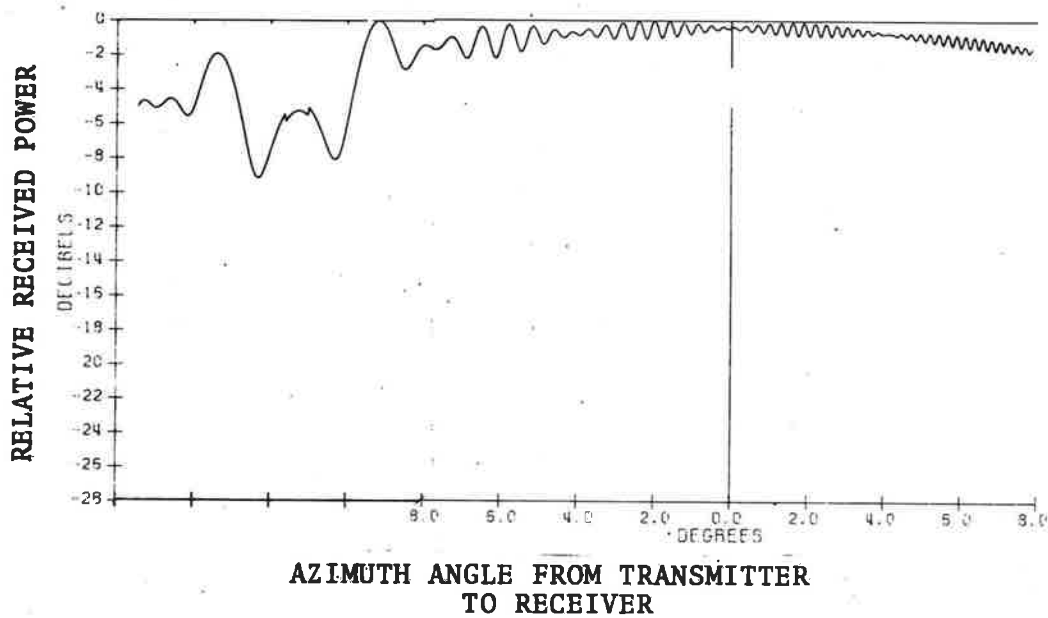


Figure 3-4b. Calculated Received Power at Second Lobe Peak for Case Shown in Figure 3-4a

