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U. S. NAVAL AIR DEVELOPMENT CENTER

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Report No. NADC-AE-6638 29 NOV 1966

CLUTTER MODEL FOR AEW RADAR DESIGN

PHASE REPORT
AIRTASK NO. A05533805/2021/000-00-000

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JOHNSVILLE
WARMINSTER, PA. 18974

Aero-Electronic Technology Department

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CLUTTER MODEL FOR AEW RADAR DESIGN

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This report provides a clutter model based on currently available data, and is intended to be used in the design and evaluation of AEW radar techniques. It presents expected values of clutter amplitude, σ_o, as related to antenna depression angle, radio frequency, and polarization of the transmitting and receiving antennas. It also indicates typical doppler spectra.

Reported by: J. A. di Toro
J. diToro
Radar Division

Approved by: M. J. Madigan
M. J. Madigan, Superintendent
Radar Division

D W Mackesmain

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SUMMARY

INTRODUCTION

This report defines a radar clutter model for use in the design and performance analysis of AEW radar systems. The work has been performed under WEPTASK No. RAV08J006/2021/000-00-000.

Examination of the radar clutter environment information listed under references (a) through (i) shows that a great deal of data has been gathered for the solution of particular problems. In the past some attempts have been made to select portions of this data and compile them in a manner that would be useful for studies of a more general nature. However, the conclusions drawn have been dependent upon the data selection procedure, and have not always been reliable, or in a form suitable for use as a clutter model for AEW radar with a land-sea capability. The Naval Research Laboratory (NRL) is currently engaged in an extensive controlled data gathering and analysis program. When this program is completed, the results should form a comprehensive treatment on the subject. Until sufficient data from the NRL program is available, it is necessary to attempt to derive tentative clutter characteristics for immediate use using the best data currently available.

RESULTS AND CONCLUSIONS

A set of curves has been derived showing the relationship of clutter amplitude versus antenna depression angle (figure 1) and radio frequency (figure 5). Some indication is given of the dependence on transmitting and receiving polarizations and of the variations about the average value of the clutter amplitude. In addition, formulas and illustrative data are presented on the doppler spectrum of the clutter return.

Due to the ambiguities of the existing data, it is necessary when using this model to consider both upper and lower bounds for some of the parameters, examining system performance at each of the bounds. For example, the data currently available pertinent to the dependence of clutter return versus frequency is ambiguous, necessitating the consideration of bounds as shown in figure 5, rather than a single valued function.

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D I S C U S S I O N

AMPLITUDE OF RADAR RETURN

The amplitude, σ_0, (radar cross section/unit area of terrain) depends on grazing angle, transmitter wavelength, type of terrain, and polarization of incident and reflected waves. The average value of σ_0 varies with depression angle, α, in such a way that three fairly distinct regions exist: near grazing incidence, plateau, and near vertical incidence. Depression angle not grazing angle is the quantity actually measured. The boundaries between the regions change with wavelength, polarization, and surface conditions.

Variation of σ_0 With Depression Angle

Based on the uncertainties inherent in much of the available data a composite plot of average σ_0 versus depression angle is given as figure 1. This graph shows the upper and lower limits to be expected over the entire frequency range of P- to X-bands and is taken from measured values (see references (a) to (h)). These bounding values are to be used as the basic average σ_0 quantities for design evaluation.

The upper limits are to be used as the design criteria. Should a system design evaluation show ineffective performance against these upper limits, then an indication should be given of the amount of clutter σ_0 against which the system could operate, relative to the upper and lower chart limits.

Variation of σ_0 With Frequency

A dearth of data at low angles makes it difficult to give a definitive statement of how σ_0 varies with wavelength in the near grazing angle incidence and what the transitional angle to the plateau region is under all conditions.

In the plateau region, much more data has been accumulated. Examination of a group of plots, figure 2 (from reference (g)), showing σ_0 versus depression angle for different frequencies with similar terrains where possible, indicates existence of an indeterminate relationship between the two variables. However, some data has been accumulated by NRL in which wavelength dependence was measured over the same terrain at the same time with consistent calibrations. One limitation existed. All data were taken at one depression angle -8 degrees. The runs were made over the areas as indicated in figure 3 using four frequencies (P, 428 mHz; L, 1228 mHz; C, 4455 mHz; X, 8910 mHz), with

Pulsewidth	=	0.5 usec.
PRF	=	778 pps
IF Bandwidth	=	10 mHz
Range	=	19,000 yd

General parameters for each of the runs are given in table I. Tables II to VIII are listings of σ_0 at different percentiles expressed as the percentage of measurements in a given sample which exceeded the given value. The polarization combinations given are (HH), (HV), (VH), and (VV) where the first letter in each pair corresponds to the transmission polarization and the second letter, the received polarization. The subscript refers to the frequency band used. Figure 4 is a plot of the spread of σ_0 (50 percent values from tables II to VIII) for both VV and HH polarization versus frequency. Fairly good agreement with a λ^{-1} relationship exists for the VV polarization values while the HH values correspond to a relationship somewhere between λ^{-1} and λ^0.

Based on the overall evidence, σ_0 dependence on wavelength of λ^0 and λ^{-1} may be considered as the bounds. Evaluation of a design should include consideration of both limits. Figure 5 plots $\Delta\sigma_0$ as a function of radio frequency. Therefore, for evaluation at the upper limit, λ^0, figure 1 should be used as the amplitude of radar return over all frequencies from P- to X-band. For evaluation at the lower limit, λ^{-1}, figure 1 should be used as the amplitude at X-band with a reduction for lower frequencies by the amount of $\Delta\sigma_0$ shown in figure 5 corresponding to the λ^{-1} line.

Variation of σ_0 With Polarization

For homogeneous terrain, σ_0 is usually larger for vertical than for horizontal polarization and a difference of 10 to 15 db between the two is possible.

For nonhomogeneous terrain which includes most land areas, there is little dependence on polarization. NRL data indicates no polarization dependence within the limits of error for measurements of HH and VV. However, the VH and HV cross-polarized components were of the order of 8 db below the directly polarized signals.

Variations About the Average Value of σ_0

Plots of σ_0 can vary considerably about a median value as indicated from NRL data. Some of that data is included here as illustration (figures 10, 11, and 12). Two types of runs were made over areas given by figures 6 to 9; sweeping runs with the antenna scanning in azimuth at a

fixed elevation angle and fixed angle runs with the antenna fixed in both azimuth and elevation. Parameters for the sweeping runs were as follows:

	Date	Pulsewidth (usec)	PRF (pps)
Figure 6	8 Sep 1964	0.25	394
Figure 7	12 Sep 1964	0.25	778
Figure 8	13 Sep 1964	0.5	778
Figure 9	16 Sep 1964	1.0	394

The results for sweeping runs are plotted in figures 10 as a cumulative distribution. The ordinate is percentage of times a sample exceeded the cross section value. As is evident, σ_o can vary from the 50 percent value by 10 db or more.

The results for fixed angle runs are shown in figures 11 as amplitude distributions of 10 percent (upper curve), 50 percent (dotted curve), and 90 percent (lower curve) versus time. These were formed from sample sizes of 1000 pulses at a PRF of 788 pps. Figures 12 are similar plots of sea return. Examination of these shows that sizable differences can occur at short intervals of time.

DOPPLER FREQUENCY OF RADAR RETURN

The Doppler frequency of the energy returned from a clutter patch is dependent on the following two factors:

Internal Motion

There is no general theory for predicting this although a spectrum of Gaussian form is usually assumed. This is discussed in reference (i) which also presents experimental data. This form is generally accepted for design purposes.

External Effects

This includes Doppler shifts caused by such contributions as antenna scanning motion and platform motion. The Doppler spectrum (f) caused by platform motion is usually assumed to correspond to the shape of the pattern of the radar antenna used or:

$$f = \frac{2V}{\lambda} \cos (\psi + \theta)$$

where: V = ground velocity

ψ = angle between ground velocity and antenna boresight

θ = angle between antenna center and a specific clutter segment

There has been little quantitative data to indicate how closely experimental values corroborate the assumption made and over how large a time period (distance) the radar return must be measured to include the extremes in return from all portions of the antenna beam. The expected spectrum shape may or may not be obtained in a time period which is reasonable considering the operational use of the radar system. Consideration should be given to the general information obtained from current NRL data of figures 13 to 24.

This data, figures 13 to 24, presents a qualitative indication of the expected shape on a short time basis and on a composite average value basis. The plots are Doppler spectra of radar return from terrain on the eastern shore of Maryland (primarily flat farmland) at X- and C-band. Using the above expression for f, with $\theta = 0$, and the nominal ground speed of 325 ft/sec, the spectrum centered at X-band has a maximum value of 5882 Hz (approximately 4 times the PRF of 1463 pps used in the radar system in taking the measurements), and at C-band, 2943 (approximately two times the PRF). If the radar pulse is considered as having sampled the Doppler return, ambiguity results since the sampling rate is less than the spectrum center frequency. Representative Doppler spectra would appear at the centers given by $f_\eta = f_o \pm \eta f_r$ where f_r = PRF, and f_o = value of the maximum Doppler spectrum, or for X-band, f_η = 5882 Hz, 4419 Hz, 2956 Hz, 1493 Hz, 30 Hz, etc., and for C-band, f_η = 2943 Hz, 1480 Hz, 17 Hz, etc.

