The

Antenna Laboratory

Department of Electrical Engineering

QUARTERLY PROGRESS REPORT

Effects of Type of Polarization on Echo Characteristics

Contract AF 28 (099)-90

For Period Ending 15 December 1951

ROME AIR DEVELOPMENT CENTER

Griffiss Air Force Base, Rome, New York

389-11 — 16 December 1951

The Ohio State University
Research Foundation
Columbus, Ohio

PROGRESS REPORT 389-11

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REPORT

by

THE OHIO STATE UNIVERSITY RESEARCH FOUNDATION

COLUMBUS 10, OHIO

Cooperator	Rome Air Development Center Griffiss Air Force Base Rome, New York
Contract	AF 28 (099)-90
Investigation of	Effects of Type of Polarization On Echo Characteristics
Subject of Report	Quarterly Progress Report Period Ending 15 December 1951
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EFFECTS OF TYPE OF POLARIZATION
ON ECHO CHARACTERISTICS

EFFECTS OF TYPE OF POLARIZATION ON ECHO CHARACTERISTICS

A. ABSTRACT

The variation in echoing area of a 1/20-scale F-80 aircraft with 1
changing direction of linear polarization has been studied at 9000 mc. For a range of aspects 40° to either side of nose on, in a horizontal plane, power patterns were obtained for polarizations at 0, 15, 30, 45, 60, 75 and 90 degrees inclined to the horizontal.

Several patterns of the return from a 1/10-scale F-80 aircraft at 2
9000 mc have been obtained for ordinary and cross-polarized components of echo.

Representative patterns illustrating the variation in echo area with 3
direction of linear polarization have been obtained from simple targets. Analysis of these patterns is discussed.

B. PURPOSE

Theoretical and experimental studies applicable to sections a, b, 4
and c of contract, entitled:

a. Optimum type of polarization for reducing the ratio of rain to aircraft return.

b. Optimum type of polarization for increased echoing area of jet aircraft.

c. The order of magnitude of the advantages to be expected from recommended types of polarization.

C. FACTUAL DATA

In order to predict the optimum polarization for increased echoing 5
area of the F-80 aircraft, as well as the return for any polarization, the variation in return with direction of linear polarization may be studied. To illustrate this technique seven patterns were taken of the return from a 1/20-scale model of the F-80 aircraft at 9000 mc. In

each case the model rotated about a vertical axis, with wings and fuselage in a horizontal plane, through a range of aspects 40° to either side of nose toward observer. Transmitting and receiving polarizations were linear and identical. The direction of linear polarization varied for each pattern, at increments of 15° from horizontal to vertical linear polarization. These patterns have been enclosed in the back cover of the report. The transparencies for each of the seven patterns may be superimposed, and the variation in echoing area at any aspect may be studied. The vertical scale is proportional to echo area; each division of the horizontal scale represents a 5° change in azimuth, from nose facing left (at the right end of the pattern), through nose on (indicated by arrow), to nose facing right (left end of pattern). The change in amplitude of each lobe with polarization may easily be seen from these patterns. Note that the return for every aspect varies with direction of linear polarization. Analysis of the average polarization properties of the target, as well as those for each aspect, may be made from patterns such as these. Experimental error is of such order, however, that additional polarizations must be utilized before these patterns yield useful quantitative information. These measurements are awaiting favorable weather conditions, and will be completed in the next quarter of this contract period.

Several patterns of the return from a 1/10-scale F-80 aircraft are 6
included for comparison with those of the 1/20-scale model in Progress Report 389-10.[1] Figs. 1 and 2 illustrate the ordinary and cross-polarized return from this model at 9000 mc. The vertical scale is proportional to power, and the divisions of the horizontal scale correspond to 10° changes of azimuth. Pattern 2 is at approximately 13 db higher gain than pattern 1. The absolute calibration is not included, since the amplitude and phase of the wave front illuminating the model were probably not constant over the entire model. These patterns illustrate the complex lobe structure and the general envelope of the return from such a model. Note the broad lobes in cross-polarized return to either side of nose on. The ordinary and cross-polarized returns around the tail on position are still low, as they were from the 1/20-scale model.

Since the advent of windy and rainy weather precluded any accurate 7
set of model measurements to illustrate the application of theory to the polarization dependence of echo, a scheme for continuous measurement of polarization patterns indoors has been devised. A small target formed by configurations of wires or simple figures traced on paper with silver paint is rotated about the beam axis of a small horn. A suitable absorbing sheet is placed beyond the target, so that only the return from the target under consideration is measured. The conventional

magic T arrangement is used to separate incoming and outgoing signals. With this apparatus, to be more fully described in a later Report, the variation in echo with changing direction of linear polarization may be measured for representative targets. The entire apparatus operates indoors under controlled atmospheric conditions. Figs. 3 to 8 illustrate the type of variation that is obtained from different targets. The vertical scale is proportional to voltage in each pattern; and 22 divisions of the horizontal scale correspond to 360° of rotation about the beam axis. Figs. 3 through 7 have axes of symmetry, since the targets used also possessed axes of symmetry in the plane of rotation. Fig. 8 is a more general type of target. Each of these patterns may be analyzed by the method outlined in the appendix to obtain the polarizations of zero return (with a four-fold ambiguity) and other polarization properties of the target under consideration.

As yet, no simple means is available for obtaining patterns such as 8
these from F-80 models supported in the usual manner. The transmitting and receiving horn may be rotated by increments and renulled and calibrated for each polarization, so that discrete points of the polarization pattern may be obtained. Such is the case illustrated earlier in this Report. However, experimental error is sufficiently great to necessitate many such measurements in order to secure a meaningful polarization pattern. A means of continuously varying antenna polarization would be very useful. This possibility will be further investigated.

D. CONCLUSIONS

The variation in return with direction of linear polarization is a 9
useful tool in the analysis of the polarization properties of a target, as well as in the direct classification of targets by the form of the pattern thereby obtained. The 1/20-scale model of the F-80 aircraft at 9000 mc shows considerable variation with direction of linear polarization in a range of aspects about the nose-on position. As yet a sufficient number of measurements have not been made to yield quantitative information on the average scattering matrix, nor the scattering matrix for a single aspect. A method of continuously varying direction of linear polarization would be of great value in model measurements. Such a system has been placed in operation indoors and representative polarization patterns obtained which agree with theory.

