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EVALUATION OF THE WATERTOWN ARSENAL BUILDING #311 AS AN ILS MODEL RANGE

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16. Abstract
The Watertown Arsenal Building #311 was evaluated for use as an indoor ILS model range using upward frequency scaling of 100 to 1. To model the effects of small buildings and aircraft in the vicinity of an airport ILS, any model range has to have very low background reflections. If background reflections are large, they will obscure the desired measurements. Sets of measurements designed to determine the amplitude and location of undesirable background reflections due to structural objects around the proposed model site show that it will be necessary to completely enclose the range with high quality absorber.

Using 200 square feet of inexpensive absorber to cover regions causing the largest background reflections and using antennas of narrow beamwidth, measurements of the effects of several large scattering objects were made. The scattered energy due to the largest target (3 feet x 3 feet) is in good agreement with calculations based on geometrical optics.

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PREFACE

As part of the FY'73 PPA, an ILS scale modeling effort has been initiated by TSC. In this initial effort an assessment of the suitability of the Watertown Arsenal (Watertown, MA) as a scale model ILS localizer and glide slope facility was made. This report is devoted primarily to presenting the experimental procedures and analysis used in this assessment. In addition, experiments were designed and performed at the arsenal which, within the experimental error, offered partial validation of the TSC theoretical physics model. This will be reported on more fully in a later report.

The work described in this report was sponsored by the Systems Research and Development Service of the FAA and conducted in the Electromagnetics Technology Division of the Transportation Systems Center. The Program Manager for this task was David Kahn. The authors wish to acknowledge the assistance of Mr. Charles L. Dunne and Mr. Robert Silva in making measurements at the Watertown Arsenal.

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1. OBJECTIVE

The objective of the work reported here was to determine the feasibility of using a portion of Building #311 at the Watertown Arsenal as an ILS model range. Figure 1 is a plan view of the test range and its immediate surroundings. The ground plane base made use of an unused machining platen which is 50 feet by 80 feet. The test range is the portion of the platen covered with aluminum sheets.

The feasibility of this site was uncertain because structures around the range can cause undesireable background reflections which will interfere with measurements. Many of these structures are of a permanent type such as the heating system, exterior walls, testing rooms and structural I beams. Microwave absorber can be used to cover some of the structures and thereby reduce reflection. It was necessary to determine which regions would need to be covered with microwave absorber in order to reduce reflections to an acceptable level.

A second objective of these tests was to record the characteristic returns from several optimumly located large scatterers of simple geometric shape for comparison with the theoretical models of scattering from these shapes.

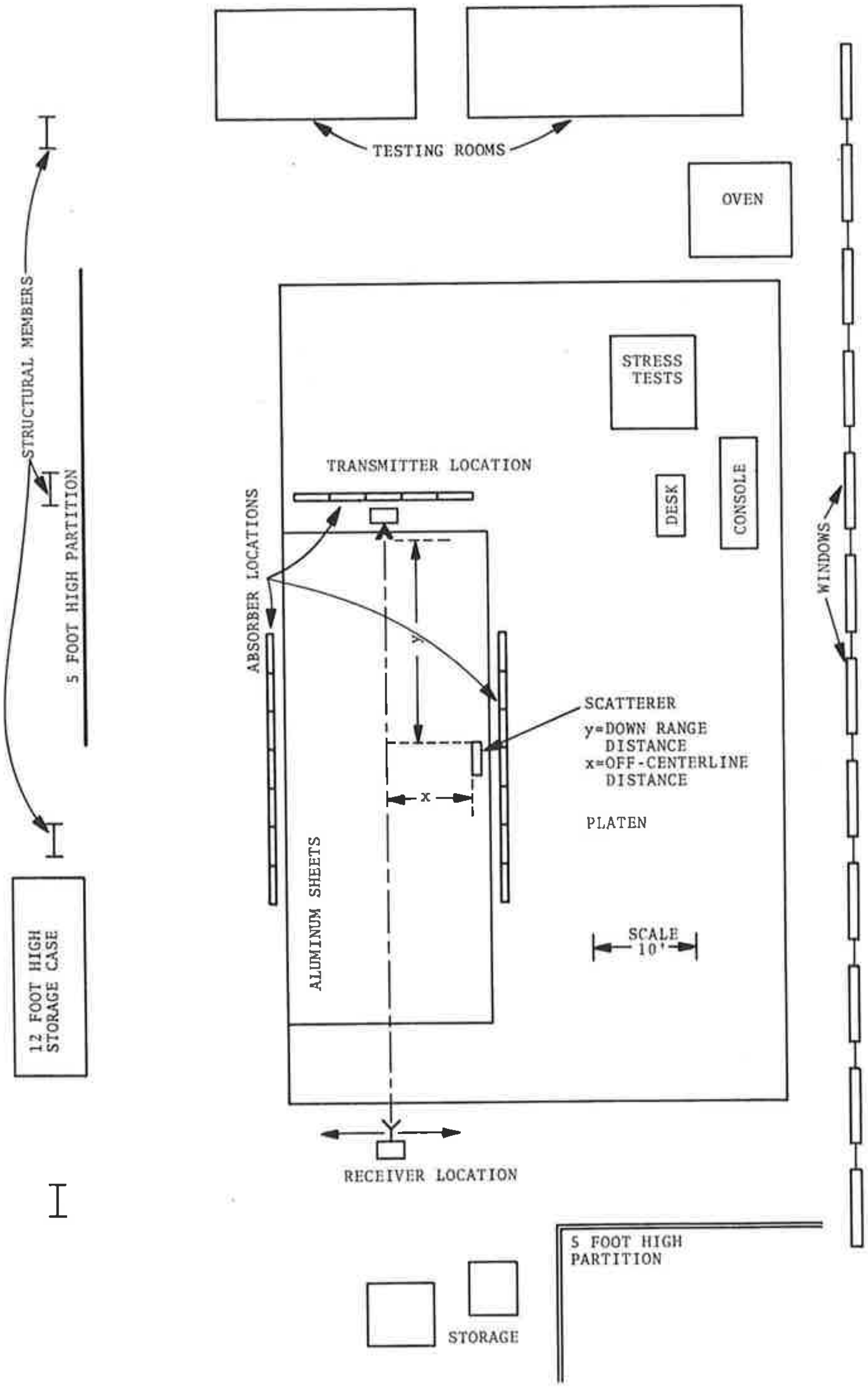


Figure 1. Platen Location in Building #311

2. METHOD

In this section the experimental range and the measurement equipment are described.

2.1 SCALING

100 to 1 scaling of the glide slope was employed in this evaluation. The 330 MHz glide slope frequency is scaled to 33 GHz.

2.2 GROUND PLANE IMPROVEMENTS

The unique feature of Building #311 at the Watertown Arsenal is the existence of several large platens. These are large flat surfaces to which heavy machining equipment can be clamped for use in the fabrication of large pieces of military hardware. The platens are flat to within thousandths of an inch. They are criss-crossed with a grid of tie-down-slots used to lock machinery in place. These regularly spaced slots would cause undesired scattering of the radiation. To eliminate this problem .090 inch thick aluminum sheets were used to cover the platen. An area 20 feet wide and 48 feet long was covered for the purposes of these experiments.

2.3 RANGE SETUP AND TARGET LOCATIONS

Figure 1 is a plan view of the test range with surrounding structures. Principal measurements were made with transmitter to receiver spacings of 31 feet and 58 feet. Typical absorber locations are indicated on the figure. The locations of the several large scattering targets measured in these experiments are specified in rectangular coordinates by: (y) the distance from transmitter along the range center line to the leading edge of the scatterer, and (x) the distance from the center line to the scatterer. Figure 2 is a photograph of a typical arrangement of the range taken from the transmitter end. A thin rectangular

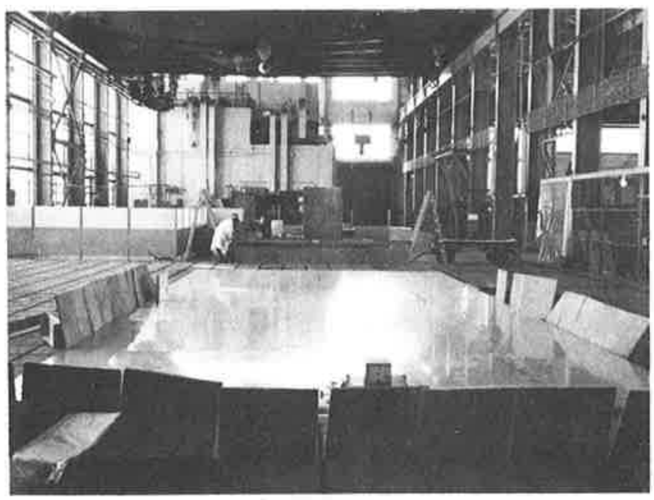


Figure 2. ILS Model Range (Seen from Transmitting End)

scattering target 16" high and 35" long is located on the left side of the range.

2.4 TRANSMITTER

The transmitter consists of a Hewlett Packard Sweep Oscillator Model 8690B with Model 8697A plug in. The oscillator is operated in the CW mode at a frequency of 33 GHz. Frequency is set and monitored using a cavity wavemeter and crystal detector. A block diagram of the equipment used in evaluating the ILS model range is shown in Figure 3.

The several transmitting horn antennas used in the course of these experiments were set at a fixed height of approximately 4 inches above the metallic ground plane. This results in a vertical interference pattern having a first peak at 1.25° above the ground plane a second peak at 3.75° with subsequent peaks occuring at 2.5° intervals. Nulls are located midway between peaks with the first null at 2.5° and subsequent nulls at multiples of 2.5°

2.5 RECEIVER

The receiver consists of one of several horn antennas clamped to a carriage which travels on a long I beam. The I beam is usually positioned horizontally, perpendicular to the range center line. It can be adjusted to operate at any desired distance from the transmitter and height above the ground plane. The length of the beam permits measurements to be made to a distance of 8 feet on either side of the range center line. A synchro-generator is used to reference the location of the carriage on the beam. This information is fed to the Scientific Atlanta, Series 1520 Rectangular Recorder to position the recording paper. Thus, a position on the recording paper bears a one-to-one relationship to a location of the carriage on the I beam. The paper used in the recorder has a calibrated scale of ±180° and is intended for plotting antenna patterns taken as an antenna is rotated through ±180°. In the case of the present experiment a 1 foot linear distance of travel by the carriage corresponds to 19.3 degrees on the recorder paper.

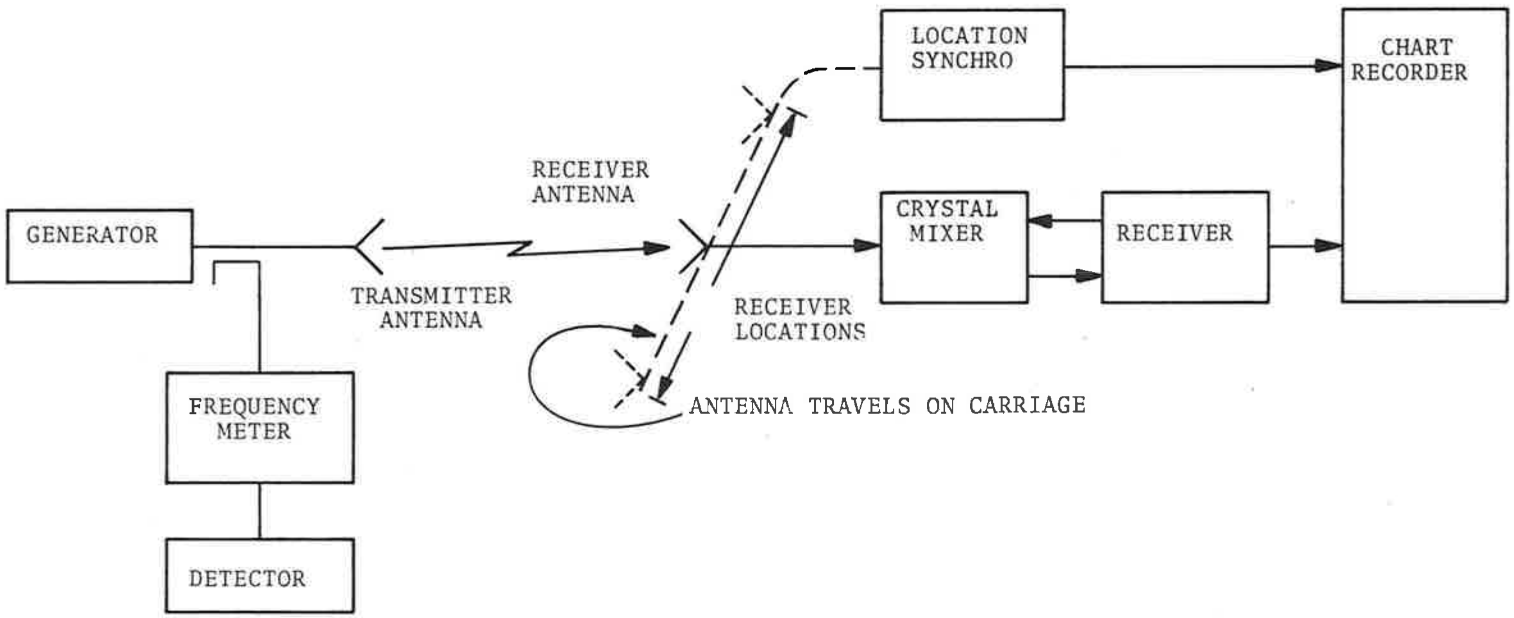


Figure 3. Block Diagram for ILS Model Range Evaluation

The power received by the receiving antenna mounted on the travelling carriage is mixed with a local oscillator signal generated by the Scientific Atlanta Series 1600 Wide Range Receiver. The resulting intermediate frequency signal is fed to the receiver which generates a voltage that is proportional to received power expressed in decibels. This voltage is fed to the pattern recorder where a plot of received power versus carriage position is recorded.