Ambiguities which might have been introduced were avoided by NRL by taking data with the antennas pointing off the ground track of the aircraft where the Doppler spectra were centered between 0 and 1/2 PRF.

An actual spectrum may vary from the sampled ones presented in figures 13 to 24 since the frequency depends on aircraft velocity and geometry. However, the relative shapes remain the same.

Figures 13 to 16 are plots showing comparison of the average spectrum obtained by combining 21 consecutive spectra (dotted lines), and the antenna power pattern converted to frequency abscissa (solid line). These averaged spectra show reasonable agreement with the predicted ones corresponding to the shape of the antenna pattern.

Figures 17 to 20 are graphs of power spectra averaged over 10 of the sample spectra. Each of the sample spectra represented 0.1 second of data, the individual plots represent 1 second of data each and 21 seconds of data in all

From observation of figures 17 to 20, the short time spectra are not representative of the antenna pattern shape. Therefore, from the standpoint of the time period over which the radar system will be processing the return, the assumption of an antenna shaped spectrum may or may not be accurate. If the time period over which a decision must be made (on presence or absence of a target) is very short (say < 1 second) an erroneous result may be obtained from the spikeness of the clutter return.

Figures 21 to 24 represent a composite spectrum giving the rms maximum and minimum value for each spectral line. These were obtained from the computed variance of the energy estimate for each frequency and plotted about the expected spectrum shape as a mean value. The interval defines an upper and lower limit between which 62.4 percent of the observed spectra fall.

R E F E R E N C E S

(a) Grant, C. R. and Yaplee, B. S., July 1957; Backscattering From Water and Land at Centimeter and Millimeter Wavelengths, Proc. IRE.

(b) Wolff, E. A., 29 Feb 1960; A Review of Theories and Measurements of Radar Ground Return, Electromagnetic Research Corporation, Washington, D. C. Report No. CRC-5198-2 (AD235972).

(c) Stanford Research Institute, Menlo Park, California, May 1960; An Investigation of the Direct Backscatter of High Frequency Radio Waves From Land, Sea Water and Ice Surfaces, Contract Nonr 2917(00) (ASTIA Catalogue No. AD278138).

(d) Ghose, S. C., Dr., Aug 1961; Radar Sea Clutter(U), Report No. DP1025, E. M. I. Electronics Ltd., Hayes, Middlesex, England, (Conf) (ASTIA Catalogue No. AD328919).

(e) MIT Lincoln Laboratory, 18 Jan 1965; Influence of the Earth's Surface on Radar, Technical Report 373.

(f) Georgia Institute of Technology, 15 July 1965; Wavelength Dependence of Sea Echo, Final Report, Project No. A-840, U. S. Naval Air Development Center Contract N62269-3019.

(g) Airborne Instruments Laboratory, Deer Park, Long Island, New York, Sep 1965; Clutter Data, Radar Systems Department, Report RTD-TR-65 under Contract No. AF33(615)-2329.

(h) NRL Data Obtained 12 Jan 1966.

(i) Skolnik, M. I., 1962; Introduction to Radar Systems, McGraw Hill Book Company, p. 146

TABLE I

MISCELLANEOUS INFORMATION ON RUNS REPORTED IN TABLES II TO VIII

Run	Depression Angle	Azimuth Angle	Antenna Scanning	Transmitted Polarization	Sample Size
1	8°	$60^{o}L \rightarrow 60^{o}R$	Yes 15°/sec	V and H	138,000
2	8°	$2^{o}R$	No	V and H	93,000
3	8°	$25^{o}R$	No	V only	187,000
4	8°	$20^{o}R$	No	H only	40,000
6	8°	$60^{o}L \rightarrow 60^{o}R$	Yes 15°/sec	V and H	104,000
7	8°	$5^{o}L$	No	V and H	94,000
10	8°	$25^{o}R$	No	V only	115,000

TABLE II

σ_o FOR DEPRESSION ANGLE OF 8 DEGREES WITH ANTENNA SCANNING IN AZIMUTH

2 July 1965 - Run 1

	σ_o (DB)					
Component	90%	75%	50%	25%	10%	0%
VV_X	-33.5	-30	-25.5	-22.5	-20	-14
VV_C	-37	-32	-27.5	-24.5	-22	-15.5
VV_L	-44.5	-39	-33.5	-30	-26.5	-18.5
VV_P	-50.5	-44.5	-39	-35	-32	-22.5
HH_X	-34	-30	-25.5	-22	-19.5	-14.5
HH_C	-39	-35	-30	-26	-23	-15.5
HH_L	-41.5	-38.5	-33	-30	-26	-14
HH_P	-43.5	-38.5	-34	-30	-26.5	-14

TABLE III

σ_o FOR DEPRESSION ANGLE OF 8 DEGREES AND AZIMUTH ANGLE OF 2 DEGREES

2 July 1965 - Run 2

σ_o (DB)

Component	90%	75%	50%	25%	10%	0%
VV_X	-34.5	-31	-26	-23.5	-21	-14.5
VV_C	-36.5	-31.5	-26.5	-24	-21.5	-15.5
VV_L	-42	-36.5	-32.5	-27	-23	-13
VV_P	-50.5	-44	-39	-35	-30.5	-21.5
HH_X	-33.5	-29.5	-25.5	-22.5	-19.5	-12.5
HH_C	-39	-36	-30.5	-27	-24	-17
HH_L	-41	-37	-31.5	-27	-22	- 9
HH_P	-37	-33	-29	-25	-22	-16.5

TABLE IV

σ_o FOR DEPRESSION ANGLE OF 8 DEGREES AND AZIMUTH ANGLE OF 25 DEGREES

2 July 1965 - Run 3

σ_o (DB)

Component	90%	75%	50%	25%	10%	0%
VV_X	-34	-30.5	-25.5	-23	-20	-14
VV_C	-37.5	-32	-27.5	-24.5	-21.5	-15.5
VV_L	-43	-37.5	-33	-29	-26.5	-18.5
VV_P	-	-50.5	-43	-38	-34	-24
HH_X						
HH_C	H POLARIZATION NOT TRANSMITTED					
HH_L						
HH_P						
VH_X	-39.5	-36.5	-33	-29	-26.5	-21
VH_C	-	-39	-37.5	-33	-30	-24
VH_L	-	-42.5	-41.5	-39.5	-37	-29.5
VH_P	-	-	-51	-47	-41	-32.5

TABLE V

σ_o FOR DEPRESSION ANGLE OF 8 DEGREES AND AZIMUTH ANGLE OF 20 DEGREES

2 July 1965 - Run 4

σ_o (DB)

Component	90%	75%	50%	25%	10%	0%
VV_X						
VV_C			V POLARIZATION NOT TRANSMITTED			
VV_L						
VV_P						
HH_X	-35.5	-31	-27	-24	-21.5	-14
HH_C	-39	-37	-31.5	-28	-24.5	-15.5
HH_L	-42	-40	-35.5	-31.5	-28.5	-15.5
HH_P	-44	-39	-32	-27.5	-24.5	- 7.5
HV_X	-42	-38	-34	-31.5	-29	-22.5
HV_C	-44	-41.5	-37	-33.5	-30.5	-23
HV_L	-48.5	-46	-42.5	-38.5	-35.5	-26.5
HV_P	-	-	-51	-26.5	-43	-32

TABLE VI

σ_o FOR DEPRESSION ANGLE OF 8 DEGREES WITH ANTENNA SCANNING IN AZIMUTH

2 July 1965 - Run 6

σ_o (DB)

Component	90%	75%	50%	25%	10%	0%
VV_X	-34.5	-31	-26	-23	-20	-11.5
VV_C	-37	-31.5	-27	-24	-20.5	-10
VV_L	-41	-36.5	-32.5	-27.5	-24.5	-15
VV_P	-44	-39.5	-34.5	-30	-27	-21
HH_X	-33.5	-29	-24.5	-21	-16.5	- 3.5
HH_C	-38.5	-34.5	-27.5	-23	-18.5	- 3.5
HH_L	-42	-38.5	-34	-29.5	-25.5	-12.5
HH_P	-47	-41	-36	-32	-27.5	-18.5

TABLE VII

σ_o FOR DEPRESSION ANGLE OF 8 DEGREES AND AZIMUTH ANGLE OF 5 DEGREES

2 July 1965 - Run 7

σ_o (DB)

Component	90%	75%	50%	25%	10%	0%
VV_X	-36	-32	-28.5	-25	-22	-14.5
VV_C	-37	-32.5	-28	-24.5	-22	-15.5
VV_L	-40.5	-36	-32	-27.5	-26	-18.5
VV_P	-45.5	-41.5	-37.5	-34	-31.5	-23
HH_X	-35	-31	-27	-24	-21.5	-15.5
HH_C	-39	-36.5	-30	-27	-24	-17
HH_L	-41.5	-37	-33	-28.5	-26	-18.5
HH_P	-42	-38	-34	-31	-28	-22.5