E. PROGRAM FOR NEXT INTERVAL

Measurement and analysis of the polarization dependence of 9000 mc 10

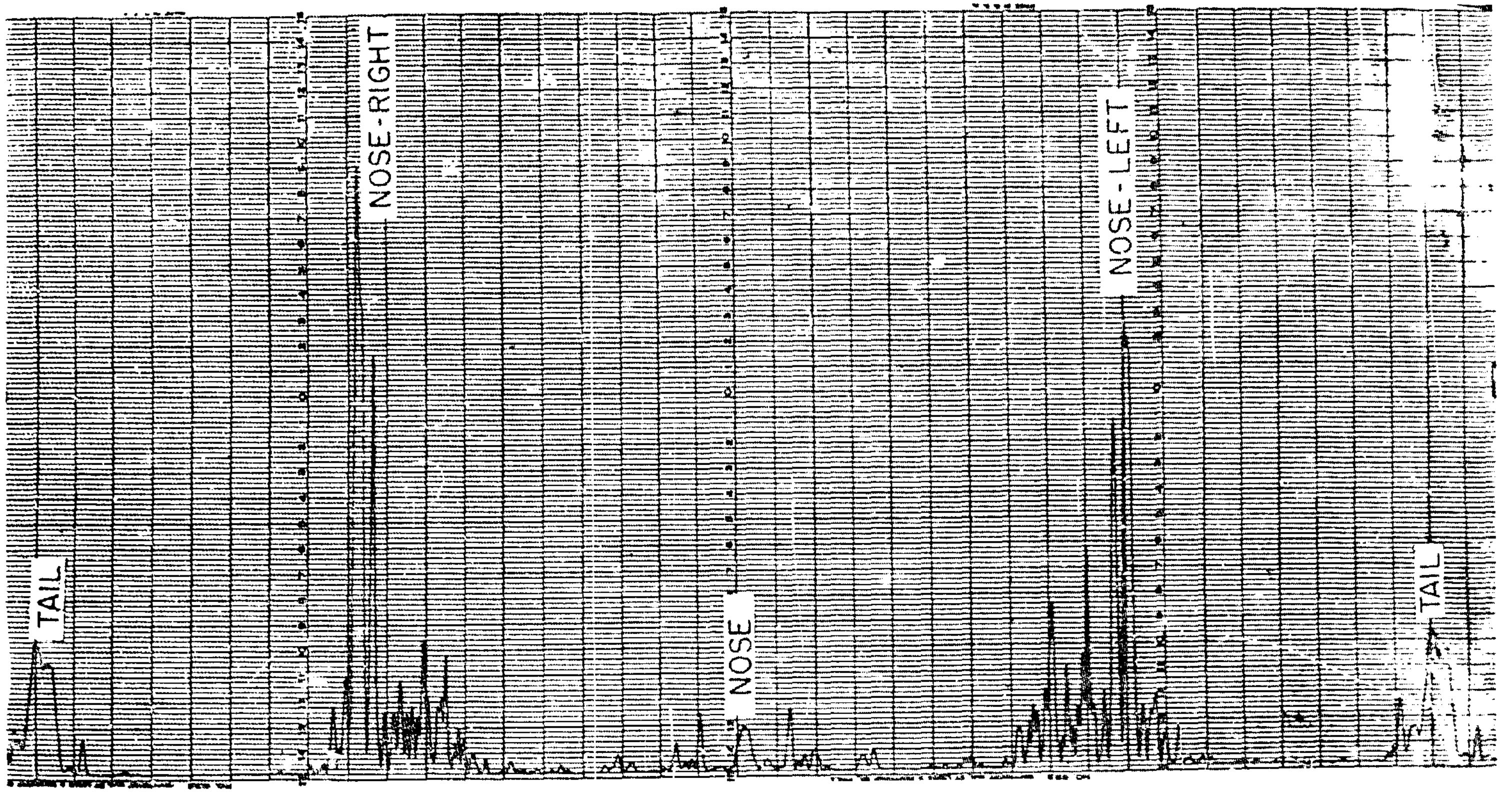


Fig. 1. Echo area vs aspect, 1/10-scale F-80 aircraft; transmitter and receiver horizontally polarized.

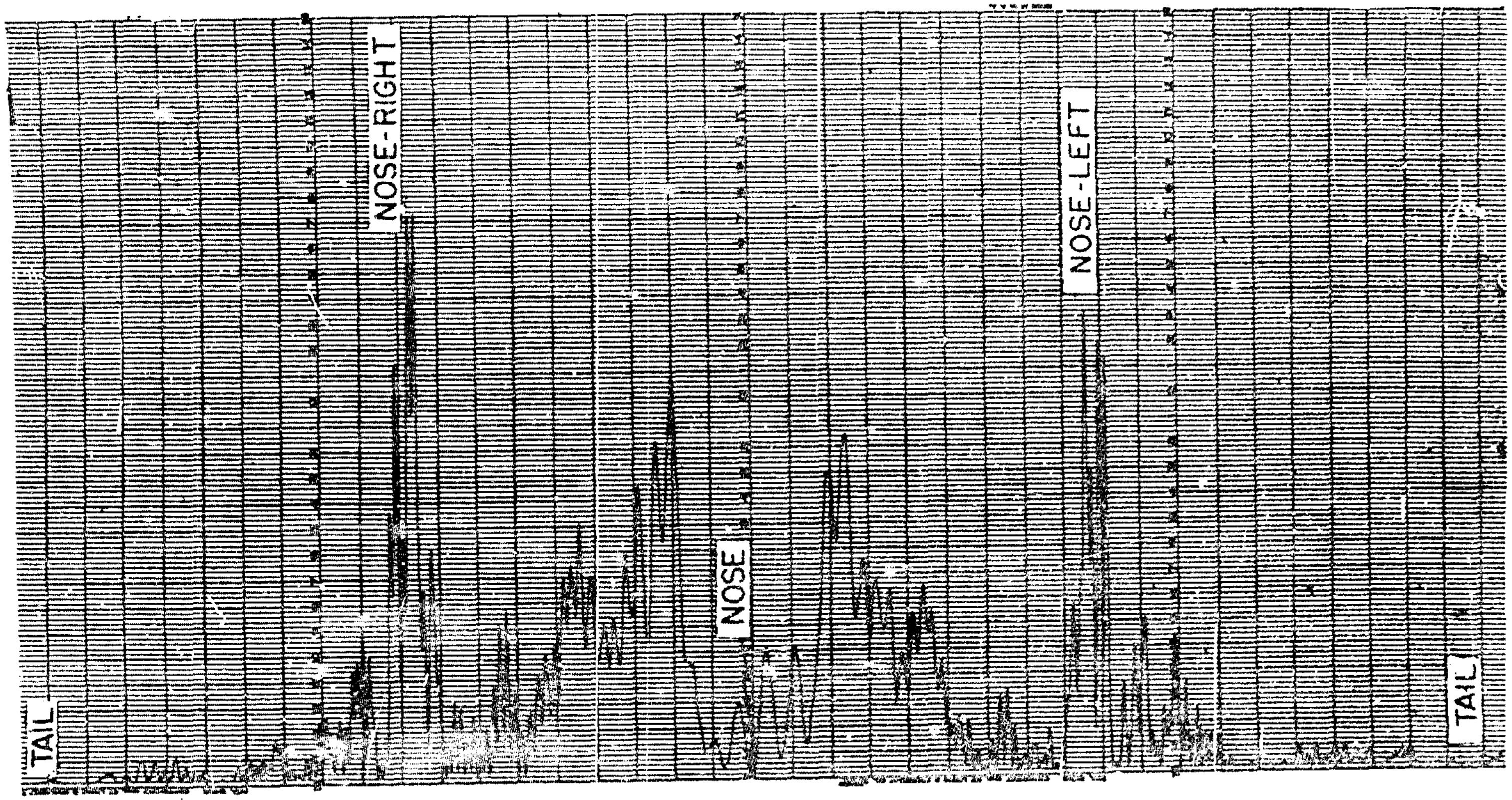


Fig. 2. Echo area vs aspect, 1/10-scale F-86 aircraft; transmitter horizontally polarized and receiver vertically polarized.

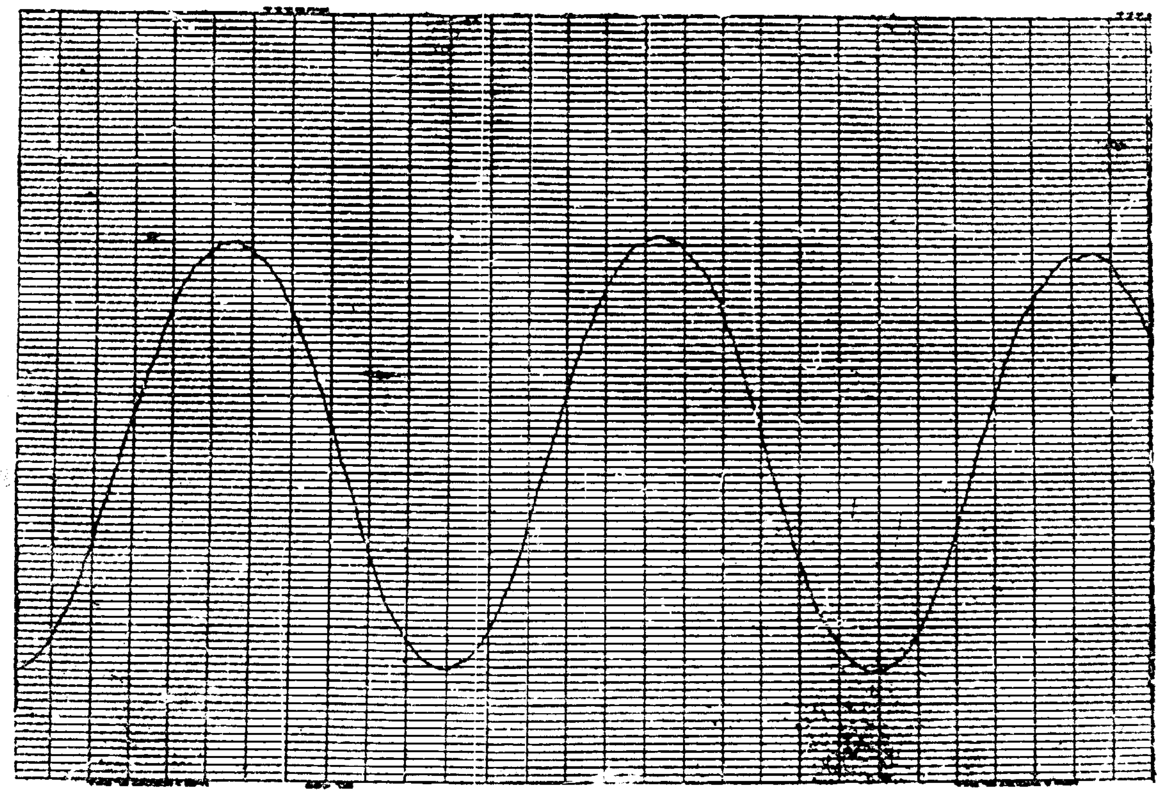


Fig. 3. Variation in echo signal with direction of linear polarization.