2.6 MODES OF OBSERVATION

Two types of measurements were made to determine the suitability of using the Watertown Arsenal as an ILS model range. Measurements were made with the receiving horn at the height of the "first minimum", midway between the first and second lobe peaks. This minimum occurs at 2.5° above the ground plane as measured from the transmitter. The "first minimum" measurement is intended to simulate the null in the "sidebands only" radiation of the ILS along the glide slope. Measurements were also made with the receiving horn at the height of the "second lobe peak". This peak occurs at 3.75° above the ground plane as measured from the transmitter. This peak is intended to simulate the "carrier plus sidebands" transmission peak of the ILS. In an actual ILS a second antenna is used to generate this peak at an angle of 2.5° above the ground plane. While there is an angular difference between this model and an actual ILS installation, it does not detract from an evaluation of the unwanted range reflections or from a measurement of the scattering due to tall simple scattering targets, such as rectangular plates and vertical cylinders.

2.7 ABSORBER

The microwave absorber material used in this experiment was Eccosorb CH which consists of curled rubberized fibers. For this experiment, 200 square feet of absorber were available to reduce the undesirable reflections from structures around the range. This material was arranged over portions of the edges and ends of the test range to a height of 2 feet. The locations were selected to prevent specular reflections from structures along the range sides and multiple reflections from the range ends.

Microwave power incident on Eccosorb CH is partially reflected. The reflected power is 20dB below incident power for angles of incidence ranging from 0° to 60° to normal. For larger angles of incidence to the normal a greater portion of the incident power is reflected.

3. RESULTS

This section presents data showing the need for absorber to reduce undesirable reflections from structures around the range. Data are also presented to show the scattering due to several large objects specifically oriented to produce reflections which are large enough to be observable in the presence of the undesirable background reflections.

3.1 RANGE REFLECTION MEASUREMENTS

Measurements of the power variations on the "second lobe peak" and "first minimum" above the ground plane are used to determine the magnitude of background reflections from a multitude of objects existing around the sides and ends of the test range. Figure 4 is a hypothetical range pattern in which direct and reflected radiation is received. Salient features of such patterns are described below.

The distance (a-b) on a decibel scale is the peak to peak received power fluctuation at the second lobe peak as a function of the lateral position of the receiving antenna. The fluctuation is due to undesirable reflected power from a multitude of reflecting structures around the range. This background reflected power is received with varying phase relative to the power received directly without reflection. If there were no undesirable reflections, the power received would not fluctuate. The gentle roll-off toward the edges of the pattern is due to the shape of the radiating and receiving antenna patterns. The peak-to-peak amplitude of the fluctuation about the mean can be used to determine the ratio of the electric field strength received by way of scattering to the electric field received by the direct ray.

$$20 \log_{10} \left(\frac{1 + E_S/E_D}{1 - E_S/E_D} \right) = (a-b)$$

where

E_D = Electric field strength of the direct ray

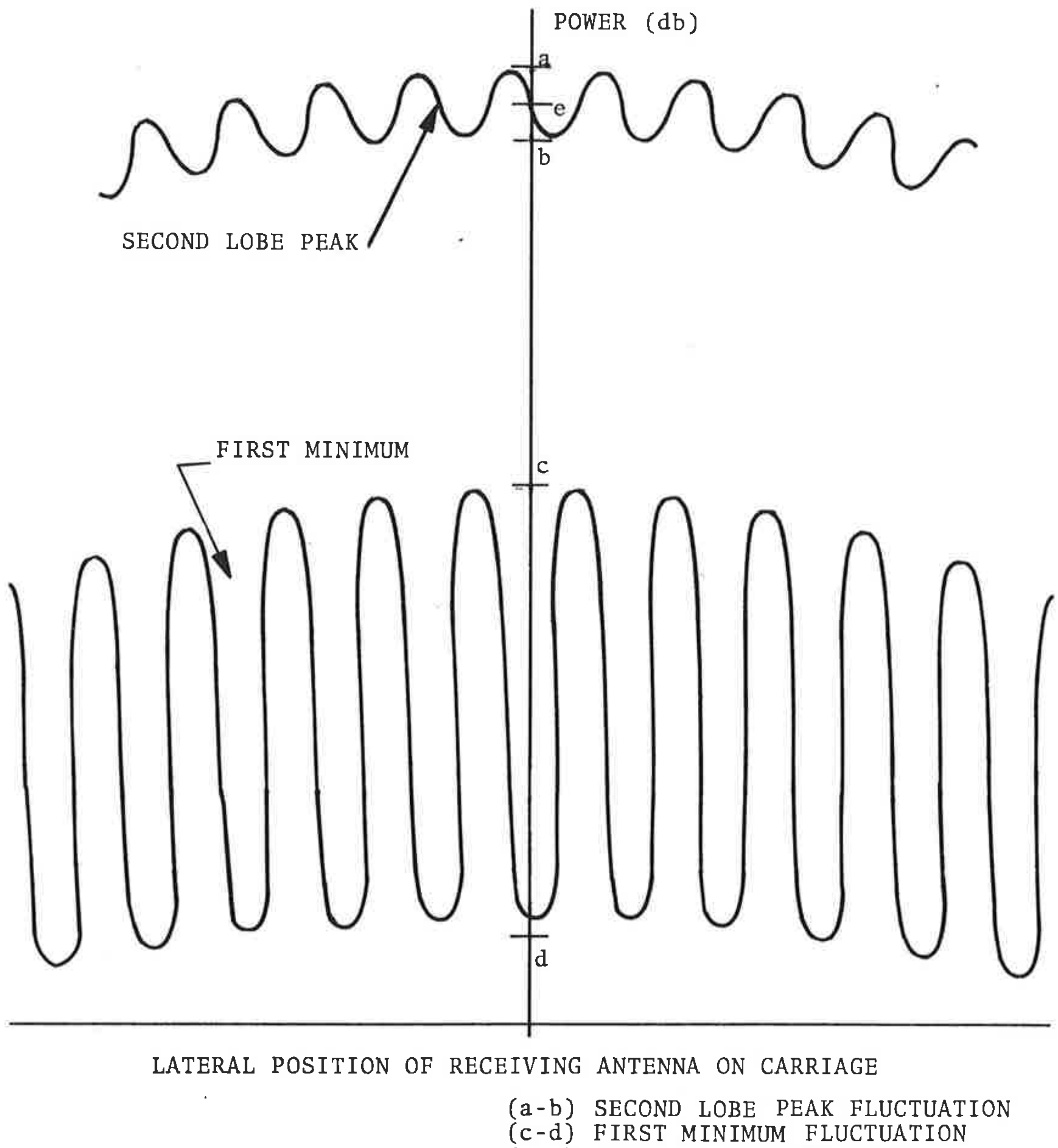


Figure 4. Typical Range Patterns

E_S = Electric field strength of the scattered ray

(a-b) = Peak to peak fluctuation in received antenna pattern expressed in dB.

Finally the ratio of the scattered power to the direct power is merely the square of the electric field strength ratio.

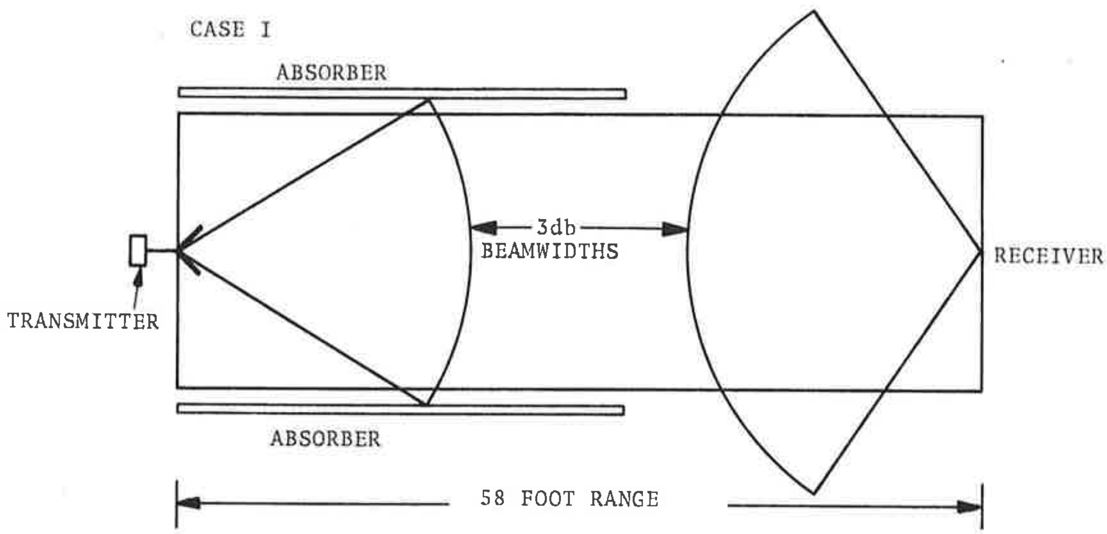
$$\frac{P_S}{P_D} = \left(\frac{E_S}{E_D}\right)^2$$

As an example: A peak-to-peak fluctuation of 2 dB corresponds to the case of the ratio of scattered to direct power of 0.0132. Therefore, the scattered power level is 18.8 dB below the direct power level.

The distance (c-d) on a decibel scale is the received power fluctuation in the first minimum above the ground plane. All power received in this minimum is due to reflections. The amplitude of the reflections (c-d) and the depth of the minimum below the average level of the second lobe peak (e-c) are measures of the background reflections encountered on the range.

In order to evaluate the need for absorber at the sides and ends of the range, two test setups were employed. In the first setup, Case I of Figure 5, the range separation from transmitter to receiver is 58 feet. The figure shows the width of the 3dB beamwidths of the transmitting antenna (55°) and receiving antenna (110°). In an actual glide slope model even broader transmitting and receiving antennas would be employed. For this test the 55° and 110° antennas give sufficient illumination along the sides of the range to evaluate the absorber requirements in that region.