TABLE VIII

σ_o FOR DEPRESSION ANGLE OF 8 DEGREES AND AZIMUTH ANGLE OF 25 DEGREES

2 July 1965 - Run 10

σ_o (DB)

Component	90%	75%	50%	25%	10%	0%
VV_X	-38	-34	-29	-25	-22.5	-16.5
VV_C	-41	-35.5	-30.5	-25.5	-23.5	-17
VV_L	-40.5	-36.5	-32.5	-27.5	-26	-18.5
VV_P	-44.5	-39	-34.5	-30.5	-26.5	-21
HH_X						
HH_C	H POLARIZATION NOT TRANSMITTED					
HH_L						
HH_P						
VH_X	-40	-38.5	-35	-30.5	-27.5	-21
VH_C	-	-39	-38	-33.5	-30	-25.5
VH_L	-42.5	-42	-40.5	-36.5	-34	-25
VH_P	-	-53	-47.5	-42	-39	-32.5

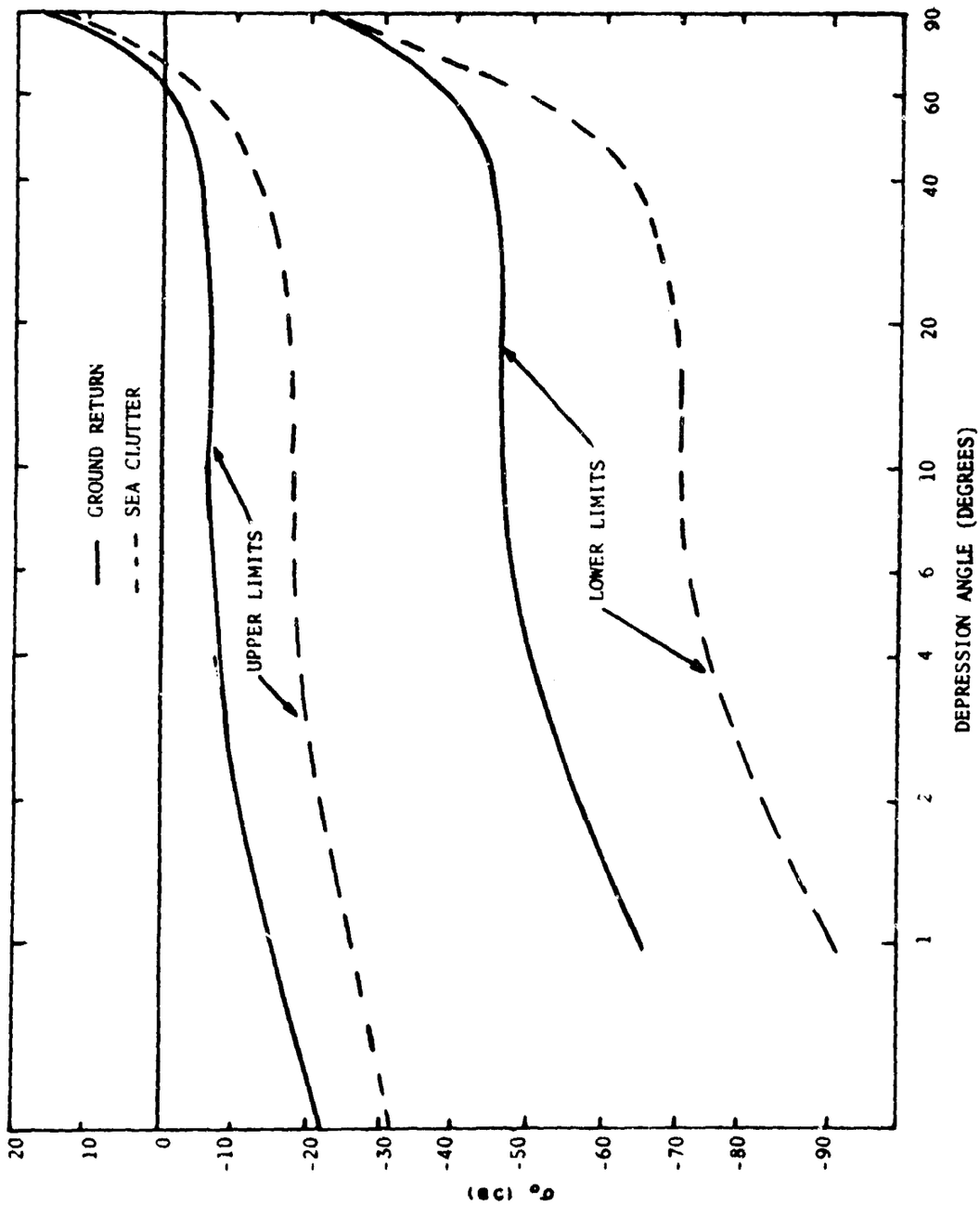

FIGURE 1 - Limits of Average σ_o

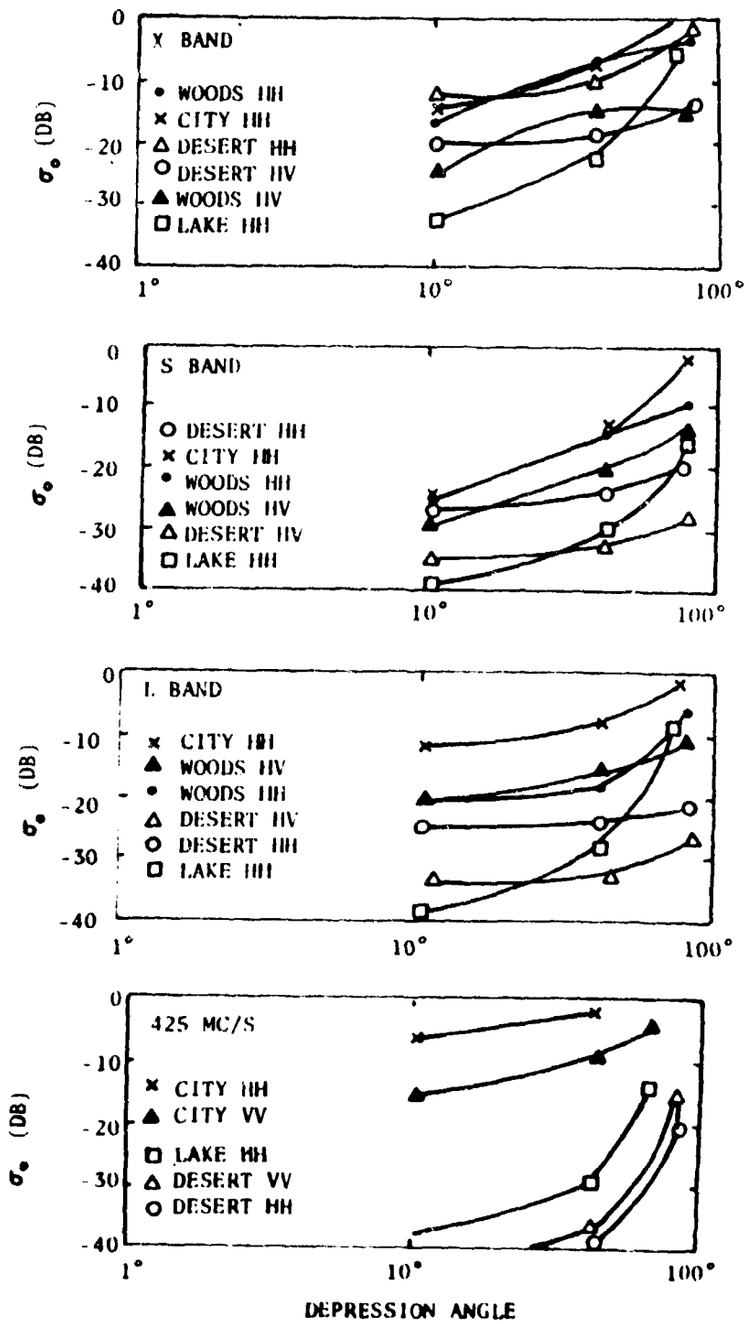

FIGURE 2 - Average σ_0 for Various Frequencies and Types of Terrain

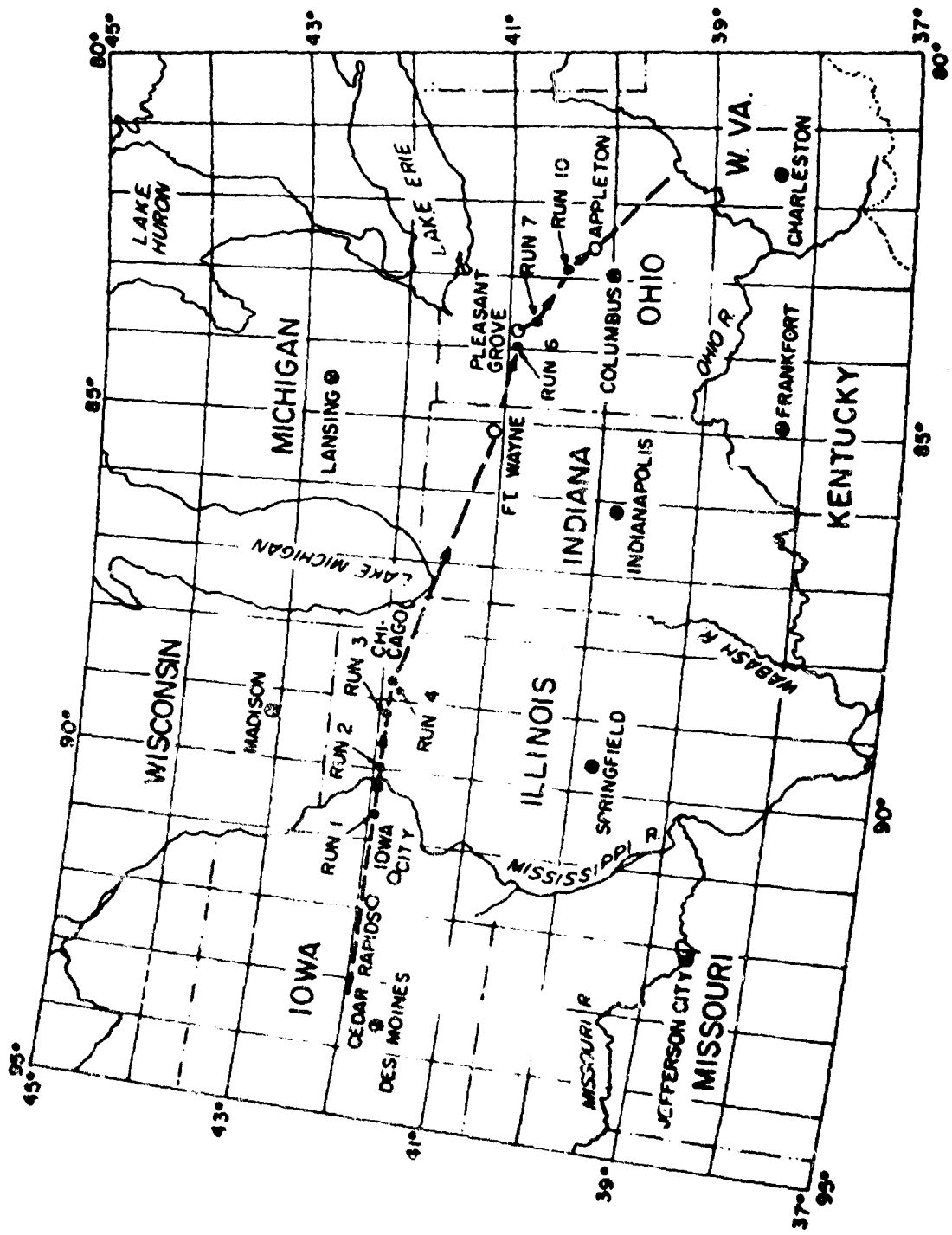

FIGURE 3 - Flight Path - 2 July 1965

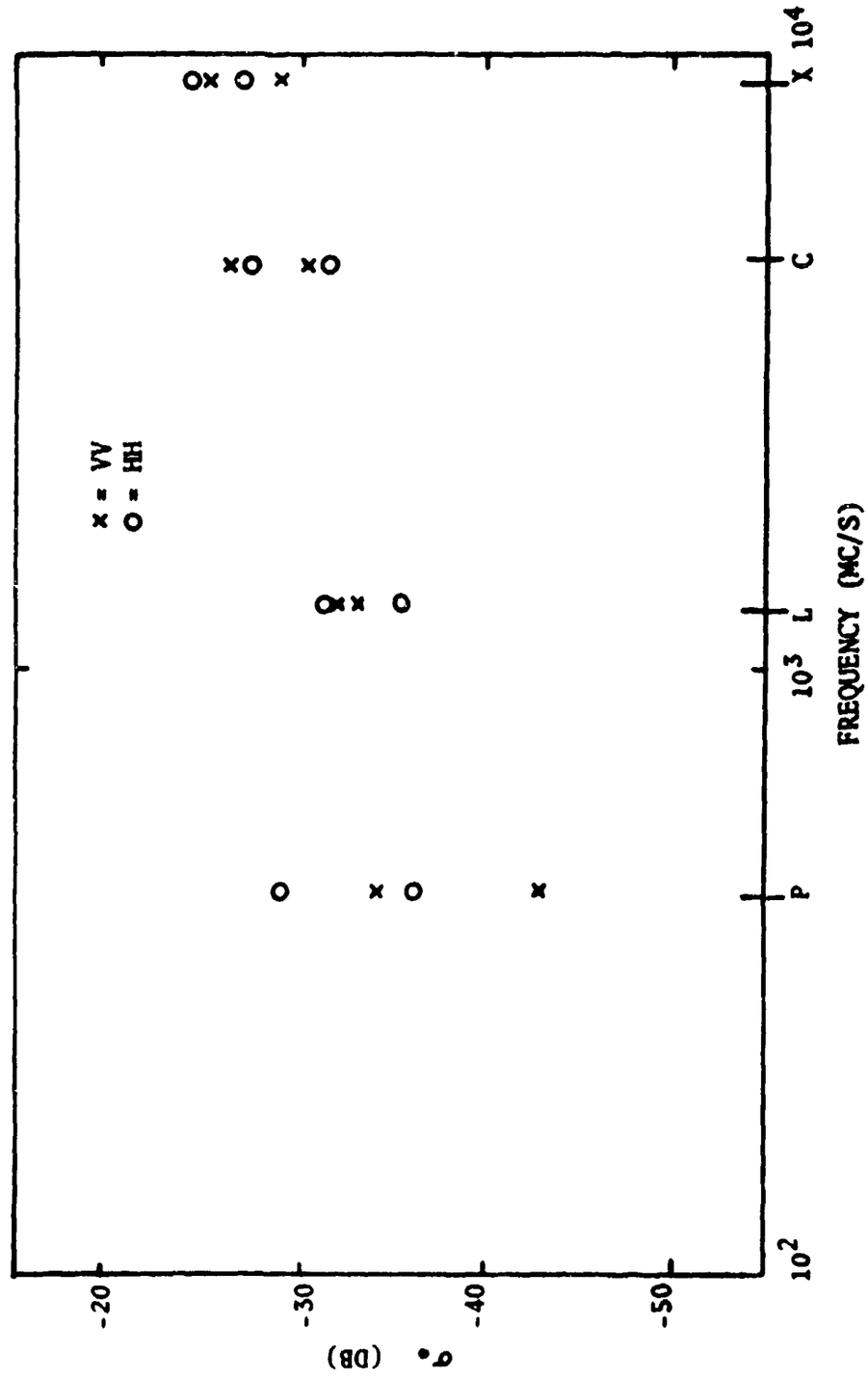

FIGURE 4 - Measured Variation of σ_o With Frequency at Depression Angle of 8 Degrees