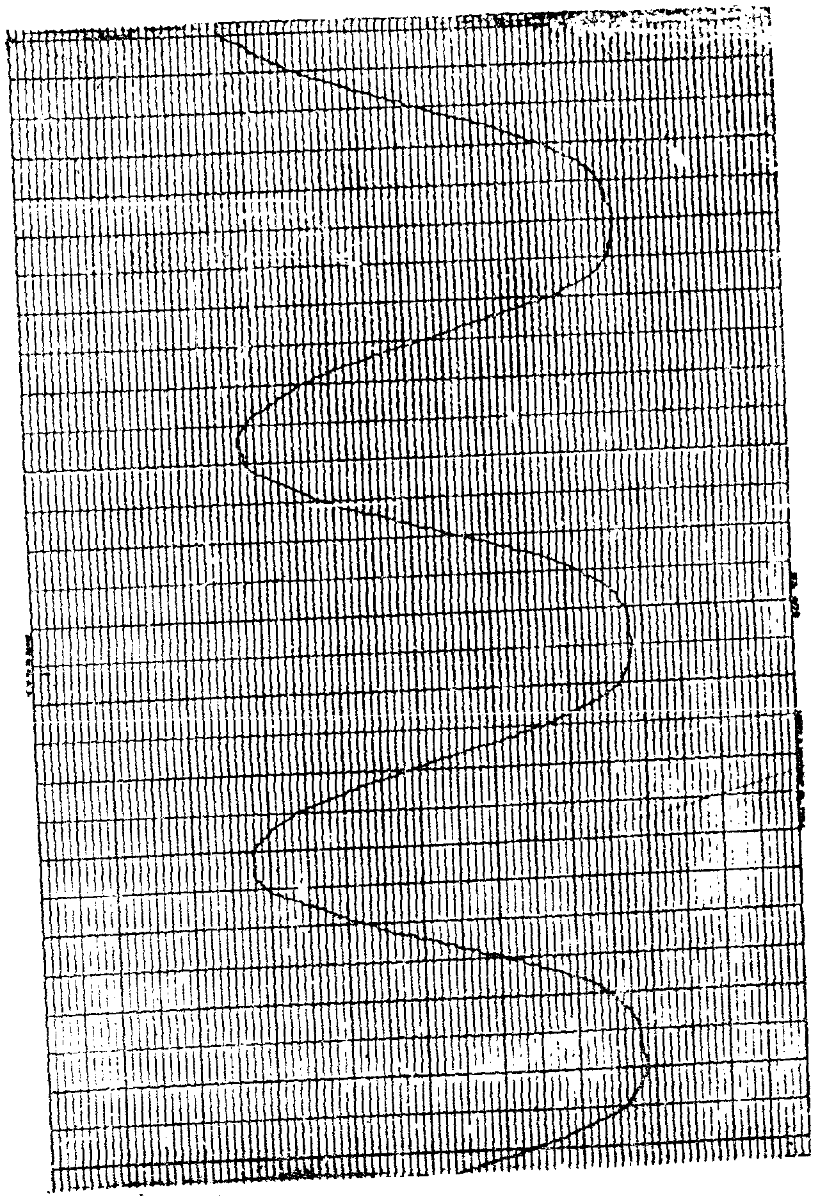


Fig. 4. Variation in echo signal with direction of linear polarization.

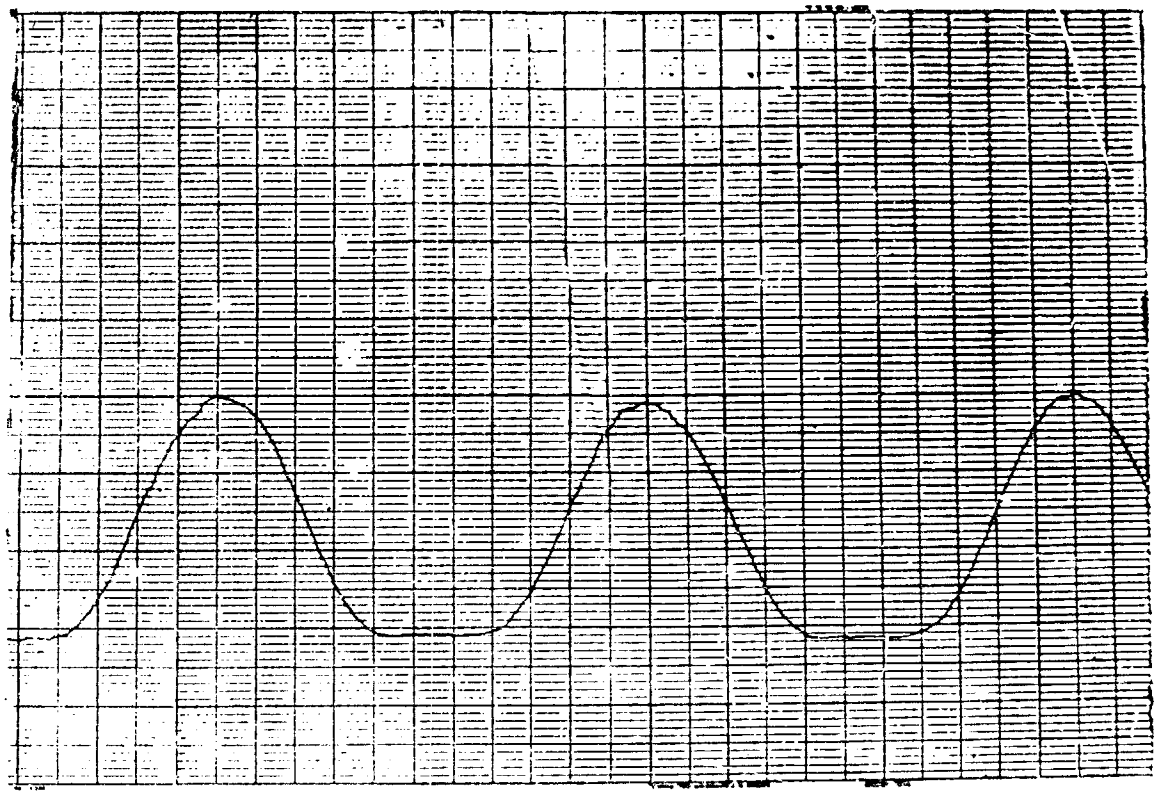


Fig. 5. Variation in echo signal with direction of linear polarization.

Fig. 6. Variation in echo signal with direction of linear polarization.