Patterns 8 and 18 (see Appendix for all patterns) are measurements of the second lobe peak and first minimum, respectively, without any absorber. The peak-to-peak power variation on the second lobe peak (a-b) is 1.8dB. The peak-to-peak power variation in the first minimum (c-d) is 16dB. The depth of the minimum be-



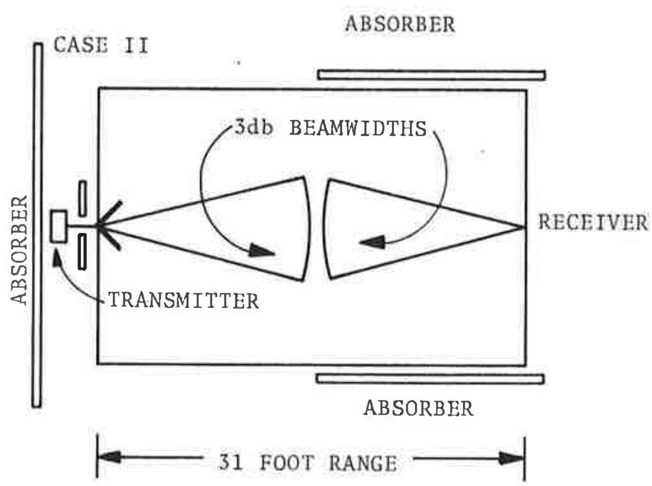


Figure 5. Range Configurations for Evaluating the Requirements for Absorbing Material

low the average level on the second lobe peak (e-c) is 11dB. Next, absorber was placed along the sides of the test range as shown in Figure 5. Patterns 10 and 16 show the degree of improvement. The results are tabulated below in order to facilitate a comparison.

TABLE 1. CASE I: REFLECTIONS FROM RANGE SIDES

Patterns	Absorber	Second Lobe Peak Fluctuation (a-b)	First Minimum Fluctuation (c-d)	Depth of Minimum Below Avg Second Lobe Peak (e-c)
8, 18	None	1.8dB	16dB	11dB
10, 16	At sides	1.3dB	10dB	16dB

The data show that reflections are coming from regions at the sides of the test range. The absorber has cut these reflections significantly but the reflections must be reduced much more by the use of more and better absorber at the range sides.

For the experimental case in which no absorber is used, the amplitude of the scattered field reaching the detecting aperture is typically 10% of the direct field. This number can be approximately related to a typical course error magnitude that would be the consequence of background interferences with a glideslope or localizer pattern simulated in this unshielded facility. In such a simulation, the off-course position derived from the received signal is determined by a "difference in depth of modulation" (DDM), which at a given range from the transmitter is proportional to the received strength of a "sideband-only" component (and DDM) are supposed to be zero. DDM "course bends" arise because of scattered E_{so} radiation from structures or irregular terrain features located off-course. The magnitude of DDM (actual or erroneous) is calibrated by the relative strength of modulation on a received "carrier plus sidebands" components E_{cs}. In the present experimental tests in which only unmodulated carrier was transmitted, the direct signal is closely analogous to the E_{cs} amplitude while the scattered or indirect rediation corresponds to a scattered E_{so} signal. Thus for example, consider the ideal null reference glide slope signal pattern shown in Figure 6. This pattern shows a peak of the carrier-sidebands amplitude E_{cs} and a null of the sidebands only amplitude E_{SO} at the glidepath angle 2.5°. The peak of the E_{SO} amplitude relative to the peak of E_{CS} is .26, which corresponds to a vertical coursewidth of 1.40°. If 10% of this peak E_{SO} amplitude were scattered to points on the glidepath the magnitude of the erroneous DDM variations can be shown to be

$$\begin{aligned} DDM &= 2m\ E_{SO}/E_{CS} \\ &= 2 \times .4 \times .026 \\ &= .021\ . \end{aligned}$$

Here m = .4 is the glideslope modulation factor. The DDM of .021 corresponds to a glideslope CDI current of 18 μA (since full scale deflection current of 150 μA corresponds to DDM of .175). An acceptable value would be no more than 1 μA, i.e., scattered amplitudes in the ILS simulation facility should be less than 0.5% of the direct amplitudes. For the 1μA case, the scattered power is 46 dB below the direct power.

Next, it is necessary to evaluate the need for absorber at the ends of the test range. Reflections from end regions are second order effects resulting from multiple reflections. In order to perceive these reflections, the side reflections which are first order specular reflections must be suppressed. To accomplish this measurement, the Case II setup of Figure 5 was employed. Here, the range length is reduced to 31 feet and both receiving and transmitting antennas have reduced 3dB beamwidths of 28°. Consequently, little power reaches the range sides and therefore range end effects are more clearly visible. Absorber is always left at the sides of the range and measurements are made with and without absorber behind the transmitting end of the range. The results are summarized in Table 2. No pattern was taken of the

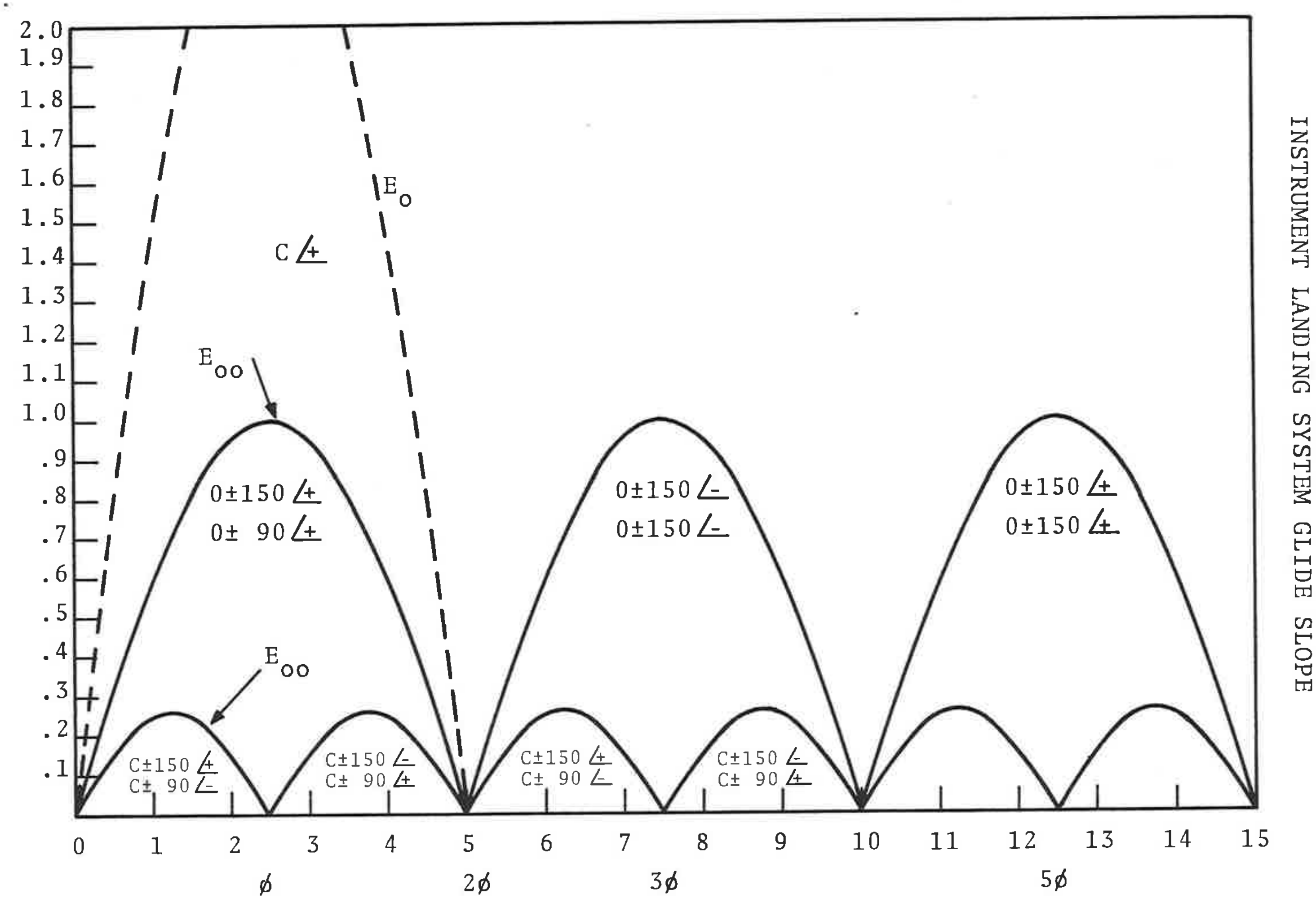


Figure 6. Null Reference Radiation Patterns

case of the second lobe peak with no absorber at the transmitter end. Due to the extremely low level of reflections in this set-up, the pattern will be almost identical to the second lobe peak pattern with absorber. The patterns in the minimum are a much more sensitive indicator of performance. The results demonstrate that multiple reflections are coming from the transmitter end of the range. The necessity of using absorber at the sides and ends of the range is demonstrated.

TABLE 2. CASE II: REFLECTIONS FROM RANGE ENDS

Pattern	Absorber	Second Lobe Fluctuations (a-b)	First Minimum Fluctuations (c-d)	Depth of Minimum Below Avg Second Lobe Peak (e-c)
90	At sides only	-	23dB	21dB
77, 84	At sides and transmitter end	0.1dB	9dB	27dB

The ceiling reflections are difficult to evaluate in the present shortened range situation. The ceilings should be expected to contribute considerable reflections at the longer proposed ILS model ranges of 150 feet. Therefore, it appears that the range would need to be completely enclosed with absorber.

3.2 SIGNATURES OF SEVERAL LARGE TARGETS

Because of the magnitude of the undesirable reflections encountered in the proposed Watertown Arsenal test range, only very large scatterers can be distinguished above the level of the range background reflections. In order to reduce reflections from the range sides, antennas with narrow beamwidths are used for these measurements. This necessitates careful placement of a scatterer so that it will be in the transmitting antenna's azimuthal main lobe.

3.2.1 Rectangular Targets on 58-Foot Range

Rectangular scatterers were detected on a 58 foot range having absorber at the transmitting and receiving ends and over a large portion of the sides. The antennas used as transmitter and receiver have a calculated 3dB azimuth beamwidth of 28 degrees and the angular position of the first azimuthal null off boresight is 31 degrees. The two rectangular scatterers were metal partitions of about 2 inch thickness. Both are 36 inches high with widths of 16 and 35 inches. The large flat surfaces of these partitions are positioned 9 feet away from and parallel to the range centerline. The leading edge of the scatterer is spaced 28 feet down range from the transmitter. Figure 1 shows the locations of such scatterers and the arrangement of the absorber. Patterns 61, 62, 70, and 71 are examples of the scattering of such large rectangles.

TABLE 3. RECTANGULAR SCATTERER, 58-FOOT RANGE

Pattern #	Scatterer		Orientation	Receiving Mode
	Height	Width		
61	36"	35"	Vertical	Second Lobe Peak
62	36"	16"	Vertical	
70	36"	35"	Vertical	First Minimum
71	36"	35"	6° Tilt	

In the case of Pattern 71, the top of the scatterer is tilted away from the range centerline. In this way, power in the first lobe peak is specularly reflected into the plane of the minimum.