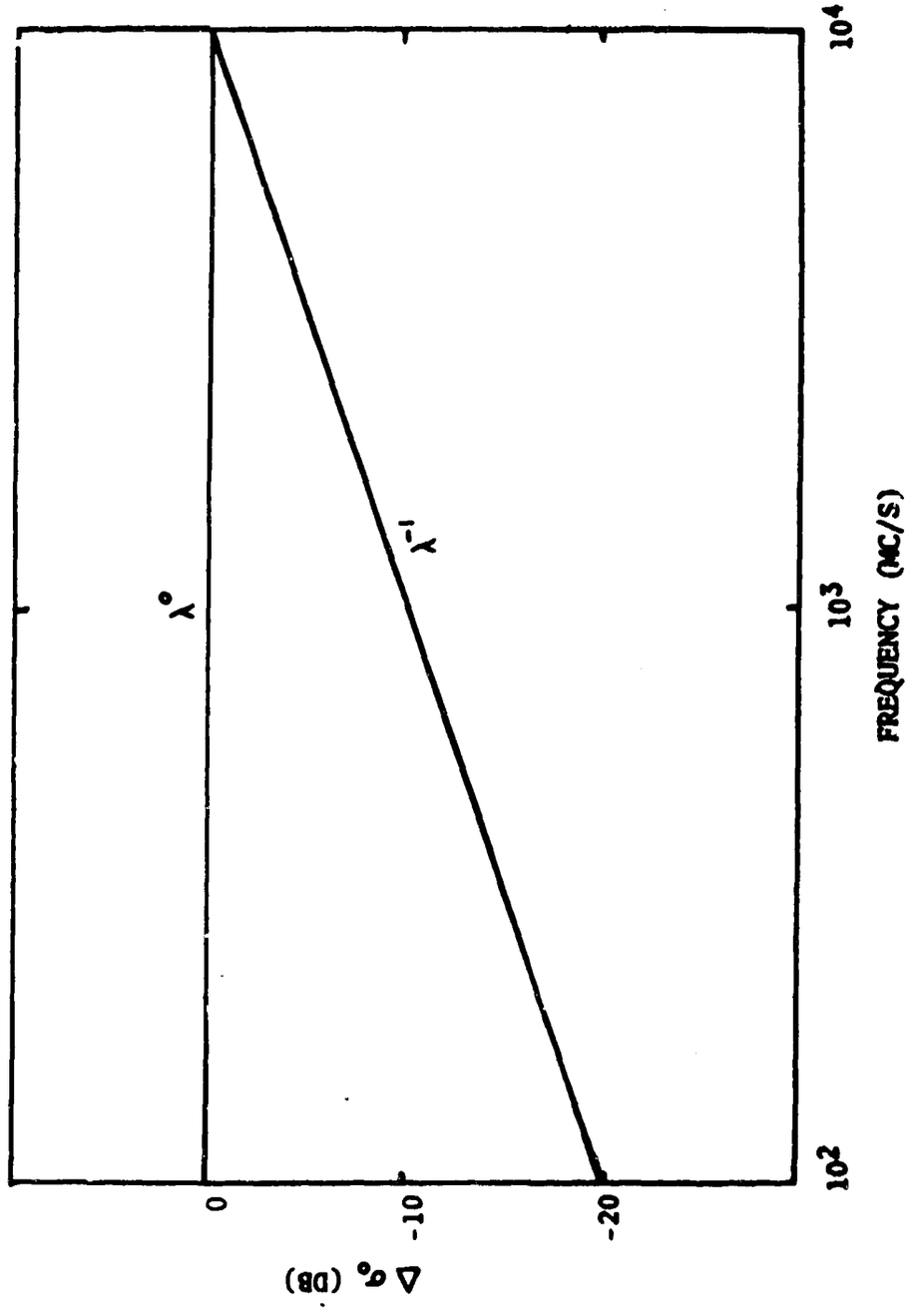

FIGURE 5 - Spread of Dependence of σ_0 on Frequency

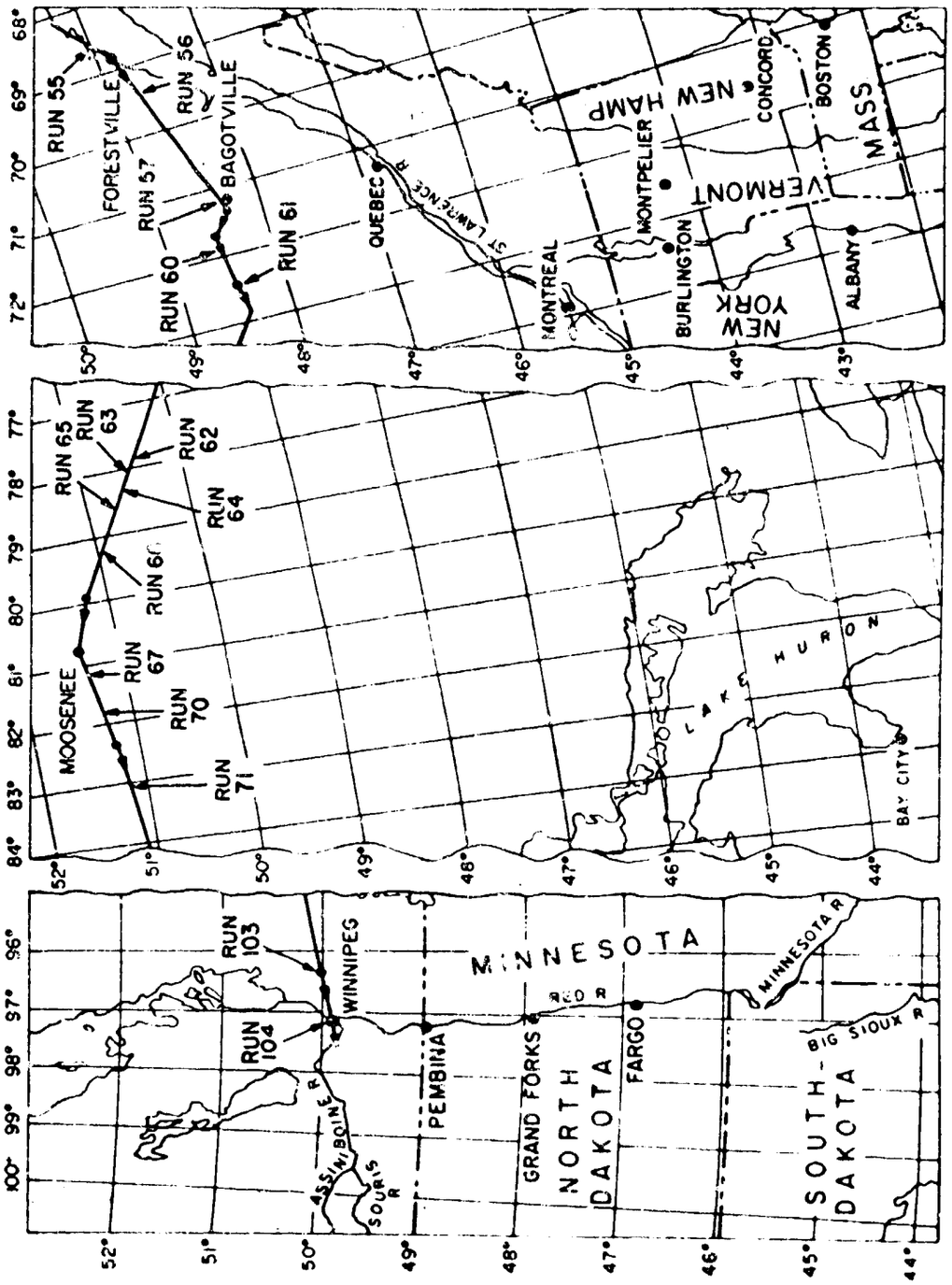

FIGURE 6 - Flight Path - 8 September 1964

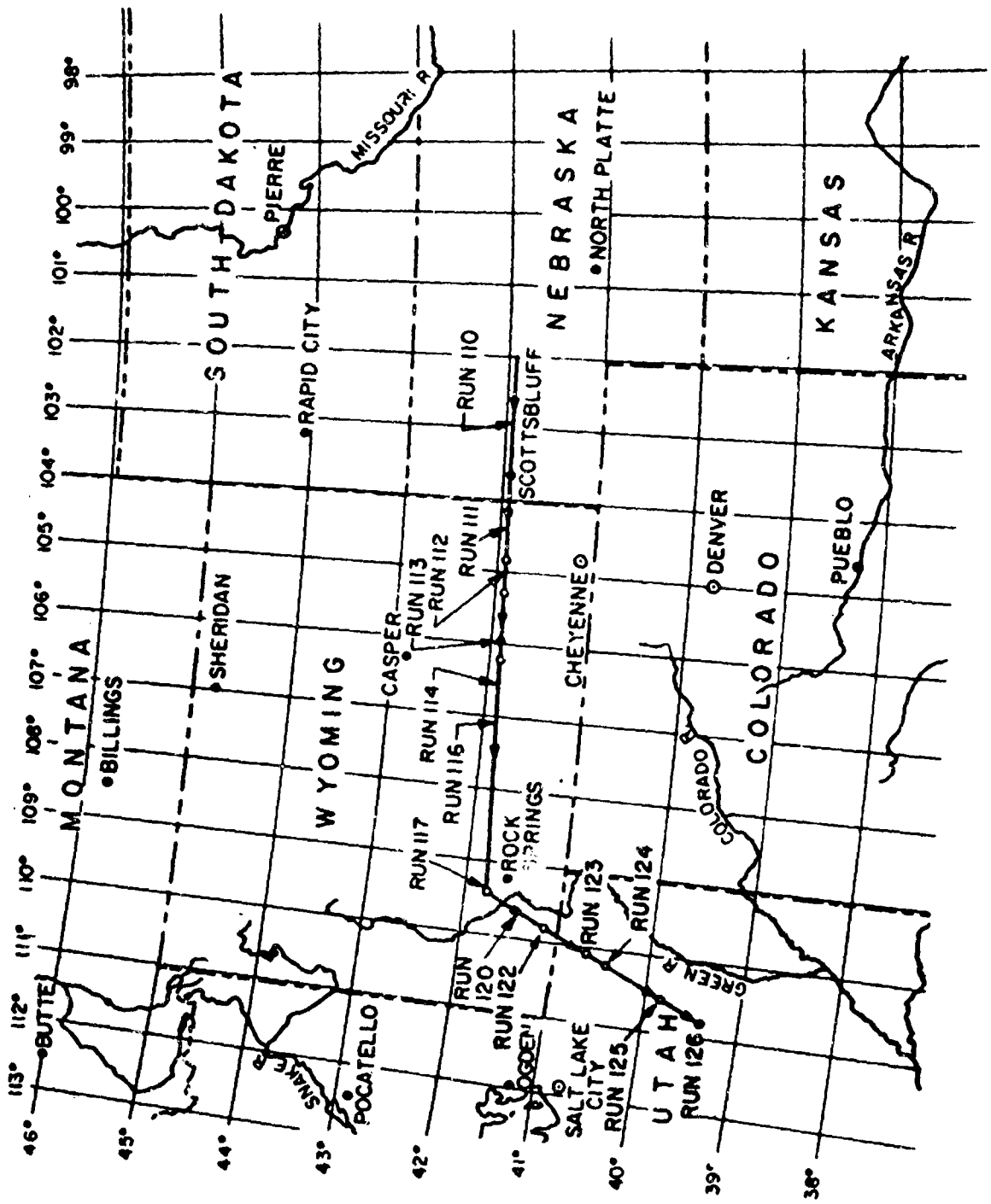

FIGURE 7 - Flight Path - 12 September 1964