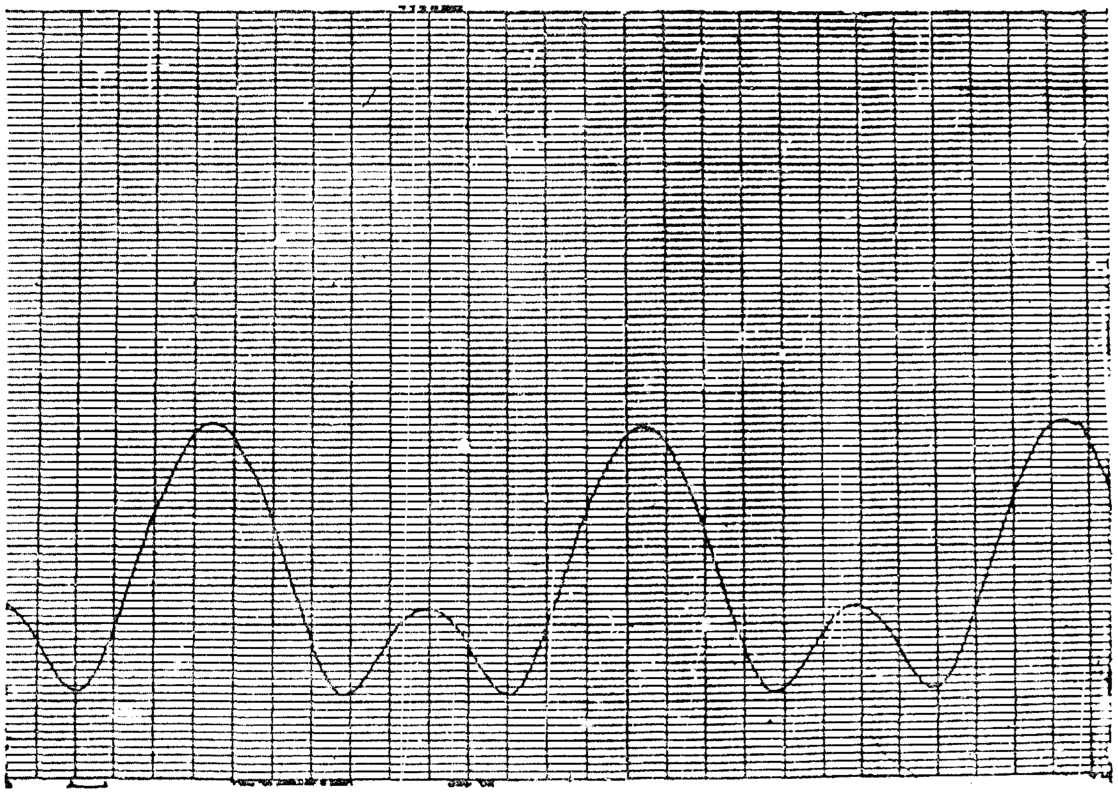


Fig. 7. Variation in echo signal with direction of linear polarization.

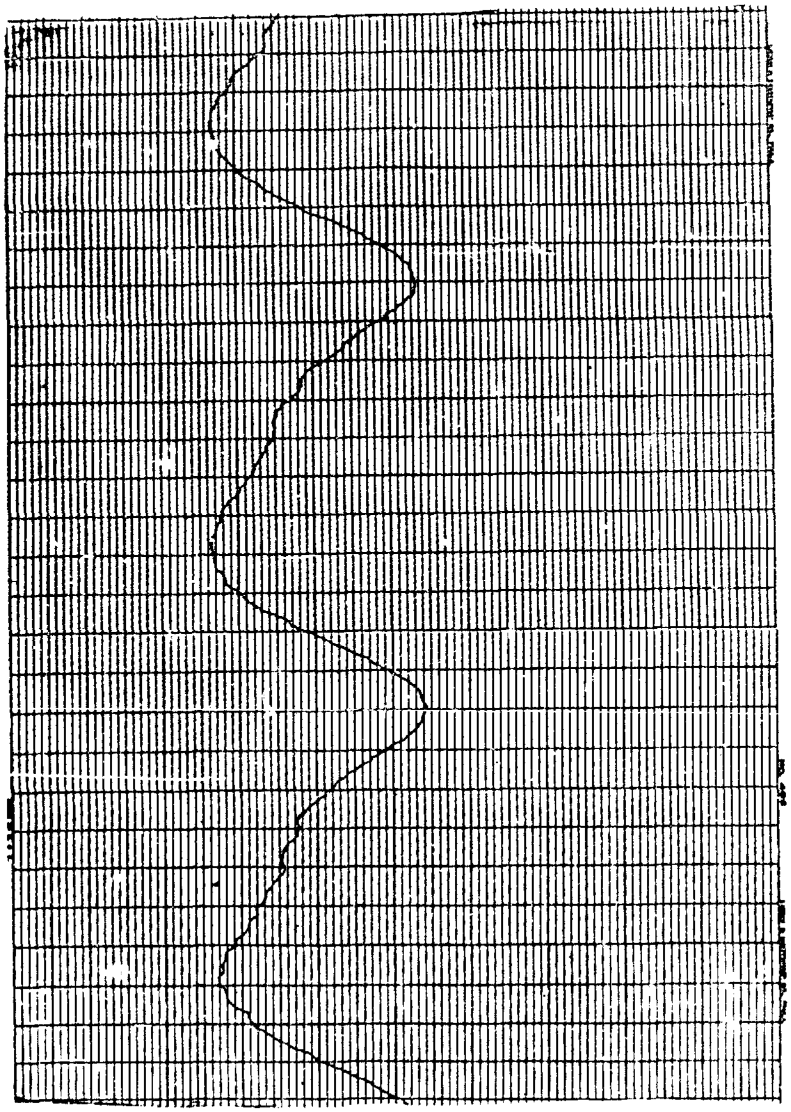


Fig. 8. Variation in echo signal with direction of linear polarization.

return from the 1/20-, 1/15-, and 1/10-scale F-80 aircraft at several aspects, and a range of aspects about the nose.

Investigation of means of continuously varying antenna polarization. 11

Theoretical and experimental investigation of average polarization properties of rainfall. 12

Experimental investigation of the "high spots" of target responsible for major lobes in return patterns. 13

F. APPENDIX

In order to apply the theory of the scattering matrix[2] to a specific radar target, the five independent quantities describing the polarization characteristics of the target must be measured. If separate transmitting and receiving antennas of continuously variable polarization were used, the echo area for any polarization could be determined directly, as well as the polarization transforming properties of the target. In practice, however, continuously variable polarization is most difficult to obtain. Conventional echo measuring systems use the same linear polarization for transmitting and receiving, and measure only the magnitude of the echo for a given choice of linear polarization. The question naturally arises as to how much information about the target polarization characteristics may be determined by the use of such a system, and what modifications and additional measurements are necessary to completely determine the five independent parameters of target reflection. Use of the polarization sphere furnishes the answer in a simple and elegant manner. 14

Referring to Fig. 9, a representative radar target with polarizations of zero return 0_1 and 0_2 is under study, using a linearly polarized echo measuring system with a common transmitting and receiving antenna. The point representing antenna polarization P varies around the equatorial circle $0P0'$, and the measured echo area varies according to the square of the product $0_1P \times 0_2P$; the factor of proportionality is the effective echo area.[2] From an analysis of this varying echo area, the effective echo area may be determined and the polarizations of zero return fixed with a four-fold ambiguity. The ambiguity arises from the fact that each of the four possible combinations 0_10_2, 0_30_4, 0_10_4, and 0_20_3 for the polarizations of zero return produce identical variation in echo area with changing direction of linear polarization. This ambiguity may be resolved by a measurement of echo area using an elliptically polarized antenna. The analysis of the linearly polarized measurements will be discussed first. 15

If a linearly polarized common transmitting and receiving antenna is rotated about the line of sight to the target, the signal voltage at the terminals of the receiving antenna will vary in a manner similar to that shown in Fig. 10. This is a plot of signal amplitude in a radial direction versus twice the angle that the direction of linear polarization makes with the vertical. From the polarization sphere analogue, this is the variation of a constant times the product $\overline{0_1P} \times \overline{0_2P}$ as P traverses the equatorial circle of Fig. 9. The multiplicative constant is the square root of the effective echo area of the target. Since the diameter of the 16