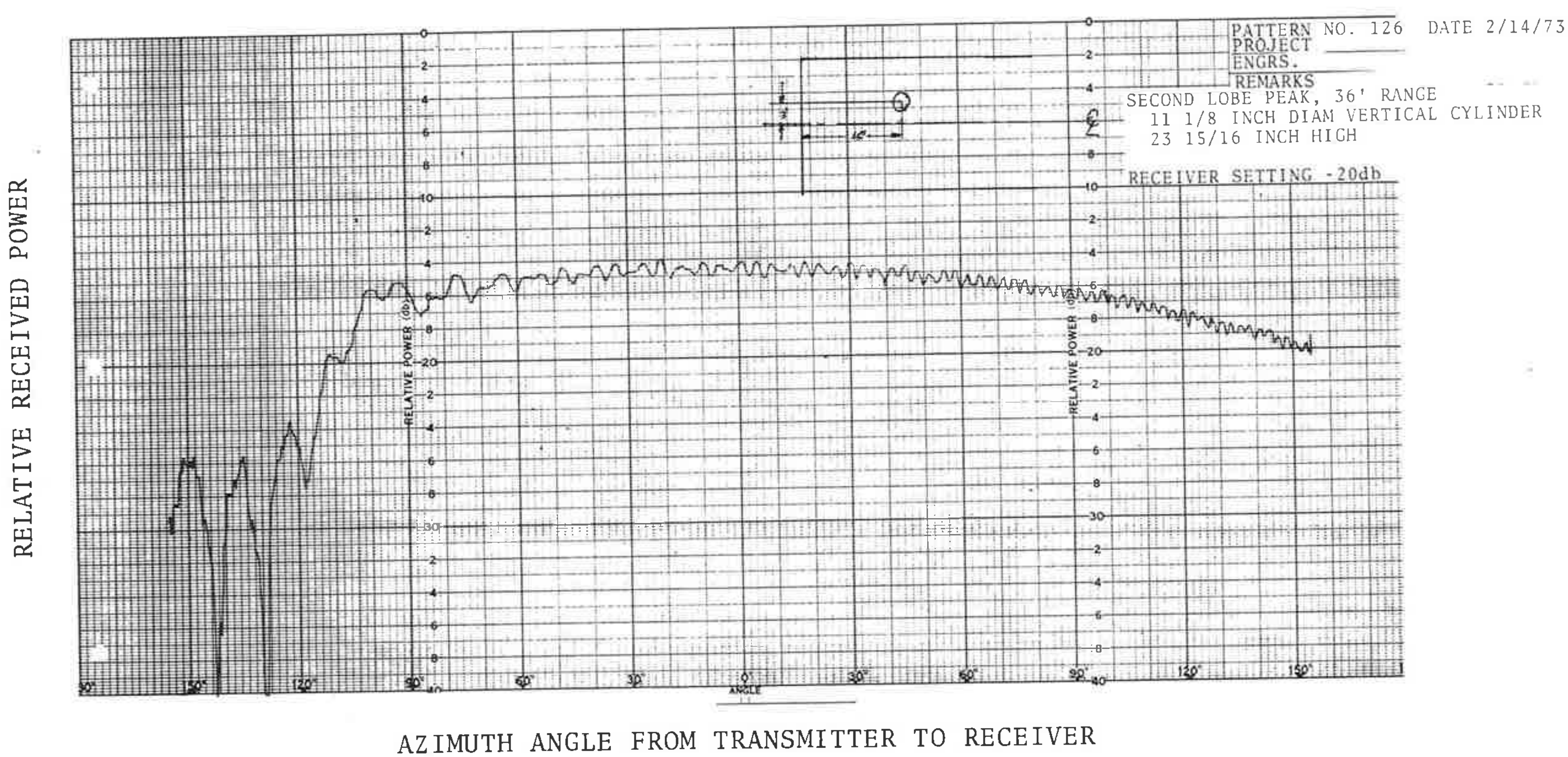


Figure 3-5a. Measured Received Power at Second Lobe Peak for Copper Vertical Cylinder Scatterer, 11 1/8" Diameter, 23 15/16" High