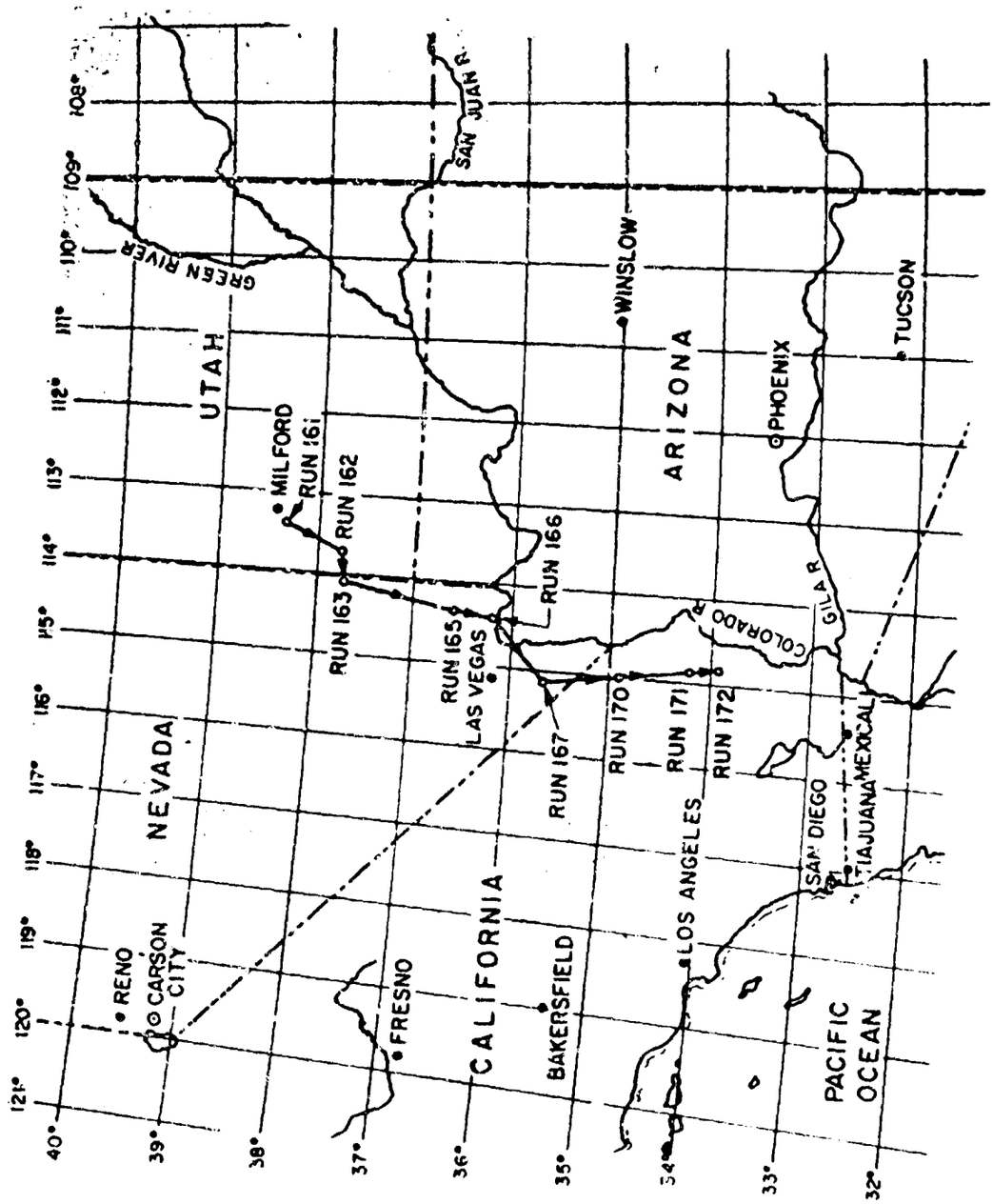

FIGURE 8 - Flight Path - 13 September 1964

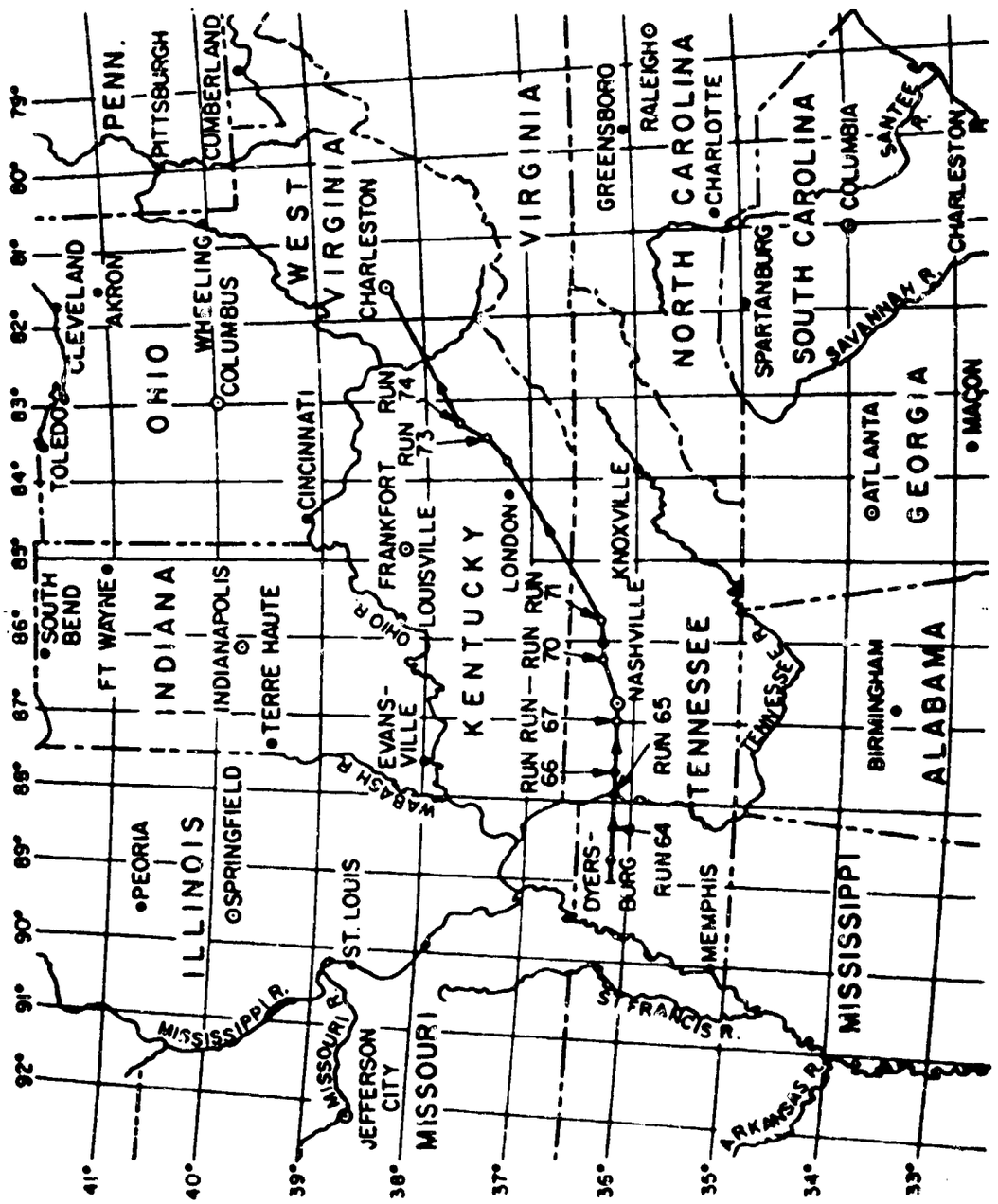

FIGURE 9 - Flight Path - 16 September 1964

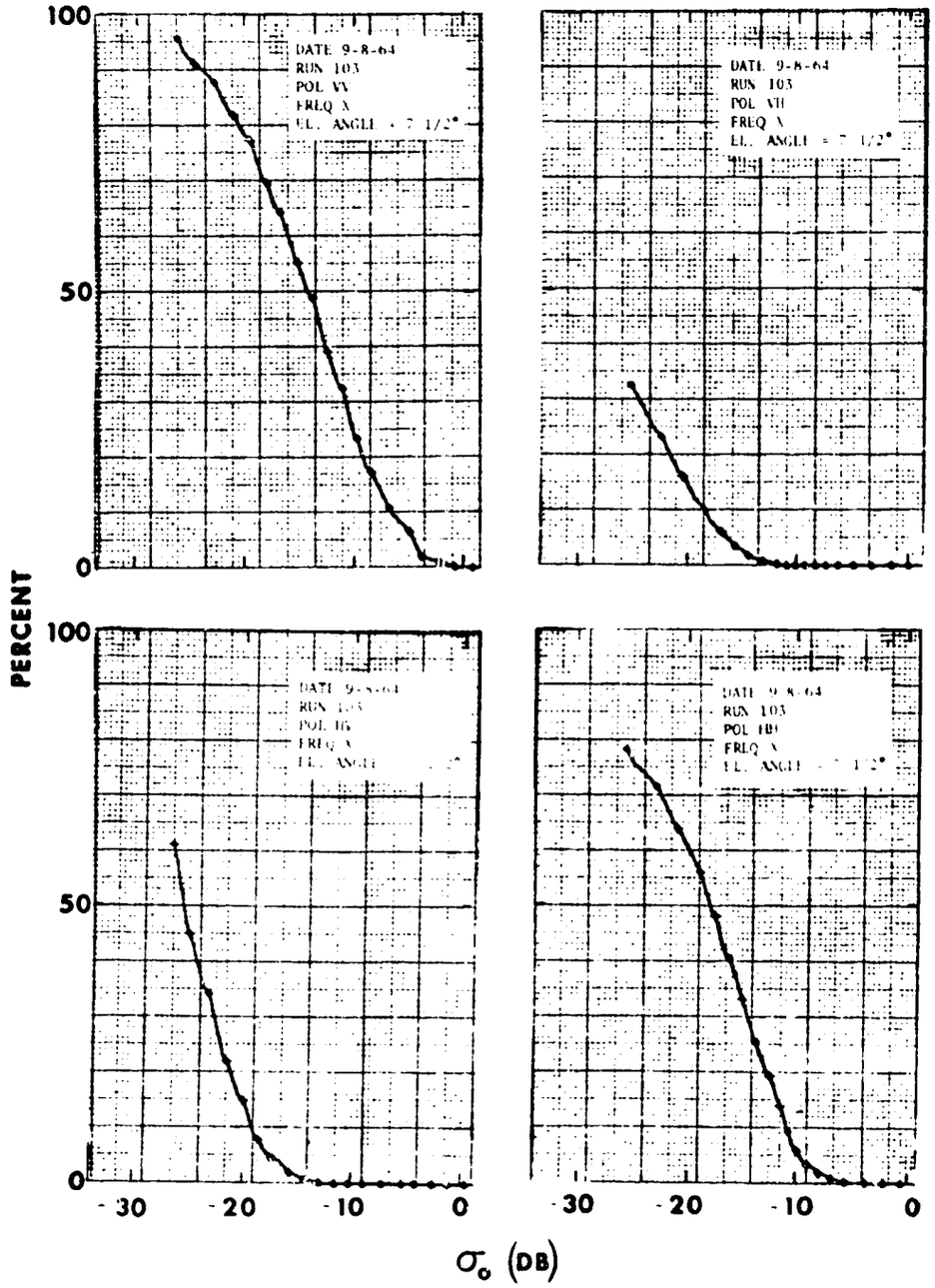