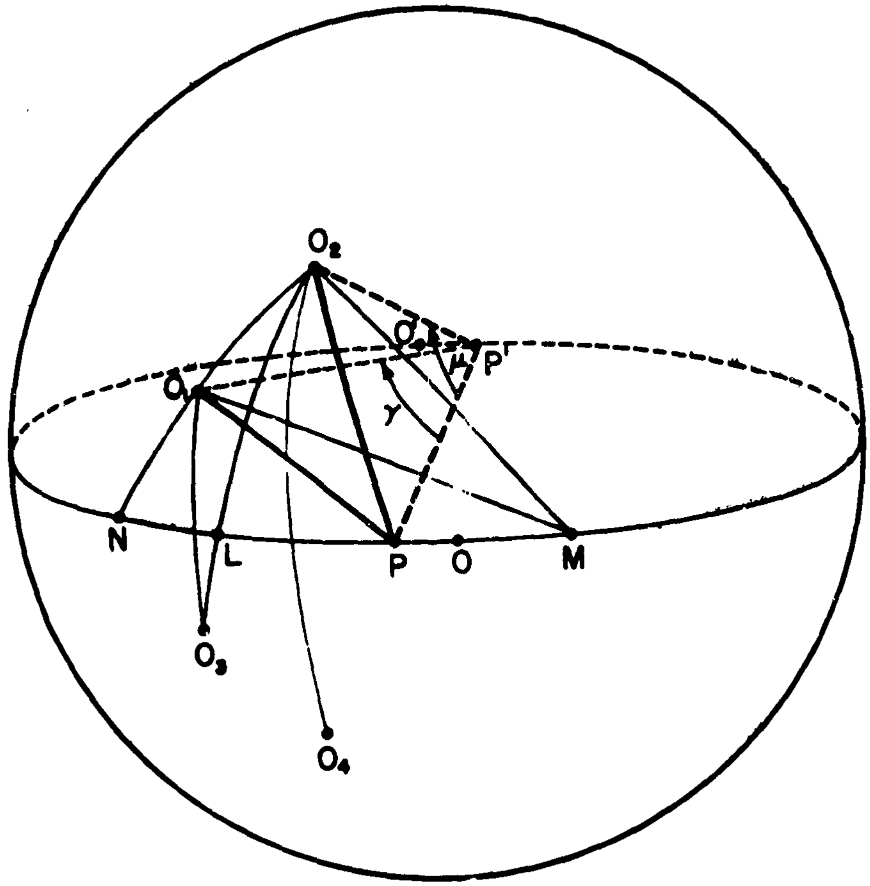


Fig. 9. Illustrating variation of echo with direction of linear polarization.

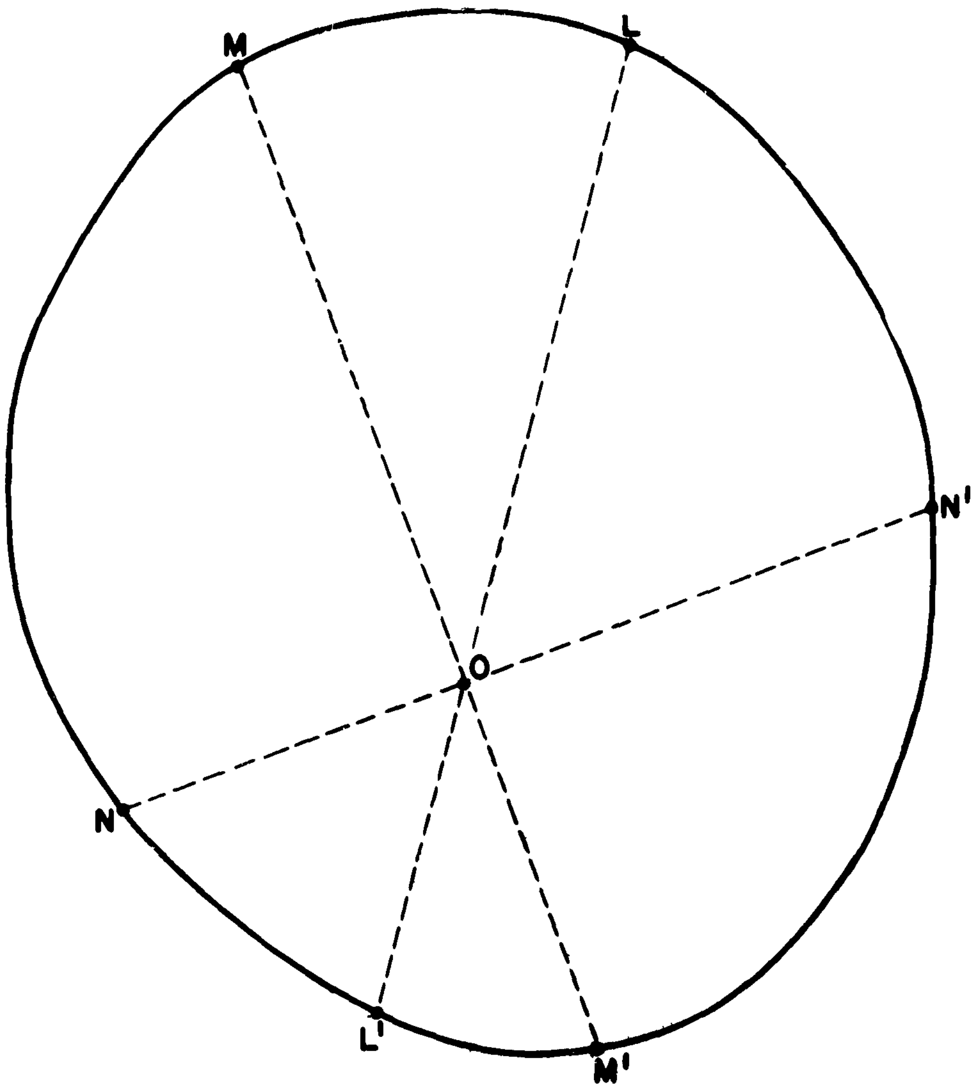


Fig. 10. Polar pattern of echo vs direction of linear polarization for representative target.

polarization sphere is unity, the chords $\overline{0_1P}$ and $\overline{0_2P}$ are given by

$$\overline{0_1P} = \sin\gamma$$
$$\overline{0_2P} = \sin\mu$$

where γ and μ vary as P traverses the equatorial circle. Also, if P' is the pole opposite to P,

$$\overline{0_1P'} = \cos\gamma$$
$$\overline{0_2P'} = \cos\mu \quad .$$

The sum of the products $\overline{0_1P} \times \overline{0_2P}$ and $\overline{0_1P'} \times \overline{0_2P'}$ is therefore given by

$$\overline{0_1P} \times \overline{0_2P} + \overline{0_1P'} \times \overline{0_2P'} = \cos(\gamma-\mu) \quad .$$

The maximum sum occurs when $\gamma = \mu$, and is equal to unity. This maximum occurs when P is equidistant from the polarizations of zero return, at point M of Fig. 9. Returning to Fig. 10, the maximum occurs at point M where the distance MM' is a maximum. Since this is a plot of the square root of the effective echo area times the product $\overline{0_1P} \times \overline{0_2P}$, the square root of the effective echo area is given directly by the distance MM'. The chord $\overline{0_1M} = \overline{0_2M}$ is given by

$$\overline{0_1M} = \overline{0_2M} = \sqrt{\frac{\overline{0M}}{\overline{MM'}}} \quad .$$

The effective echo area of the target is now determined, and the polarizations of zero return must lie on the circle $0_10_20_30_4$, defined by the constant chord length 0_1M. To further fix the points corresponding to the polarizations of zero return, note that the arc $\widehat{0_10_2}$ is given by

$$\cos(\widehat{0_10_2}) = \frac{NN'}{MM'}$$

where NN' is the minimum value of the distance shown in Fig. 10. The arc length $\widehat{0_20_3}$ is given by

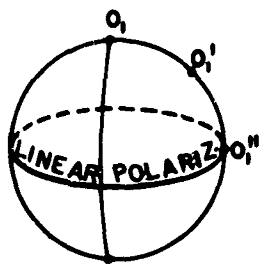
$$\cos(\widehat{0_20_3}) = \frac{LL'}{MM'}$$

where LL' is the maximum value of the difference 0L - 0L' shown in Fig. 10. The four points 0_1, 0_2, 0_3, and 0_4 are the vertices of the trapezoid $0_10_20_30_4$ with known sides 0_10_2 and 0_30_4 and diagonals 0_10_4 and 0_20_3 inscribed in the circle $0_10_20_3$, with parallel sides perpendicular to a fixed diameter. This completely determines the locations of all four points, and is the maximum amount of information concerning the polarizations of zero return which may be obtained from the data of

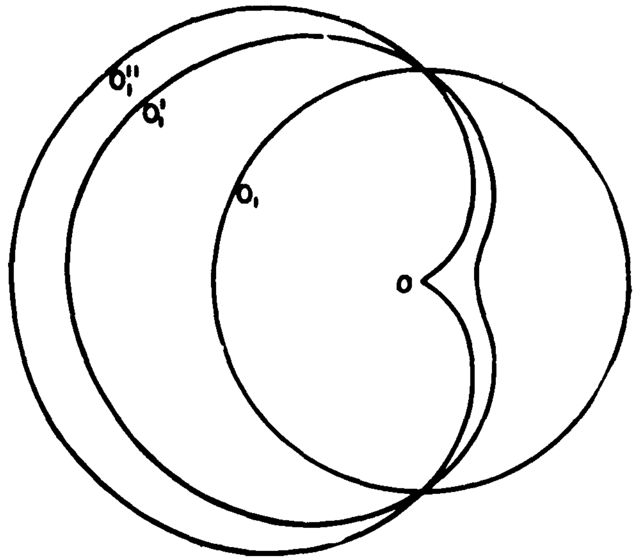
Fig. 10. A further measurement of the signal return, using a common elliptically polarized transmitting and receiving antenna, must be made to determine which of the four possible combinations of the points 0_1, 0_2, 0_3, and 0_4 is the correct one for the target under study. This measurement need not be precise, since only one of four possible choices must be selected.