It is of interest to compare the results of the range measurements with calculations based on geometrical optics for the case of the largest specular reflector. This case is represented by Pattern 61 for a rectangle 36" high and 35" long. Figure 7 shows the geometry of this situation. The peak of the return is 0.3 feet from the range centerline as shown. The center of the rectangle is 17° off boresight for transmitter and receiver. Figure 8 shows the

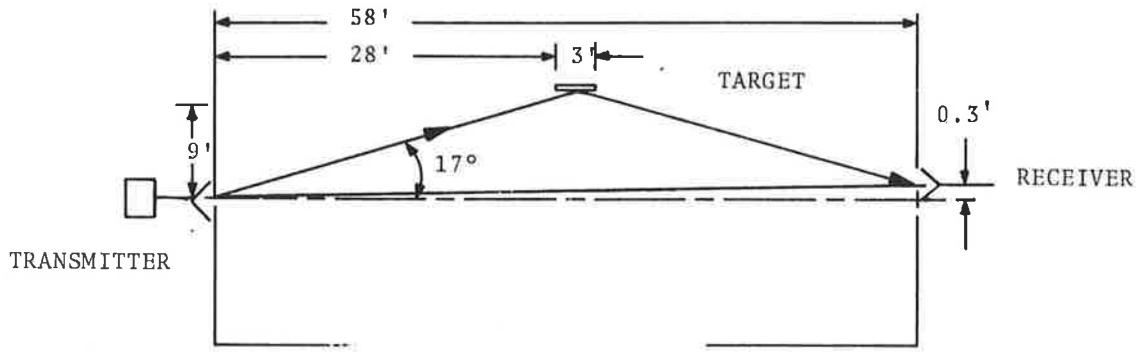
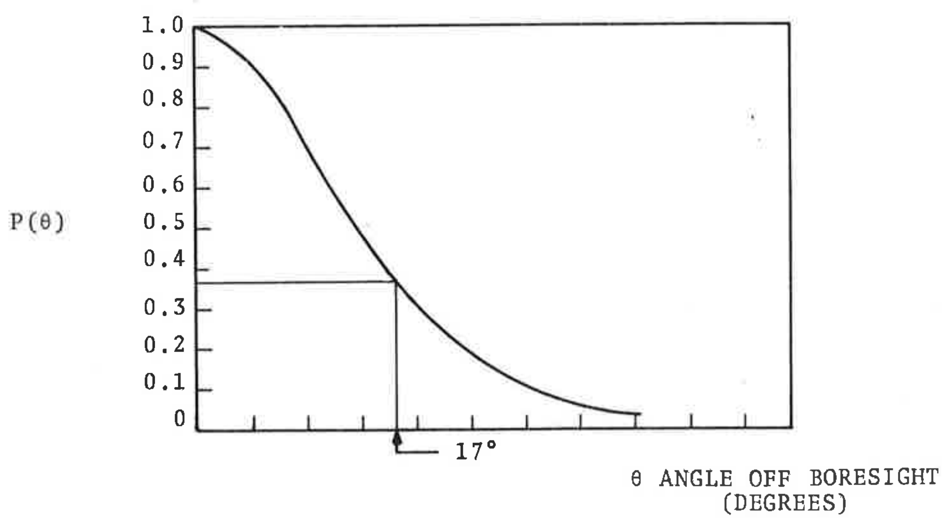


Figure 7. Range Geometry for Large Rectangular Scatterer



E PLANE PATTERN FROM RECTANGULAR APERTURE

Figure 8. Azimuthal Antenna Pattern

typical E plane pattern for a rectangular antenna aperture. The normalized power pattern is .37 for 17° off boresight. The direct ray from transmitter to receiver travels at an angle of 0.3° from boresight. The normalized power pattern is approximately 1.0. In addition, the R^2 path loss must be taken into account since the scattered ray travels a greater distance than the direct ray. Finally, the power at the receiver from the scattered ray versus the direct ray is given by:

$$\frac{P_S}{P_D} = \frac{P_T\ (17°)}{P_T\ (0.3°)} \times \frac{P_R\ (17°)}{P_R\ (0.3°)} \times \left(\frac{R_D}{R_S}\right)^2$$

$\frac{P_T\ (17°)}{P_T\ (0.3°)}$ = normalized power pattern of transmitting antenna at 17°

= 0.37

$\frac{P_R\ (17°)}{P_R\ (0.3°)}$ = normalized power pattern of receiving antenna at 17°

= 0.37

$\frac{R_D}{R_S}$ = ratio of direct path length to scattered path length

= 0.956

Therefore,

$$\frac{P_S}{P_D} = 0.125$$

The ratio of the electric field strength received from the scatterer to the electric field strength received from the direct ray is

$$\frac{E_S}{E_D} = \left(\frac{P_S}{P_D}\right)^{\frac{1}{2}} = .354$$

Using

$$20 \log_{10} \left(\frac{1 + E_S/E_D}{1 - E_S/E_D}\right) = (a-b)$$

it is calculated that the peak-to-peak fluctuation at the second lobe peak should be 6.35dB.

The peak-to-peak amplitude of the interference as measured in Pattern 61 is 5.4dB. Thus for the 36 inch high and 35 inch wide rectangular target, the results calculated using geometrical optics are in good agreement with measurements. This scatterer has an azimuthal angular extent of approximately 1 degree as seen from the transmitter. If this power is reflected specularly, the azimuthal spot size due to reflected power at the receiver is approximately 2 feet. A scale indicating 2 feet is superimposed on Pattern 61. Examination of Pattern 61 shows that the spot size is also in good agreement with the calculations. In Pattern 62, which is the pattern resulting from a narrower scatterer, geometric optics fails to predict the amplitude and width of the target. Returning to the effect of the larger scatterer, when measurements are made in the minimum with the scatterer inclined to specularly reflect power from the first lobe peak into the plane of the first minimum, the power level at the specular point is 10dB below the average value in the second lobe peak. This is the distance previously defined as (e-c). This result is in good agreement with the previously calculated P_S/P_D of .125 or -9.0dB.

3.2.2 Cylindrical Target at 31-Foot Range

Attempts were made to measure the effect of a vertical cylinder of 14" diameter and 27" height on the 58 foot range. The results were unsatisfactory due to the amplitude of background range reflections. The measurements were repeated using a 31 foot range. At the 31 foot range, the same transmitting and receiving antennas with calculated 3dB beamwidths of 28 degrees are used. At 31 feet, background range reflections are much smaller than at the 58 foot range. Pattern 77 previously described is the received power pattern on the second lobe peak with no scatterer on the range. Pattern 80 shows the effect in the second lobe peak of a cylindrical scatterer of 14" diameter and 27" height. The target was located so that the tangents to the cylinder are spaced 5 feet down range from the transmitter as shown on the pattern. The effect of this same target on the first minimum is seen in Pattern 88. This should be compared to previously presented Pattern 84 for the case when no scatterer is present. The foregoing measured reflection patterns are representative of somewhat larger set of data which will be fully presented and discussed in another report.

3.3 VERTICAL PATTERN

In order to demonstrate the interference pattern generated due to the proximity of the ground plane to the transmitting antenna, a vertical cut was made through the antenna pattern at the 58 foot range. To accomplish this, the I beam on which the receiving carriage travels was positioned vertically. Pattern 75 shows the location of the first minimum and second lobe peak on which all previous measurements were made.

4. CONCLUSIONS AND RECOMMENDATIONS

The work reported here demonstrates the need for absorber on all sides of the range. With the present absorber quantity and quality, only very favorably placed large scatterers can be seen. To accomplish even this, antennas with narrow beamwidths had to be used to suppress unwanted reflections.

If the Watertown site is to be employed for ILS modeling, it is recommended that the range be completely enclosed with better quality absorber. In addition, the enclosure should have a heating and air conditioning system independent of the building's present system. This would ensure a laboratory environment which could be well regulated and not subject to the conditions that are tolerated in a heavy machining facility.