FIGURE 10a - Percentage Variation of σ_o, Angle = 7-1/2 Degrees, Run 103

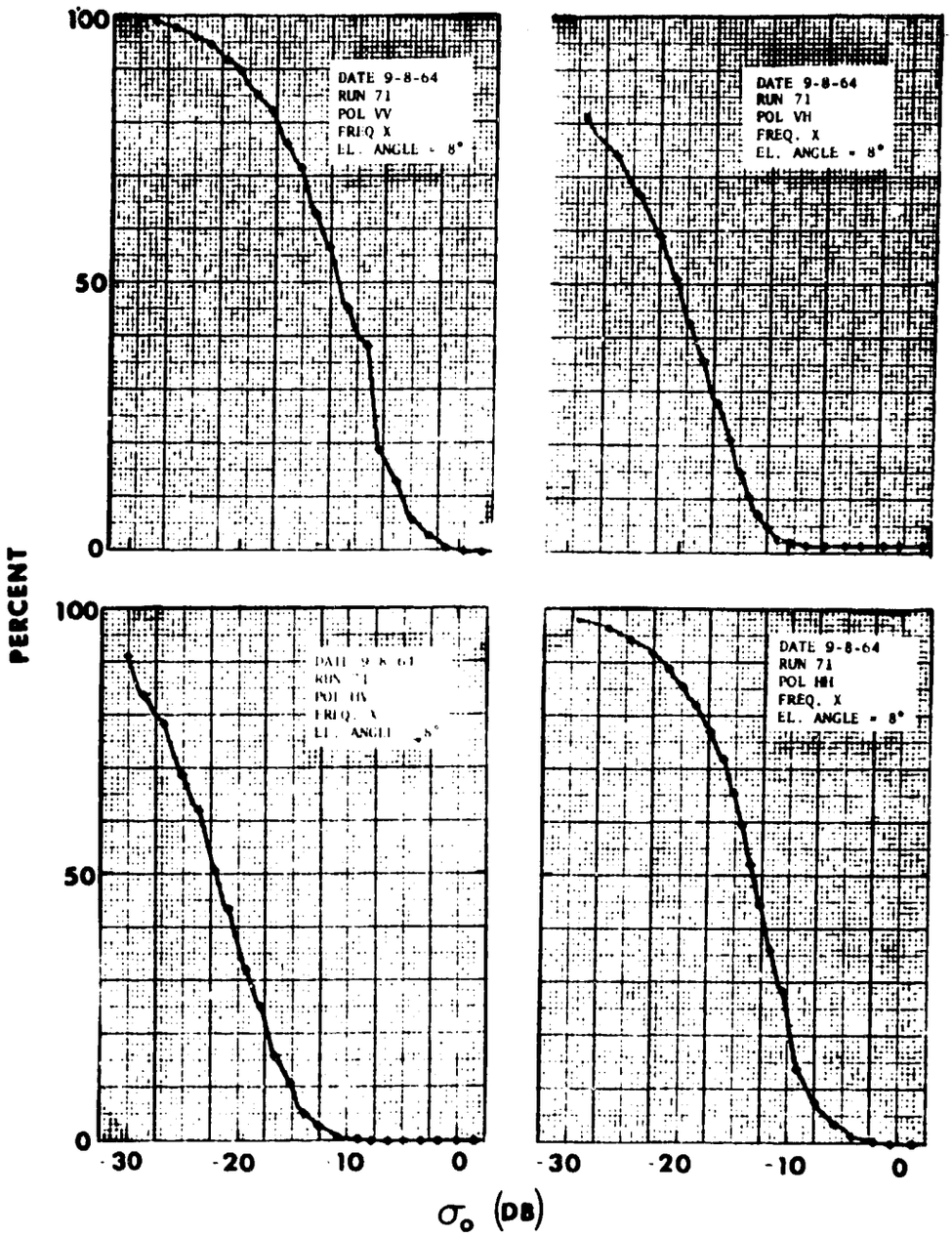

FIGURE 10b - Percentage Variation of σ_o, Angle = 8 Degrees, Run 71

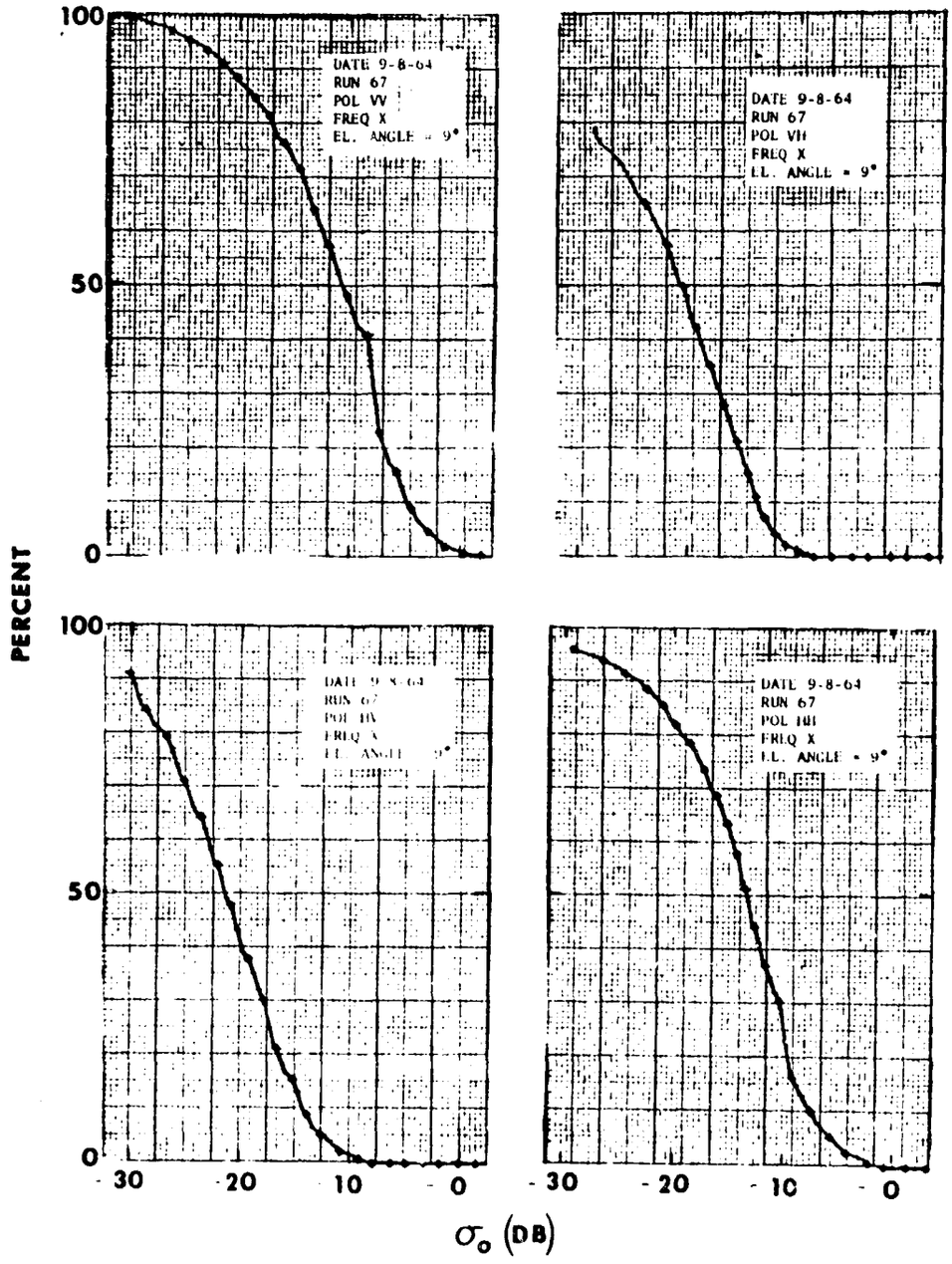

FIGURE 10c - Percentage Variation of σ_o, Angle = 9 Degrees, Run 67