Since the data obtainable with linearly polarized echo measuring systems may be analyzed to obtain almost all of the parameters of the target, patterns such as shown in Fig. 11 for several simple classes of target are of interest. Fig 11(a) shows the variation in received voltage with direction of linear polarization for several representative linear targets. In each case the polar angle corresponds to twice the angle between the vertical and the direction of linear polarization. Note that the distance MM′ is a constant on the patterns obtained from such a target. Fig. 11(b) shows the variation obtained fron an isotropic target. Note that for such a target the distance 0L - 0L′ is a constant over the entire pattern. From these considerations it is seen that a target may be classed as linear, isotropic, or general from data obtained using a linearly polarized measuring system. 17

Other systems for measuring the polarization characteristics of a target may be readily analyzed by the use of the polarization sphere concept. The problem of determining the polarizations of zero return and the effective echo area may thus be reduced to a geometrical one, in which the information content of each measurement may be readily visualized. A discrete set of measurements may be made, rather than the continuous data of Fig. 10, but the derivation of the target-echoing parameters is more complicated. In general, since the scattering matrix contains five independent variables, three of which are positive and two of which are signed quantities (three amplitudes and two relative phases), five independent measurements of the magnitude of the return using different polarizations plus two sign-determining measurements must be made. In all, therefore, seven amplitude measurements are needed to completely determine the target polarization characteristics. 18

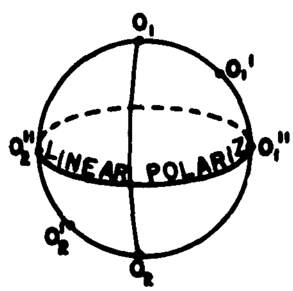


Polarization sphere showing polarizations of zero return for three targets.

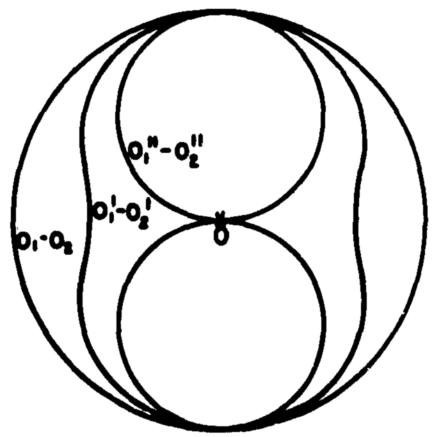


Patterns associated with targets.

a. Linear targets.



Polarization sphere showing polarizations of zero return for three targets.



Patterns associated with targets.

b. Isotropic targets.

Fig. 11. Polarization patterns associated with simple targets.

G. BIBLIOGRAPHY

1. Project Report 389-10, 16 September 1951, Antenna Laboratory, The Ohio State University Research Foundation; prepared under Contract AF 28(099)-90 with Rome Air Development Center, Rome, New York. 19

2. Project Report 389-4, 16 June 1950, Antenna Laboratory, The Ohio State University Research Foundation; prepared under Contract AF 28(099)-90 with Rome Air Development Center, Rome, New York.

H. IDENTIFICATION OF TECHNICIANS

MAN HOURS WORKED

	August	September	October	November	Total
Alvin F. Buttler Technician	184	152	184	168	688
Robert A. Fouty Assistant to the Supervisor	23	19	23	21	86
Everett L. Huey Design Draftsman	--	--	--	84	84
Edward M. Kennaugh Project Engineer	184	152	184	168	688
Jeanne C. McCoy Clerk-Typist	23	--	46	42	111
Paul Morando Research Associate	184	152	--	--	336
Dorothy McGinty Editorial Assistant	--	--	--	40	40
M. Frances Nichols Computor	92	76	92	84	344
Victor H. Rumsey Supervisor	23	19	23	21	86

William M Ryan Photographer	46	38	46	42	172
William J Schwartz Mechanic	23	19	23	21	86
Louis L Taylor Technician	184	152	184	168	688
HOURLY					
Jack Bendure Photographer	--	-	4	--	4
Thomas W Feick Clerk	84	53	--	--	137
Max Gordon Design Draftsman	--	--	24	--	24
Weldon Mortine Clerk	--		--	56	56
Arabella Powell Multilith Operator	4	--	---	8	12
George Walter Clerk	-	-	72	20	92
	1054	832	905	943	3734

NOTE: In submitting this report it is understood that all provisions of the contract between The Foundation and the Cooperator and pertaining to publicity of subject matter will be rigidly observed.

Investigator. Edward M. Kennard .... Date. 17 Jan 1952

Investigator. Louis L. Taylor .... Date. 17 Jan 1952

Investigator. Alvin Buttler by EMK .... Date. 17 Jan 1952

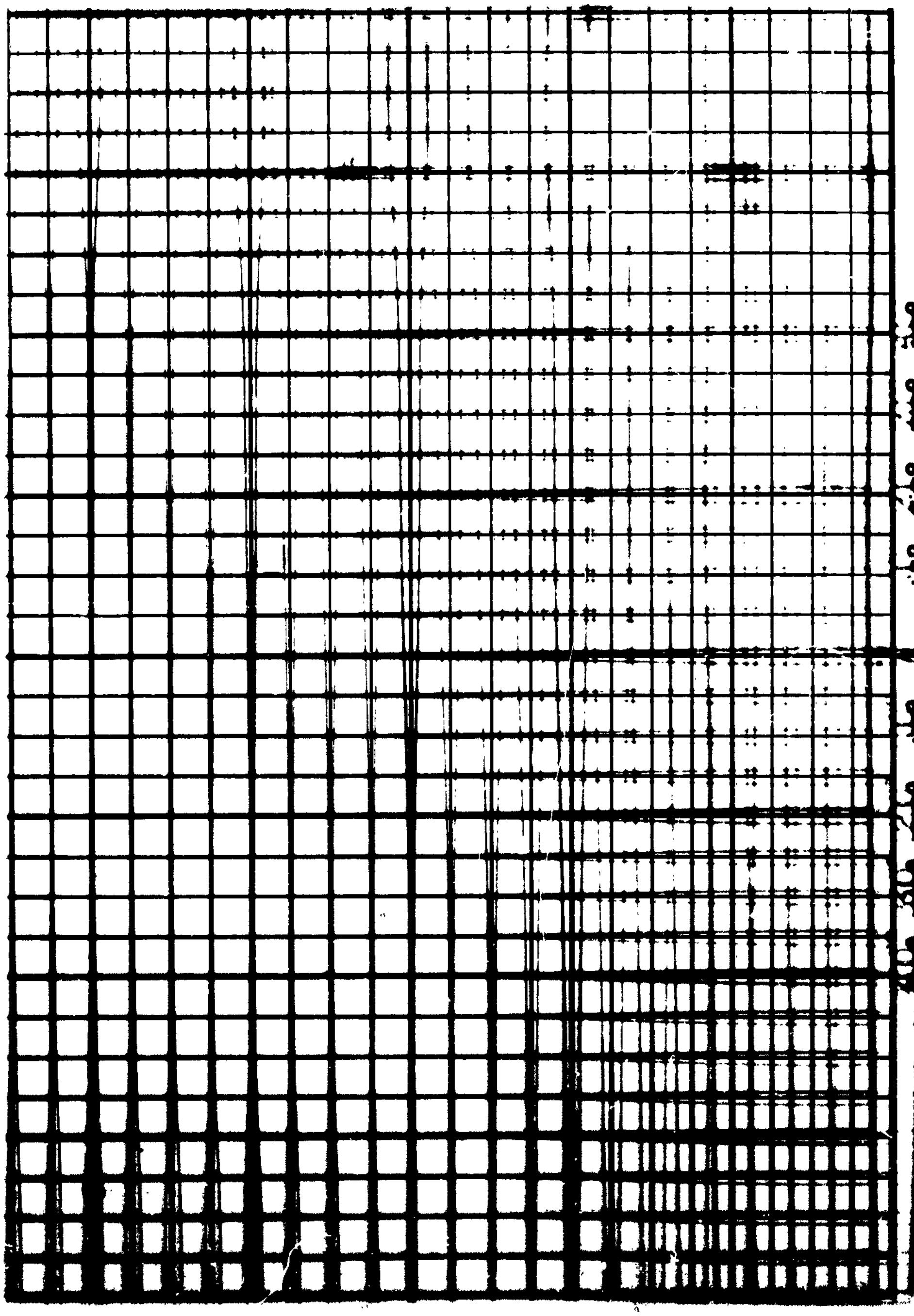
Investigator.. Date....................