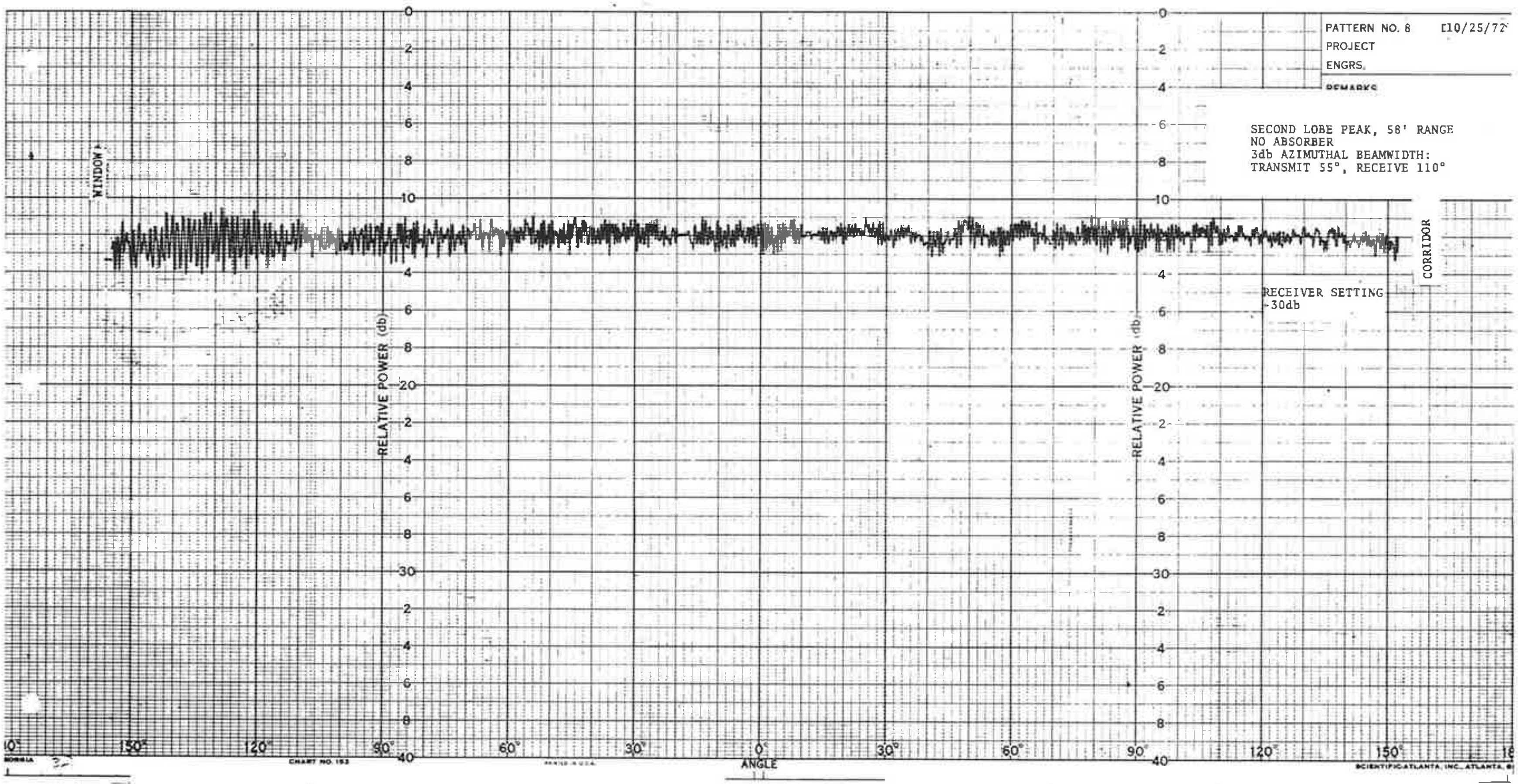


Figure A-1. Pattern No. 8. Second Lobe Peak, 58' Range, No Absorber

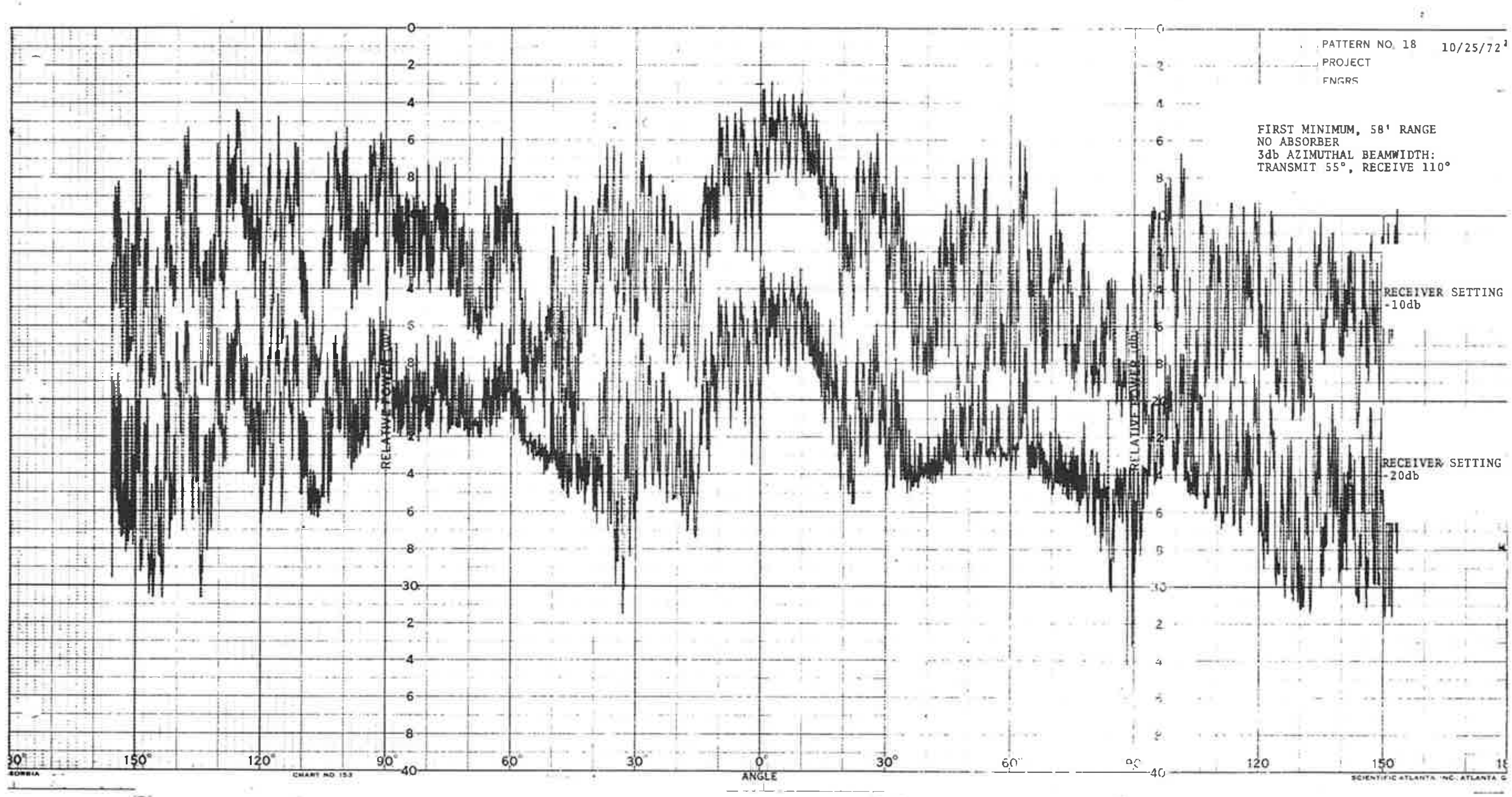


Figure A-2. Pattern No. 18. First Minimum, 58' Range, No Absorber

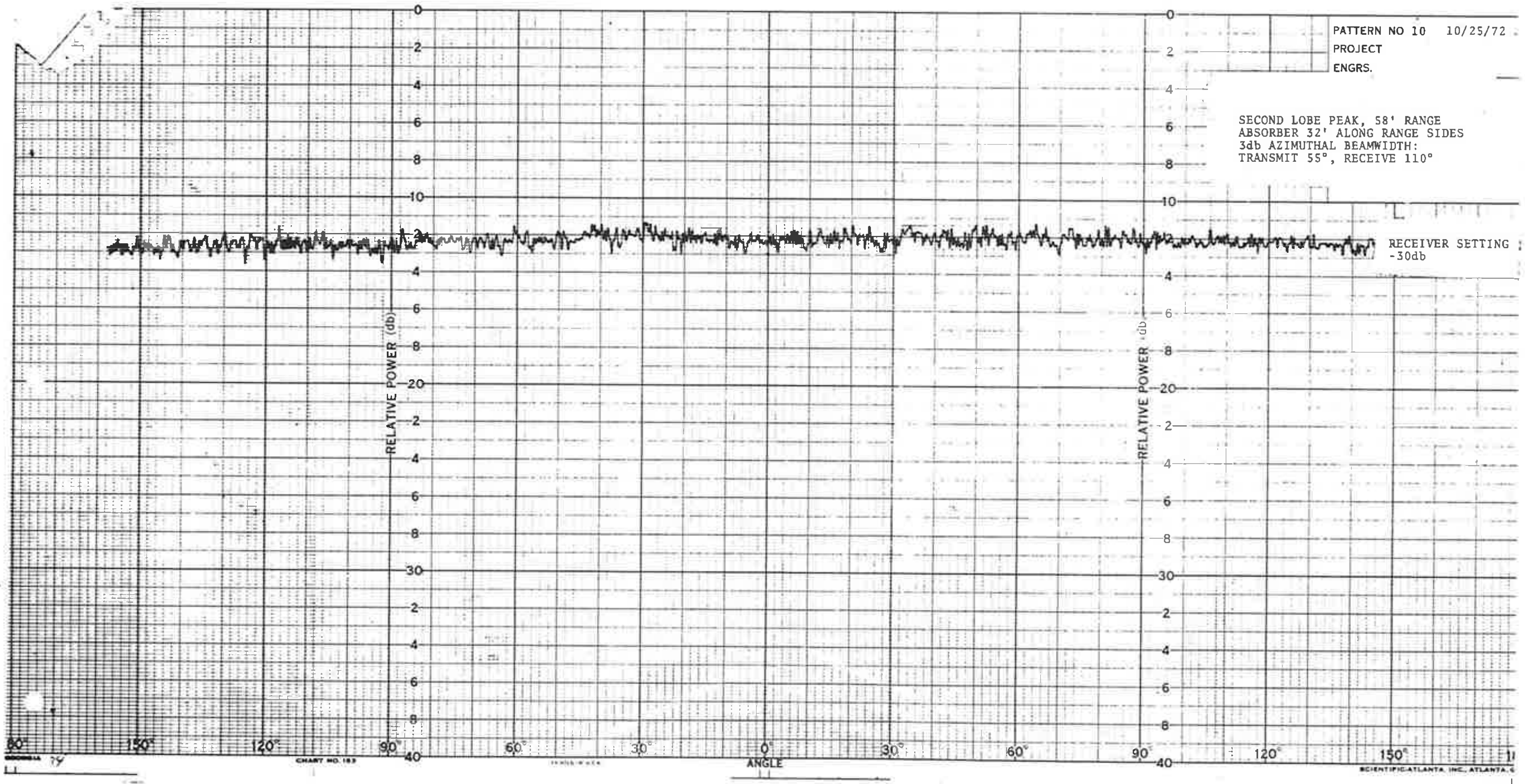


Figure A-3. Pattern No. 10. Second Lobe Peak, 58' Range, Absorber Range Side

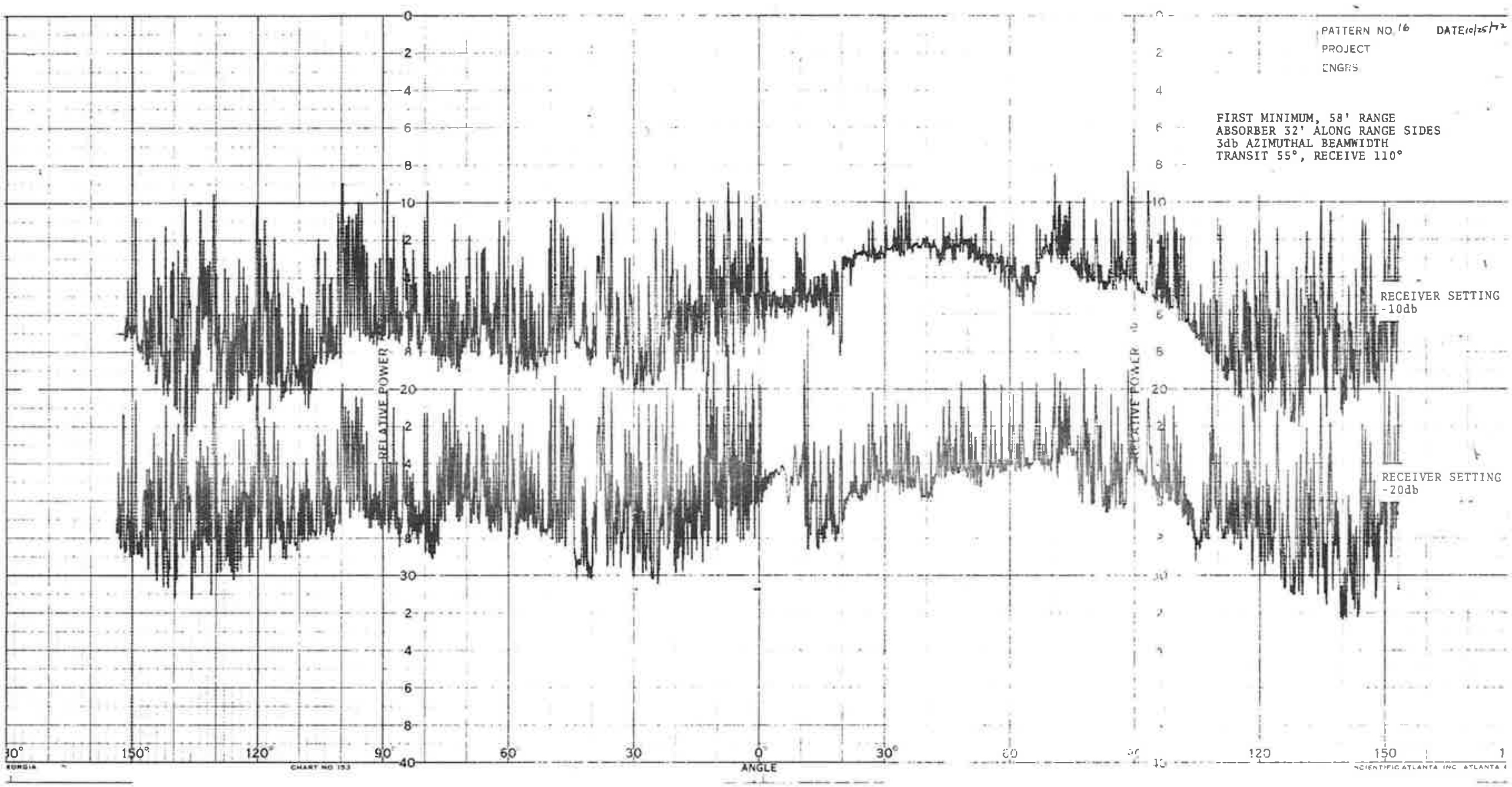


Figure A-4. Pattern No. 16. First Minimum, 58' Range, Absorber Range Side