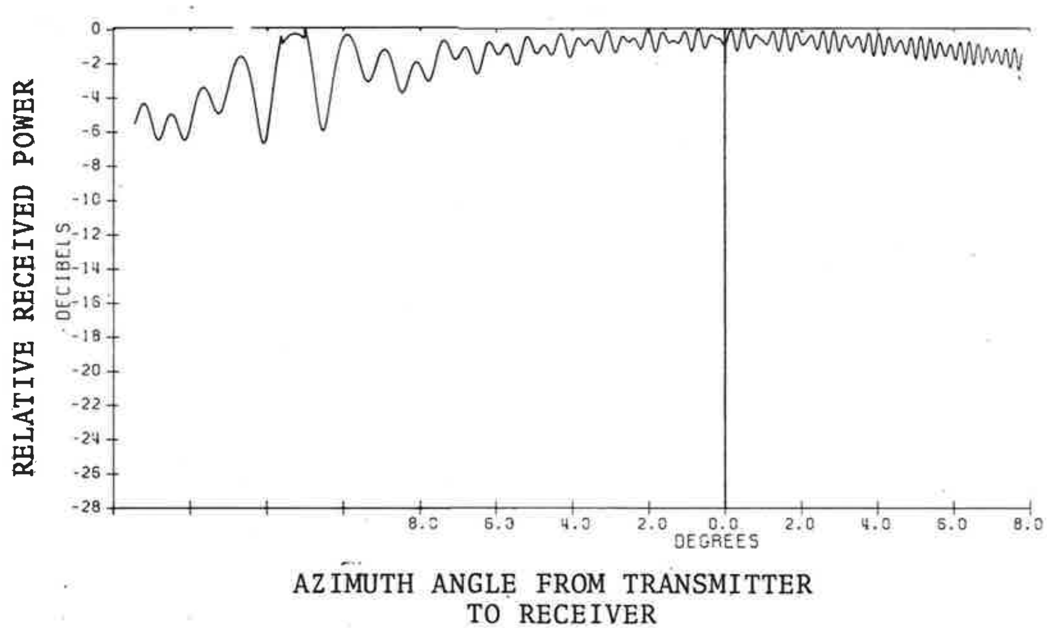


Figure 3-5b. Calculated Received Power at Second Lobe Peak for Case Shown in Figure 3-5a

4. SUMMARY AND CONCLUSION

Scale model (100/1 ratio) experimental measurements were made at the U. S. Army Watertown Arsenal on the scattering effects caused by large objects deliberately placed in the electro-magnetic radiation field of the transmitter. Absorbers were placed around the range to somewhat reduce the environmental scattering - Figure 2-1. Measurements of the horizontal radiation interference patterns were made with the receiver at the height of the vertical antenna pattern's second lobe peak (to simulate the "carrier plus sideband" transmission peak of the glide slope instrument landing system - Figure 2-2). Measurements were also made at the height of the first minimum between the first and second lobe peaks (to simulate the measurement in the null of the "sidebands only" radiation of the ILS along the glide slope, since the test antenna transmits a continuous wave). The receiver was moved perpendicular to the center line 36 feet down range.

Mathematical - physical models developed at TSC were used to calculate the Fraunhofer scattering from a tilted perfectly conducting rectangular slab and a vertical perfectly conducting cylinder.

Measured and calculated radiation power patterns at the second lobe peak caused by rectangular metallic scatterer (17 inches high, 72 inches long) are presented for tilt angles from the vertical of 1° and 15° (Figures 3-1a, b and 3-2a, b). There is good agreement with regard to fluctuation amplitude, envelope shape and angular location of peak values.

Measured and calculated power patterns at the first minimum caused by the rectangular scatterer are also presented (Figures 3-3a and b) for the tilt angle 1°. There is favorable agreement. The peak magnitude above the background is about the same for the experimental and the calculated cases. For some presently unknown reason, however, the calculated peak is narrower than the measured case.

Measured and calculated received power patterns at the second lobe peak caused by a metallic vertical cylinder are presented - Figure 3-4a and b (3 3/8 inches in diameter, 24 1/8 inches high), and 3-5a and b (11 1/8 inches in diameter, 23 15/16 inches high). Reasonably good agreement between the experimental and the theoretical curves exists.

For summary, within the limitations of the experimental environment which produced significant unwanted reflections, the cases show good agreement between experiment and theory.

REFERENCES

1. R.M. Weigand and F.J. La Russa, Evaluation of the Watertown Arsenal Building #311 as an ILS Model. Interim Report. Rep. No. FAA-RD-73-193. Transportation Systems Center, Kendall Square, Cambridge, MA 02142. Prepared for Dept. of Transportation, FAA, Systems Research and Development Service, Washington, DC 20591.

2. G. Chin, L. Jordan, D. Kahn, and S. Morin, Instrument Landing System Scattering. Final Report. Rep. No. FAA-RD-72-137. Transportation Systems Center, Kendall Square, Cambridge, MA 02142. Prepared for Dept. of Transportation, FAA, Systems Research and Development Service, Washington, DC 20591.

3. G. Chin, L. Jordan, D. Kahn, and S. Morin, Instrument Landing System Performance Prediction, Final Report (to be published in 1974). Appendix A.