Investigator.. Date....................

Supervisor. V. H. Rumsey by R. G. Fouty .... Date. 17 Jan 52

FOR THE OHIO STATE UNIVERSITY RESEARCH FOUNDATION

Acting Executive Director. Thomas E. Davis .... Date. 21 Jan 1952



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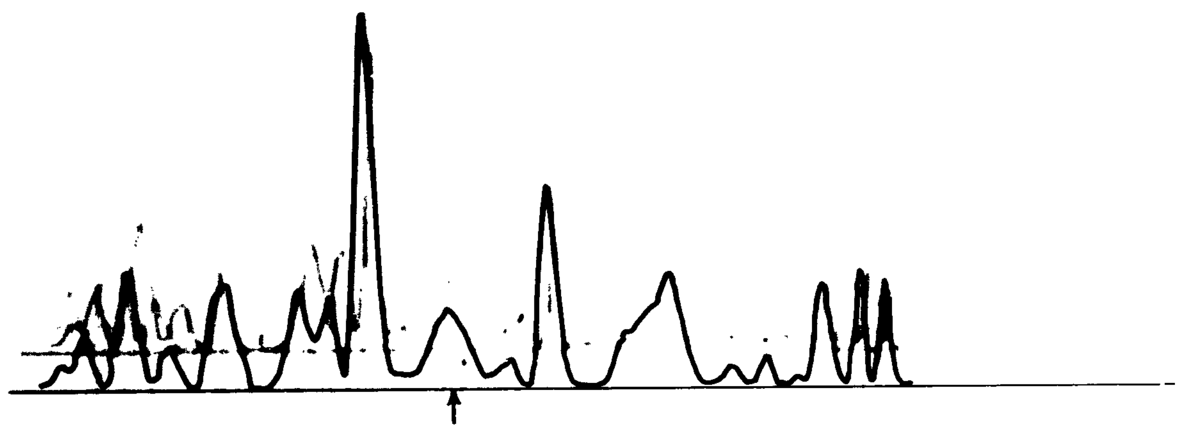

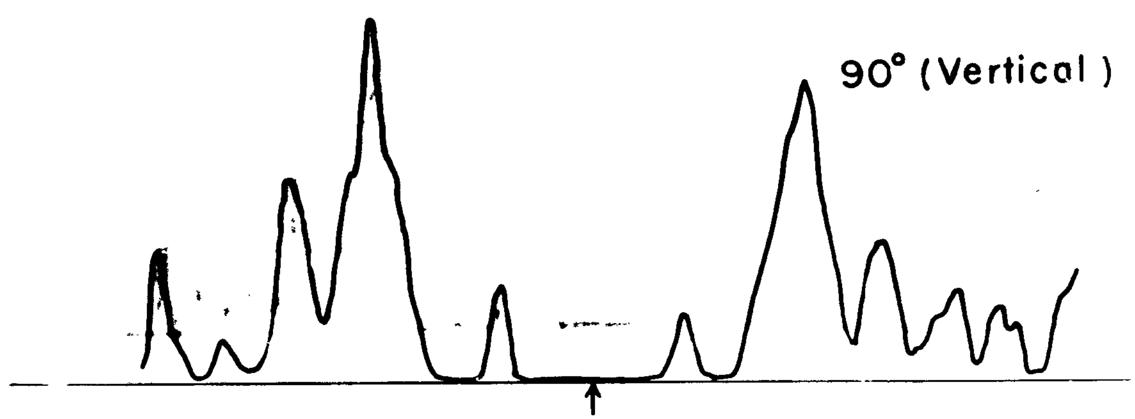
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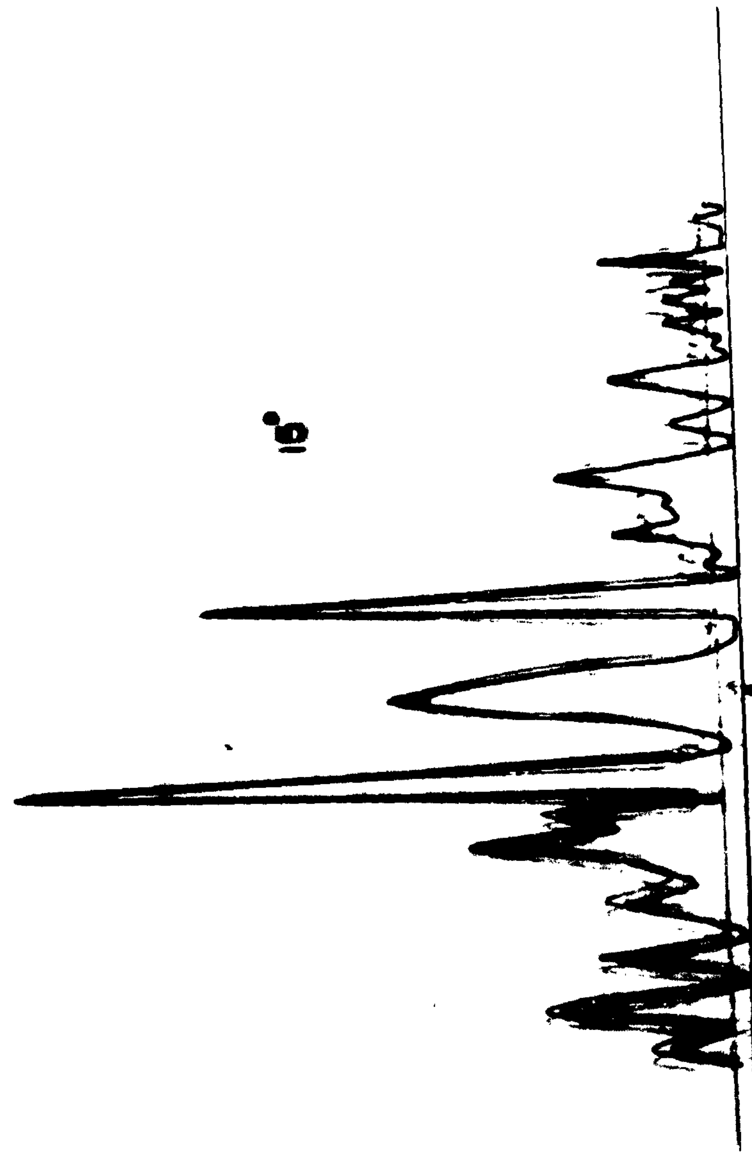