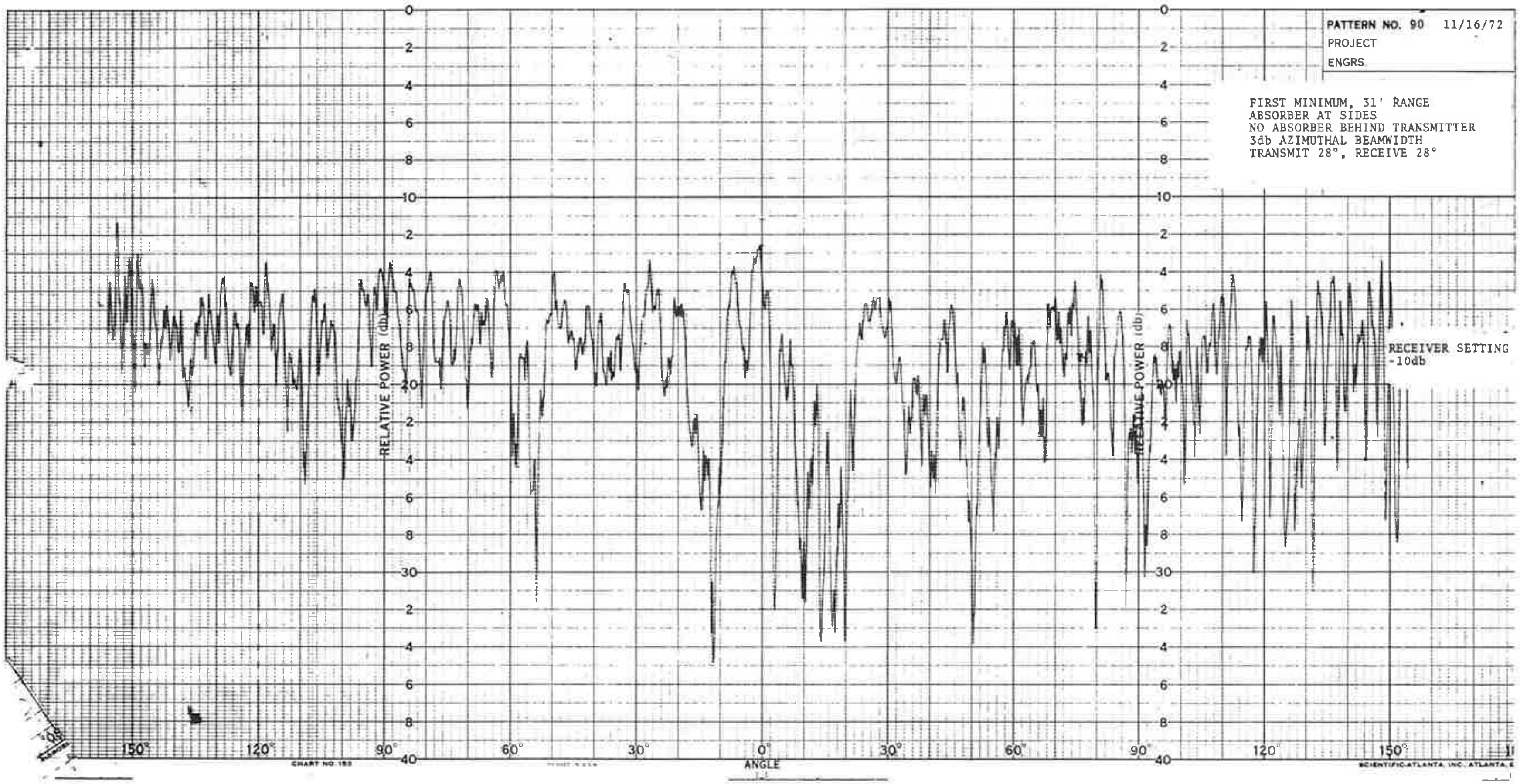


Figure A-5. Pattern No. 90. First Minimum, 31' Range, No Absorber Range End

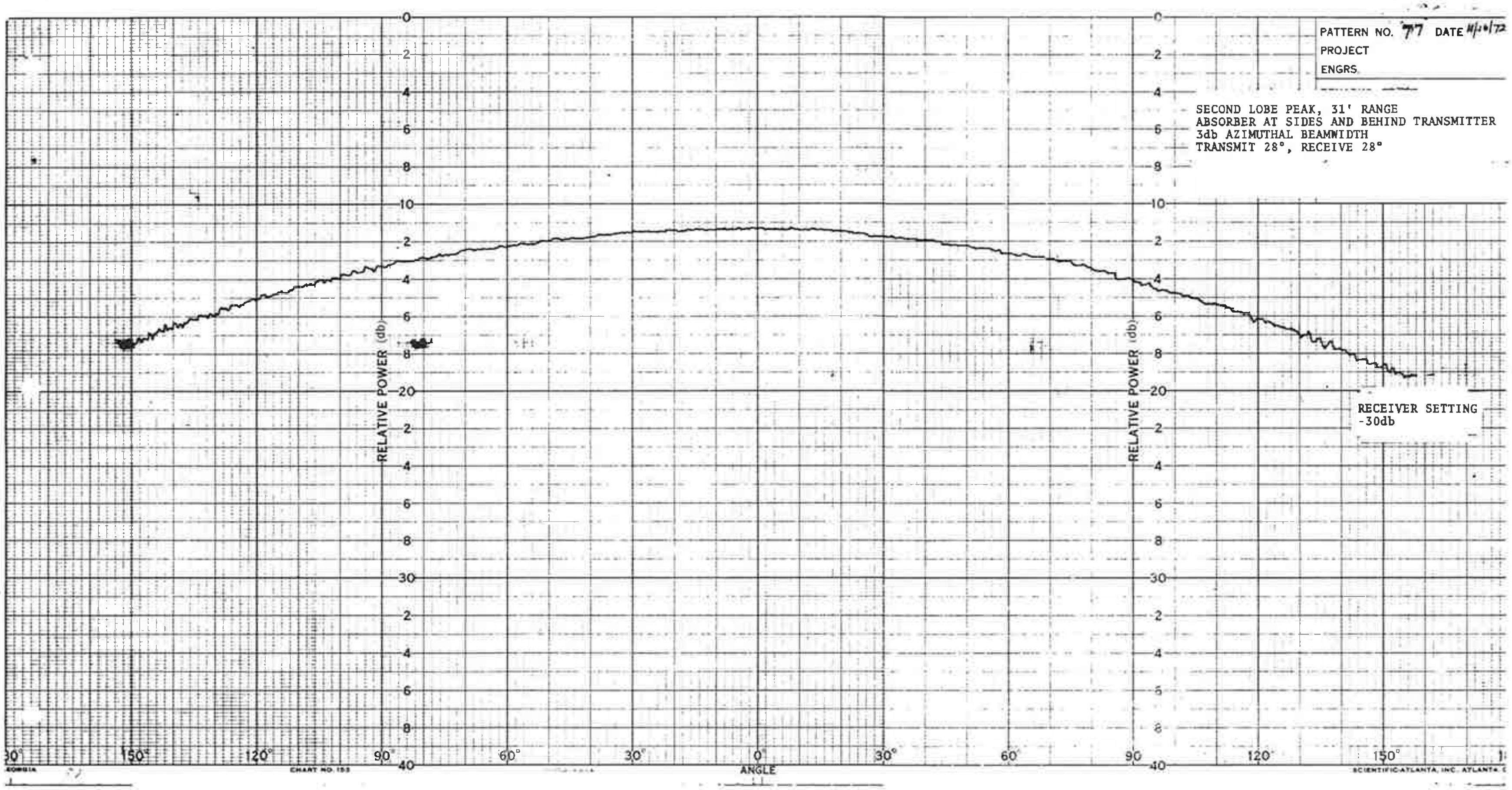


Figure A-6. Pattern No. 77. Second Lobe Peak, 31' Range, Absorber Range End

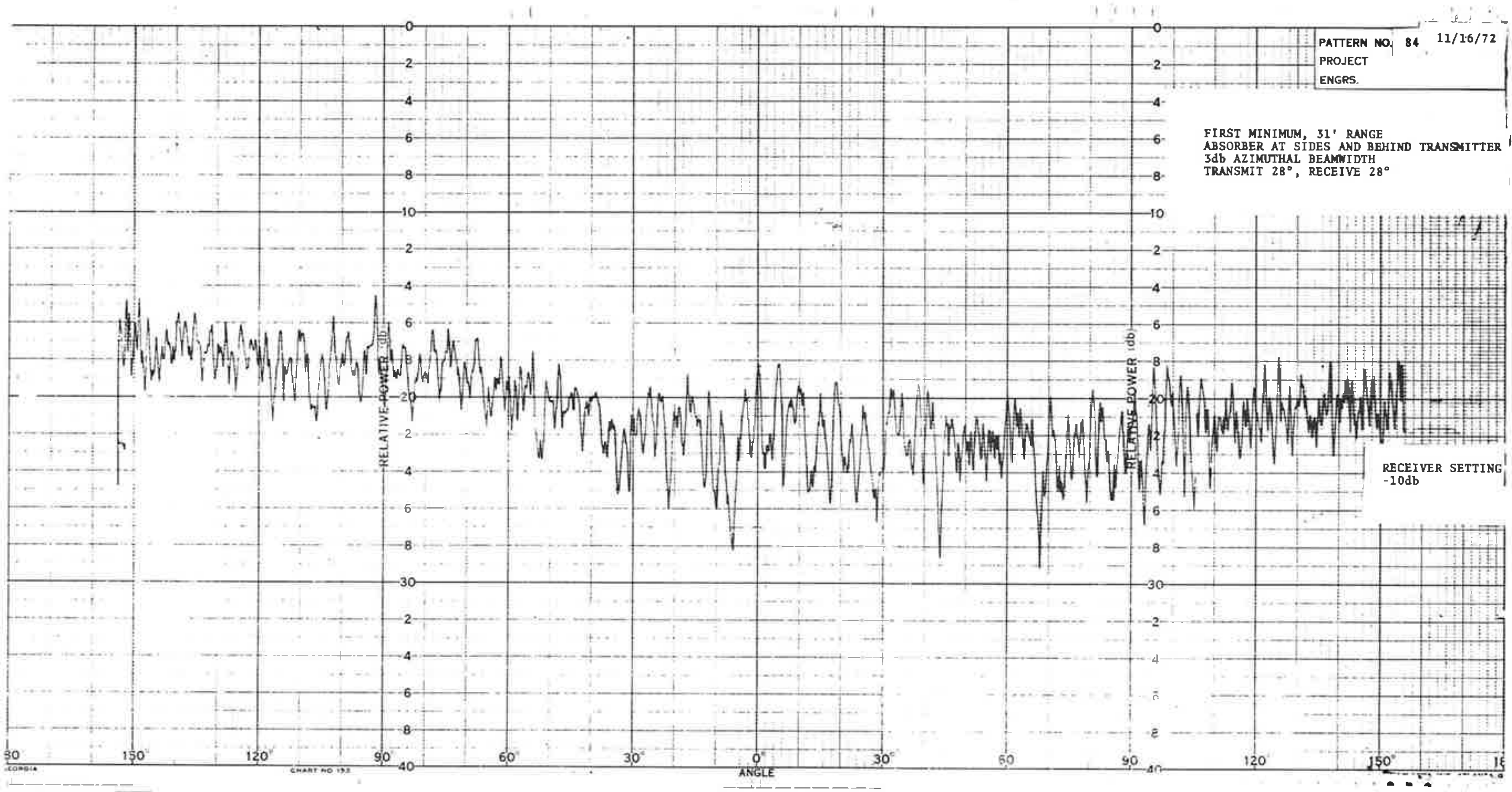


Figure A-7. Pattern No. 84. First Minimum, 31' Range, Absorber Range End

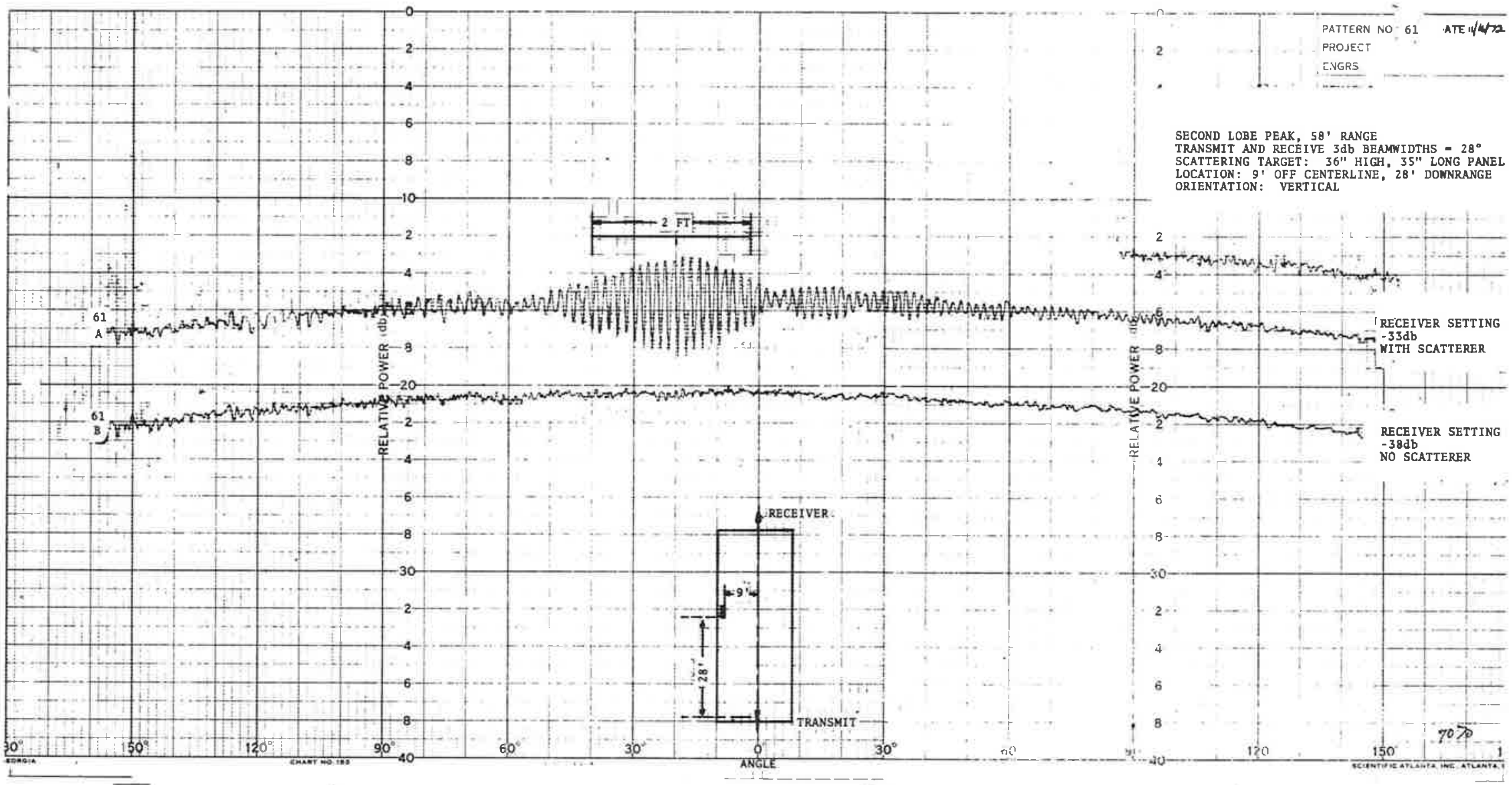


Figure A-8. Pattern No. 61, Second Lobe Peak, 58' Range, 36" x 35" Planar Scatterer