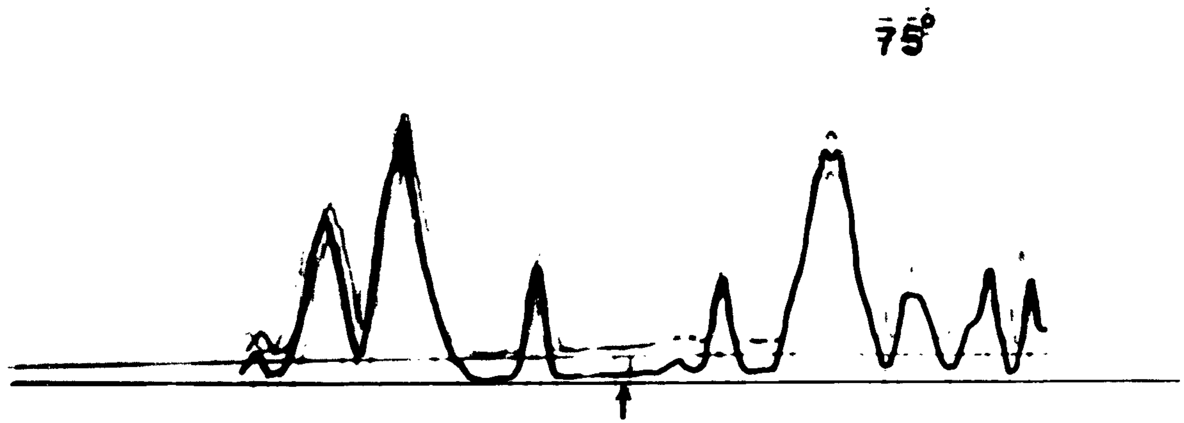
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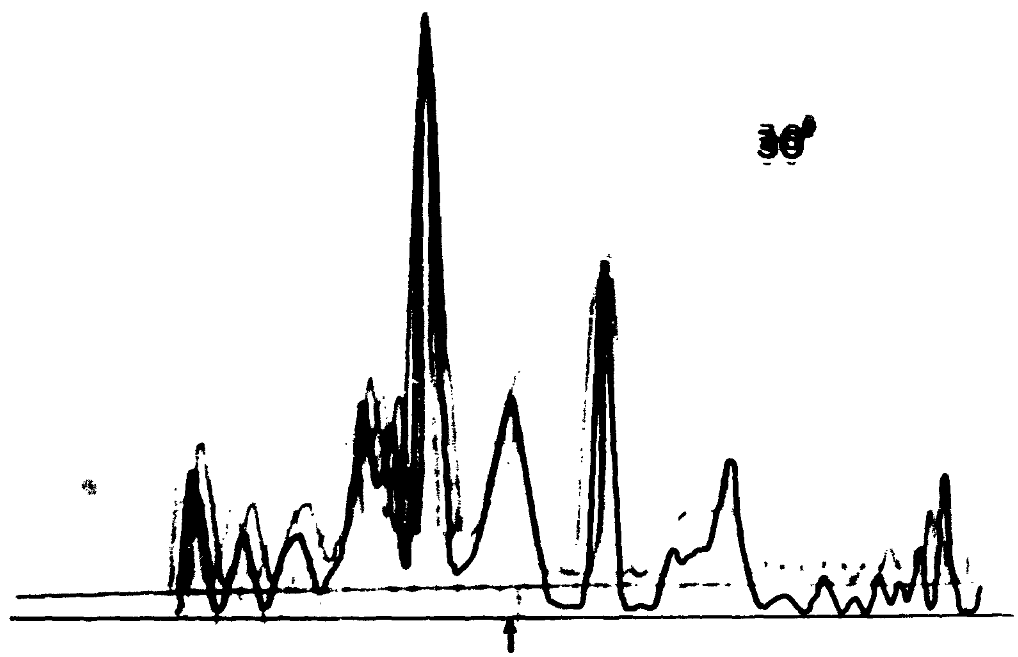
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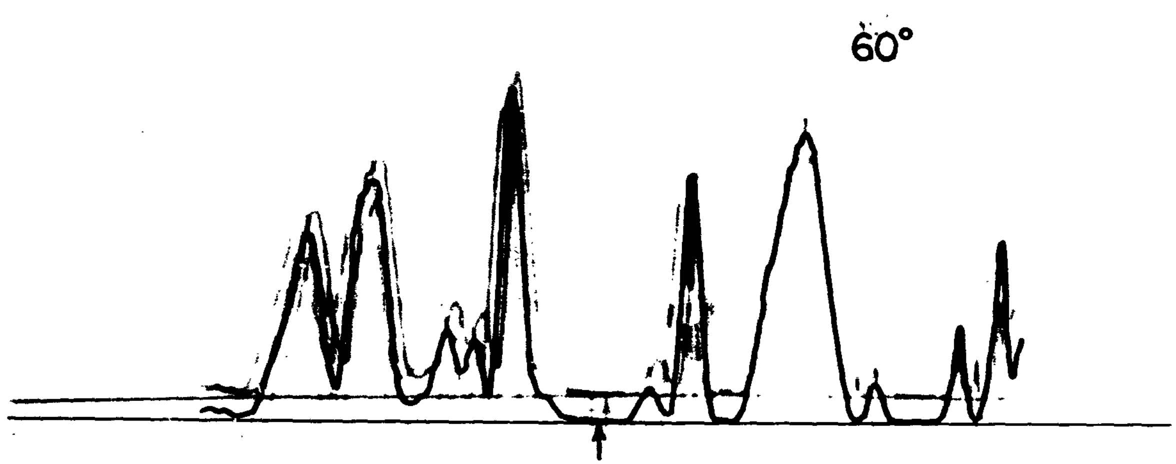
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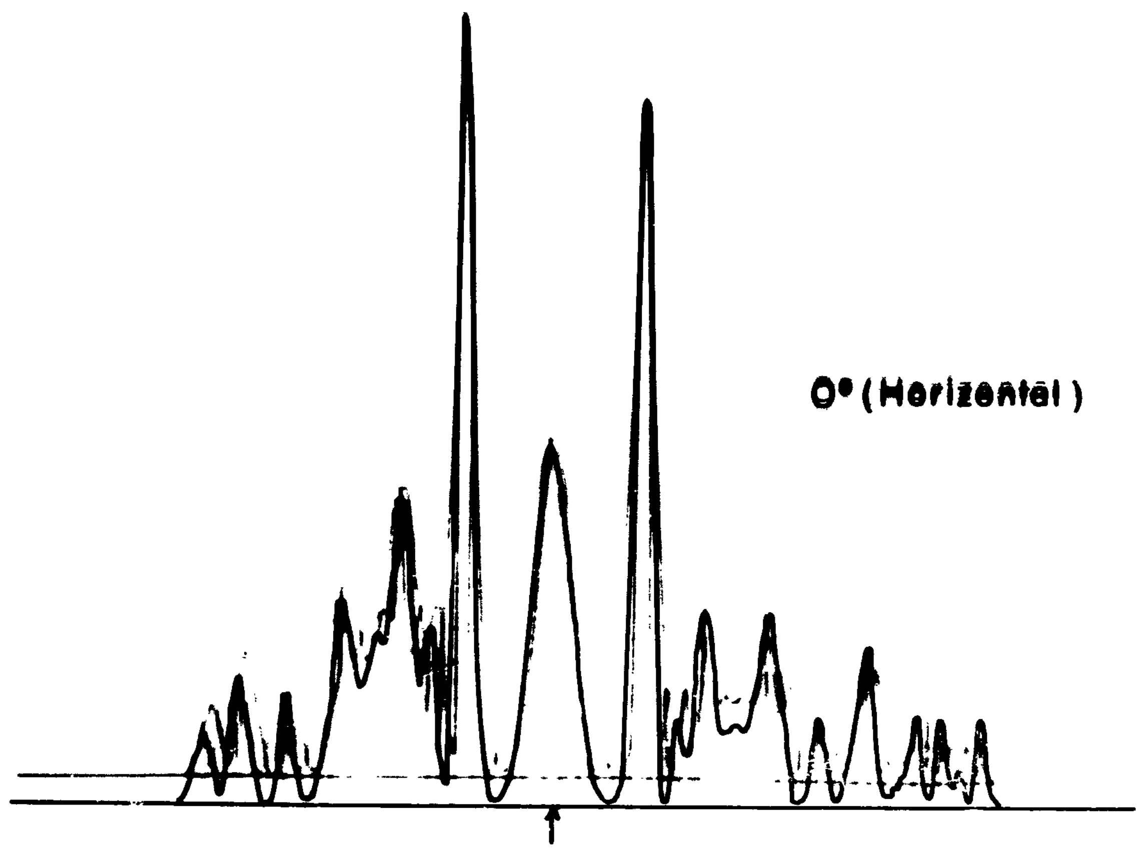
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