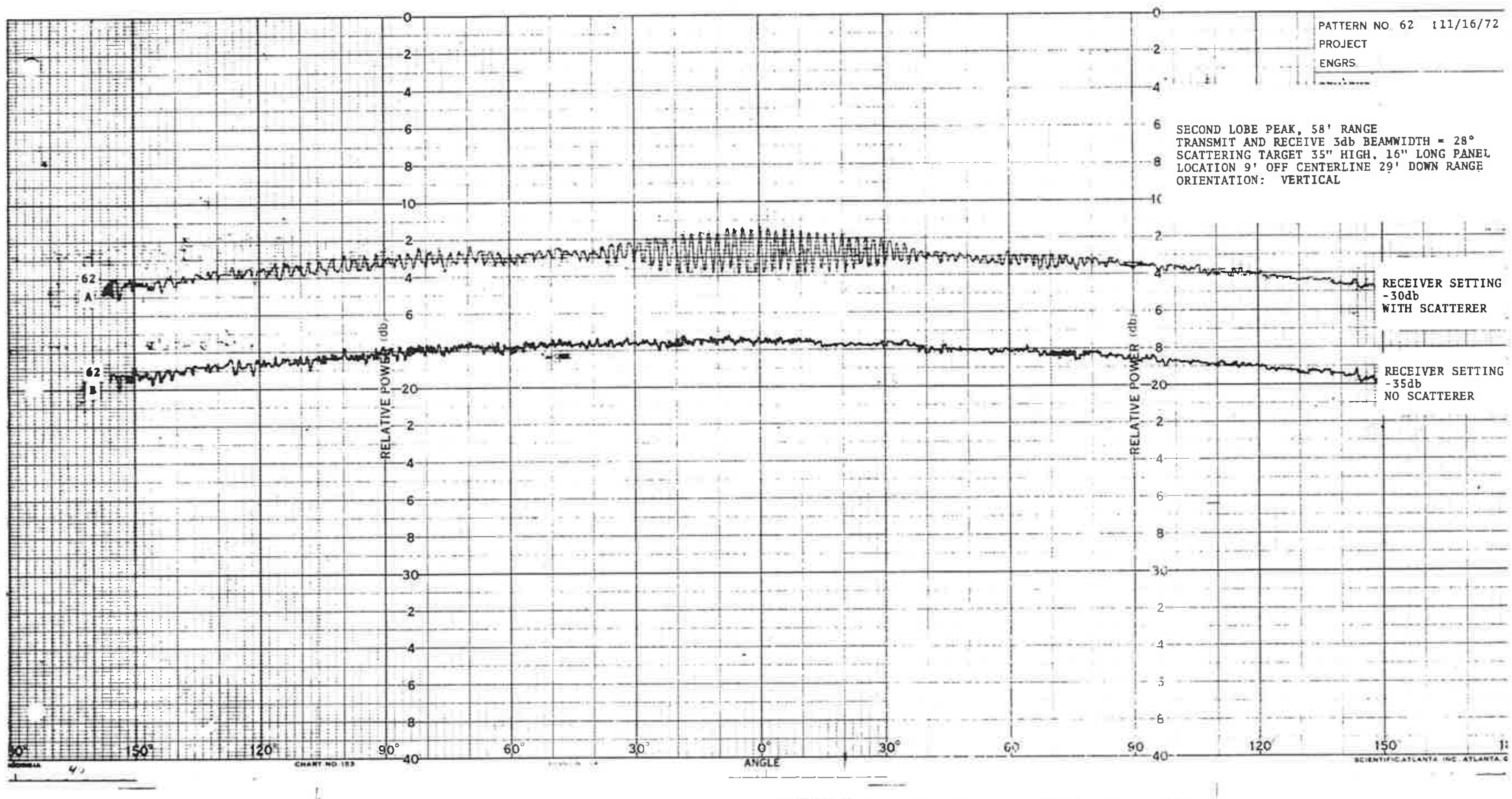


Figure A-9. Pattern No. 62. Second Lobe Peak, 58' Range, 36" x 16" Planar Scatterer

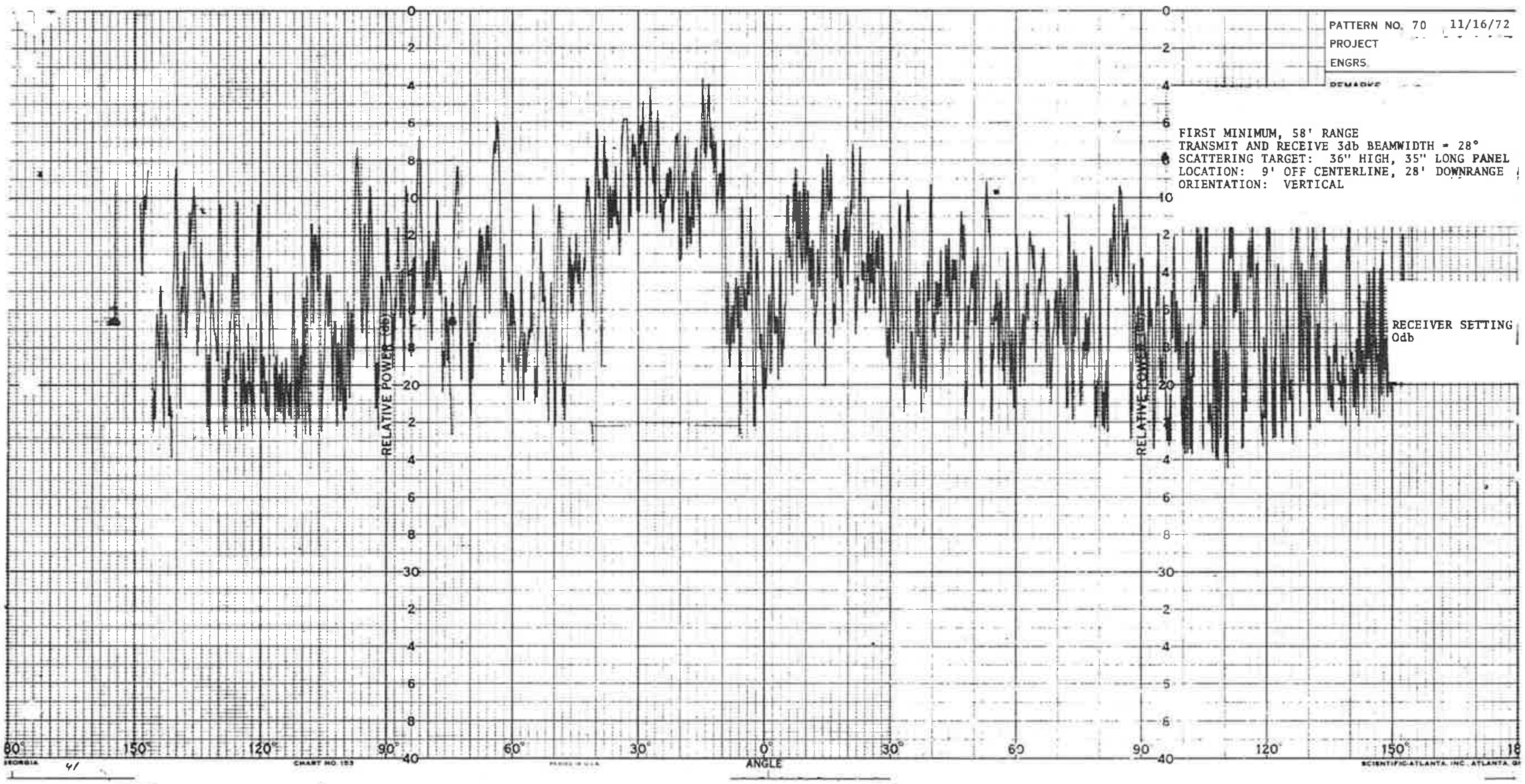


Figure A-10. Pattern No. 70. First Minimum, 58' Range, 36" x 35" Planar Scatterer

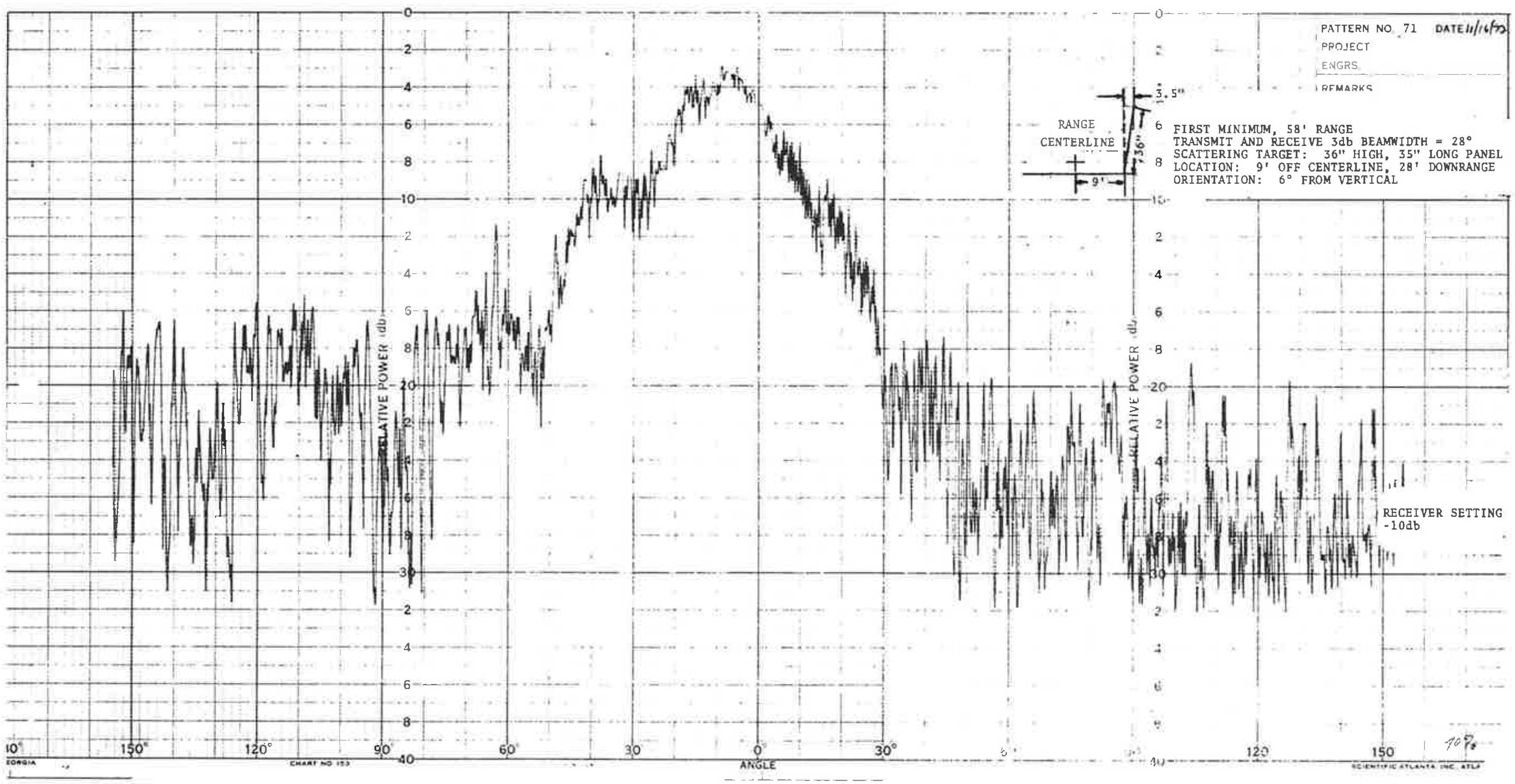


Figure A-11. Pattern No. 71. First Minimum, 58' Range, 36" x 35" Planar Scatterer Tilted

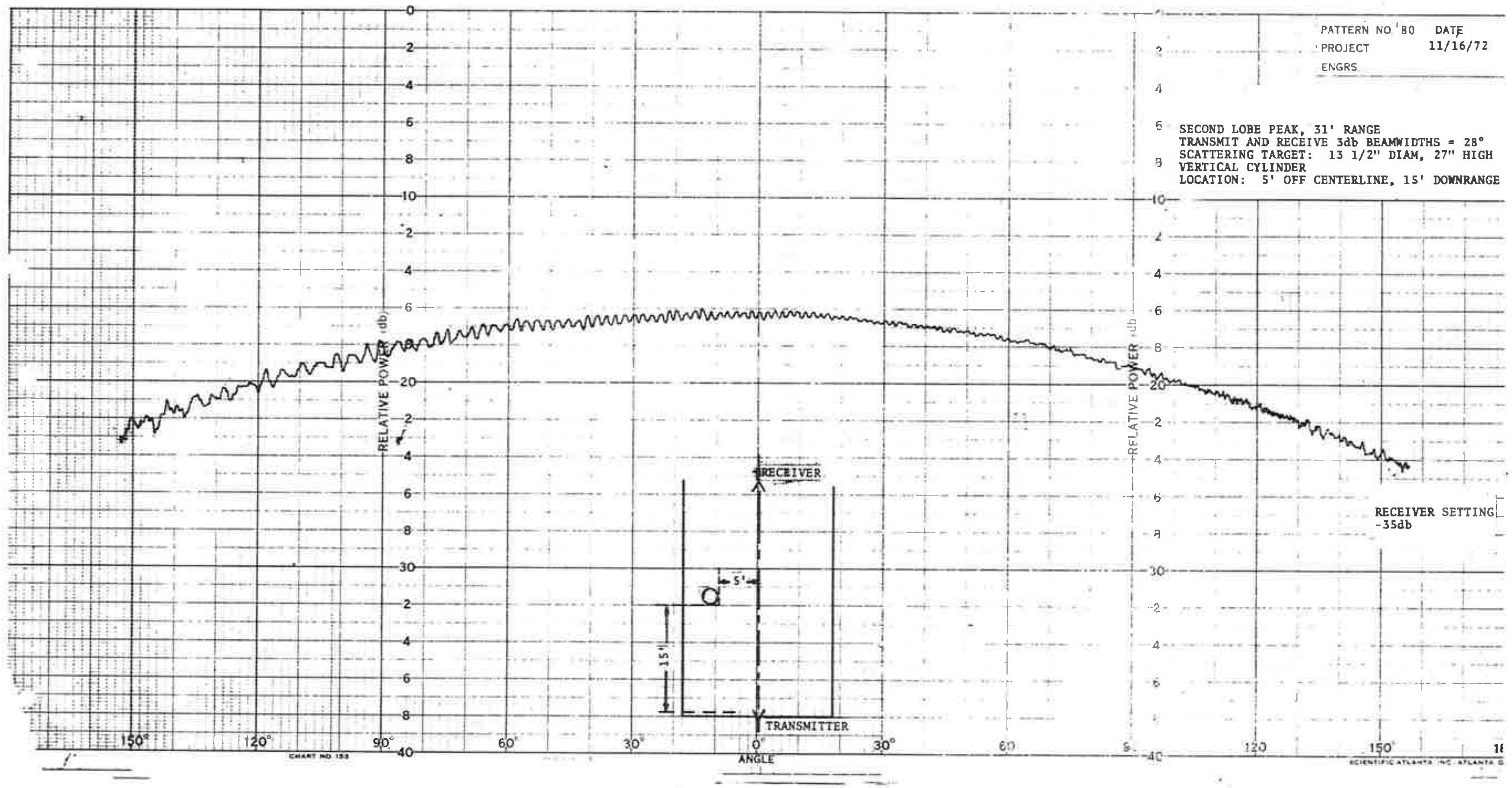


Figure A-12. Pattern No. 80. Second Lobe Peak, 31' Range, 13 1/2" Diam. Vertical Cylinder

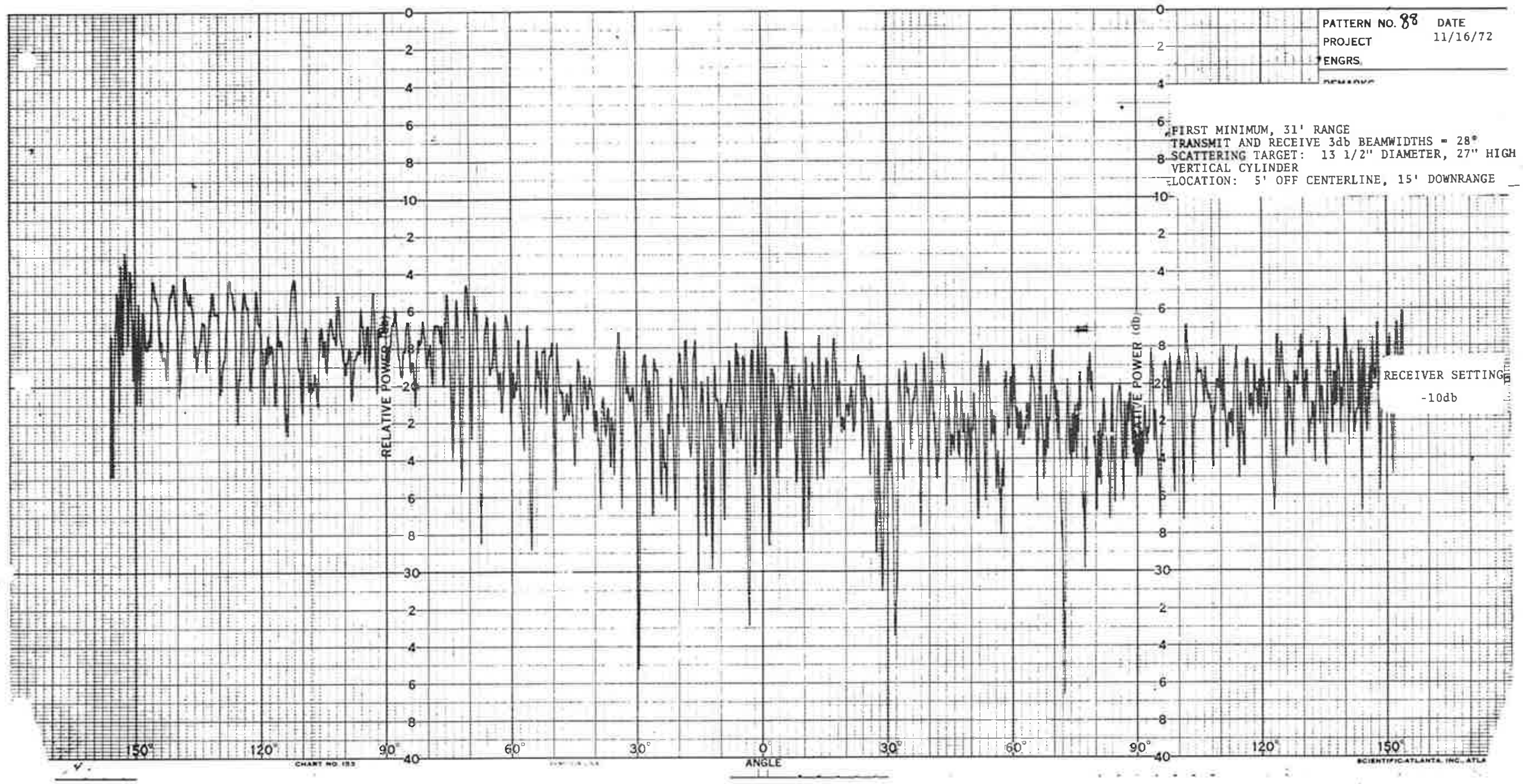


Figure A-13. Pattern No. 88. First Minimum, 31' Range, 13 1/2" Diam. Vertical Cylinder

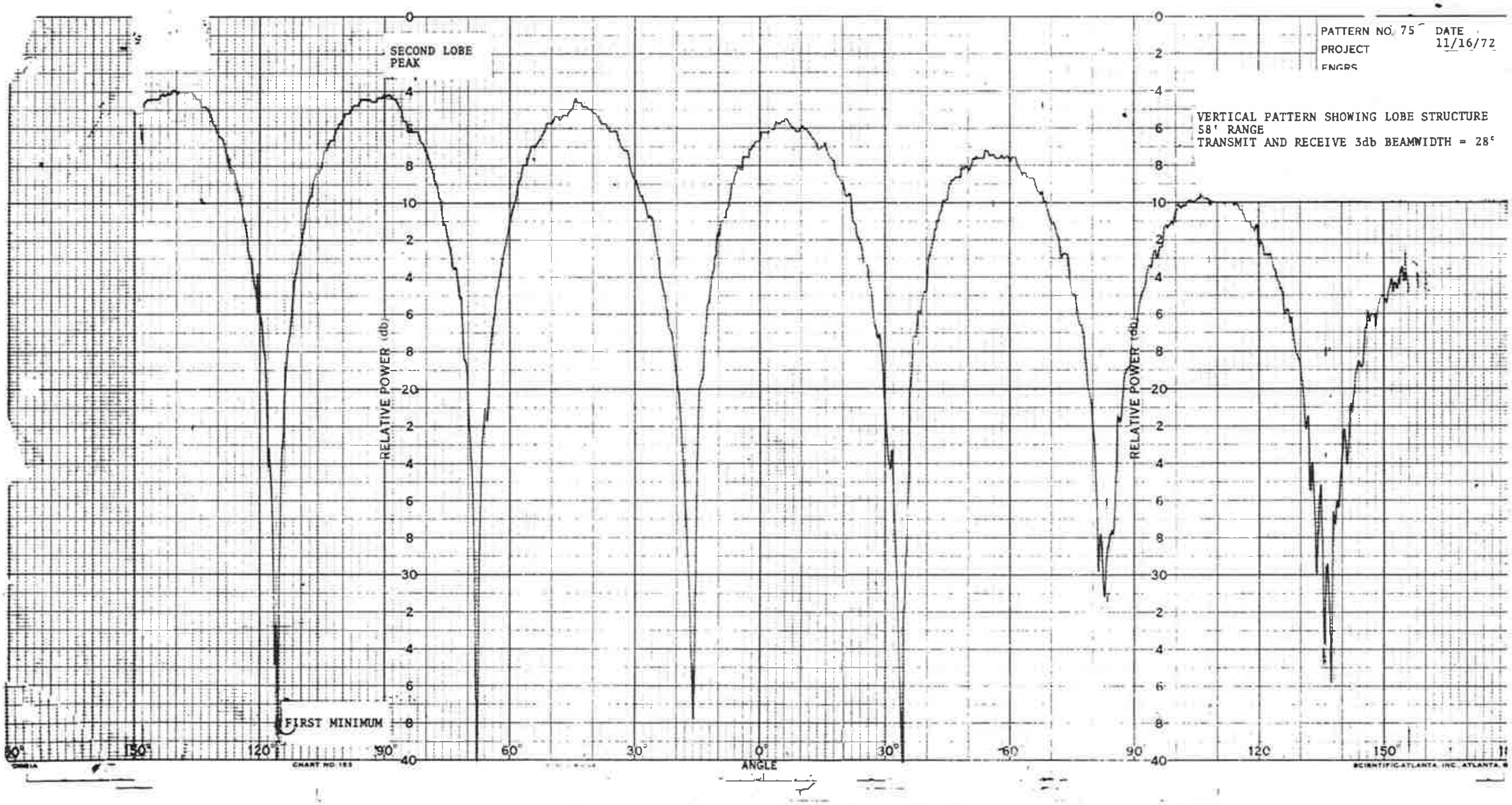


Figure A-14. Pattern No. 75. Vertical Pattern Showing Lobe Structure