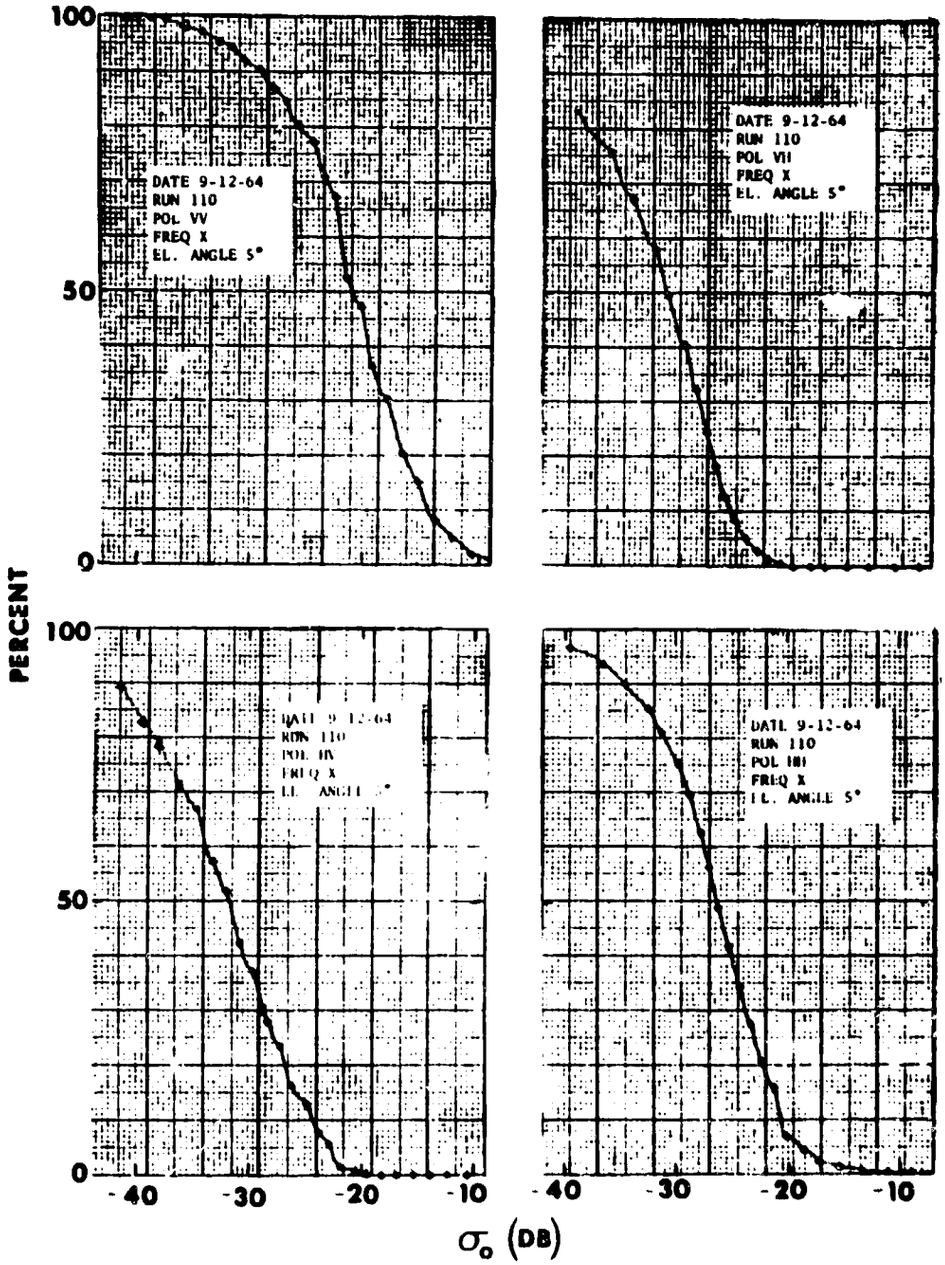

FIGURE 10d - Percentage Variation of σ_o, Angle = 5 Degrees, Run 110

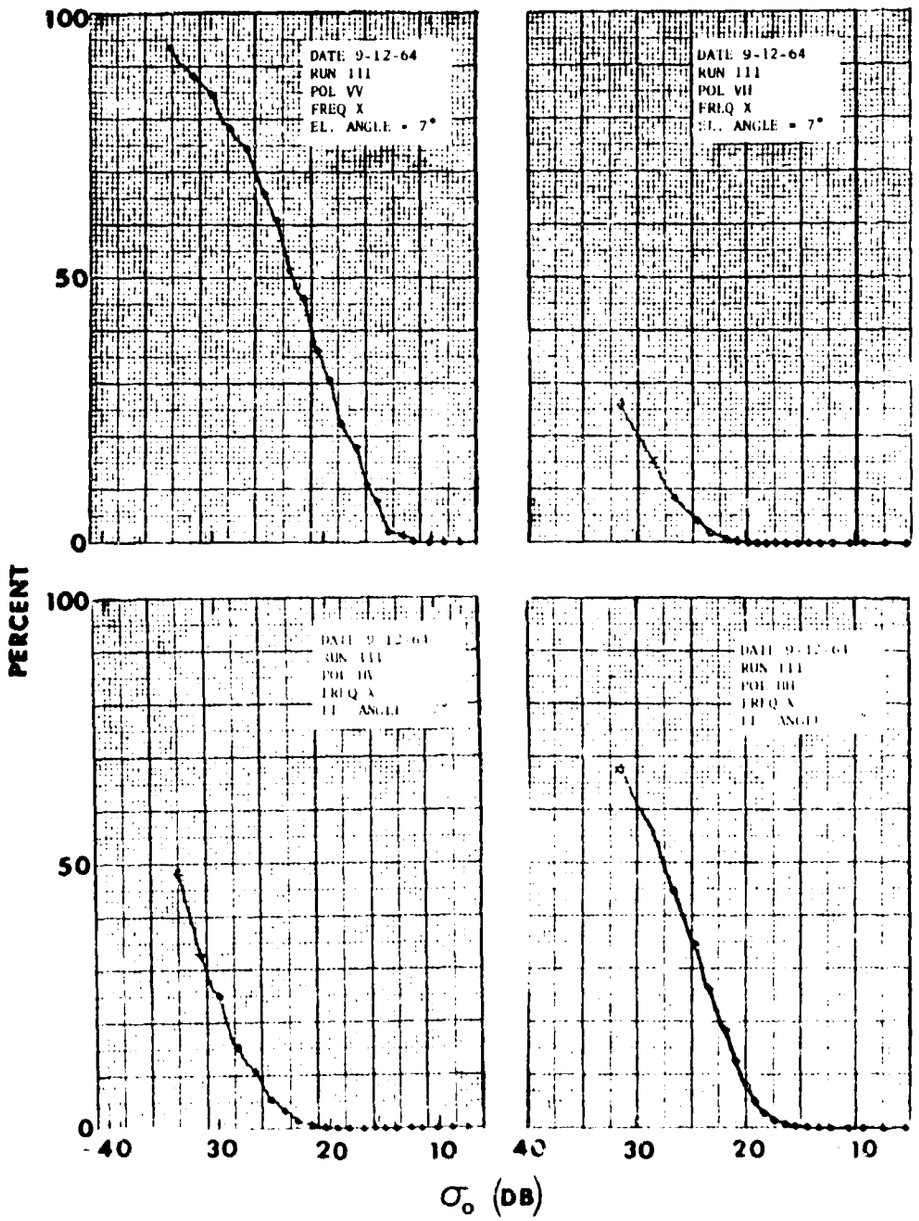

FIGURE 10c - Percentage Variation of σ_o, Angle = 7 Degrees, Run 111

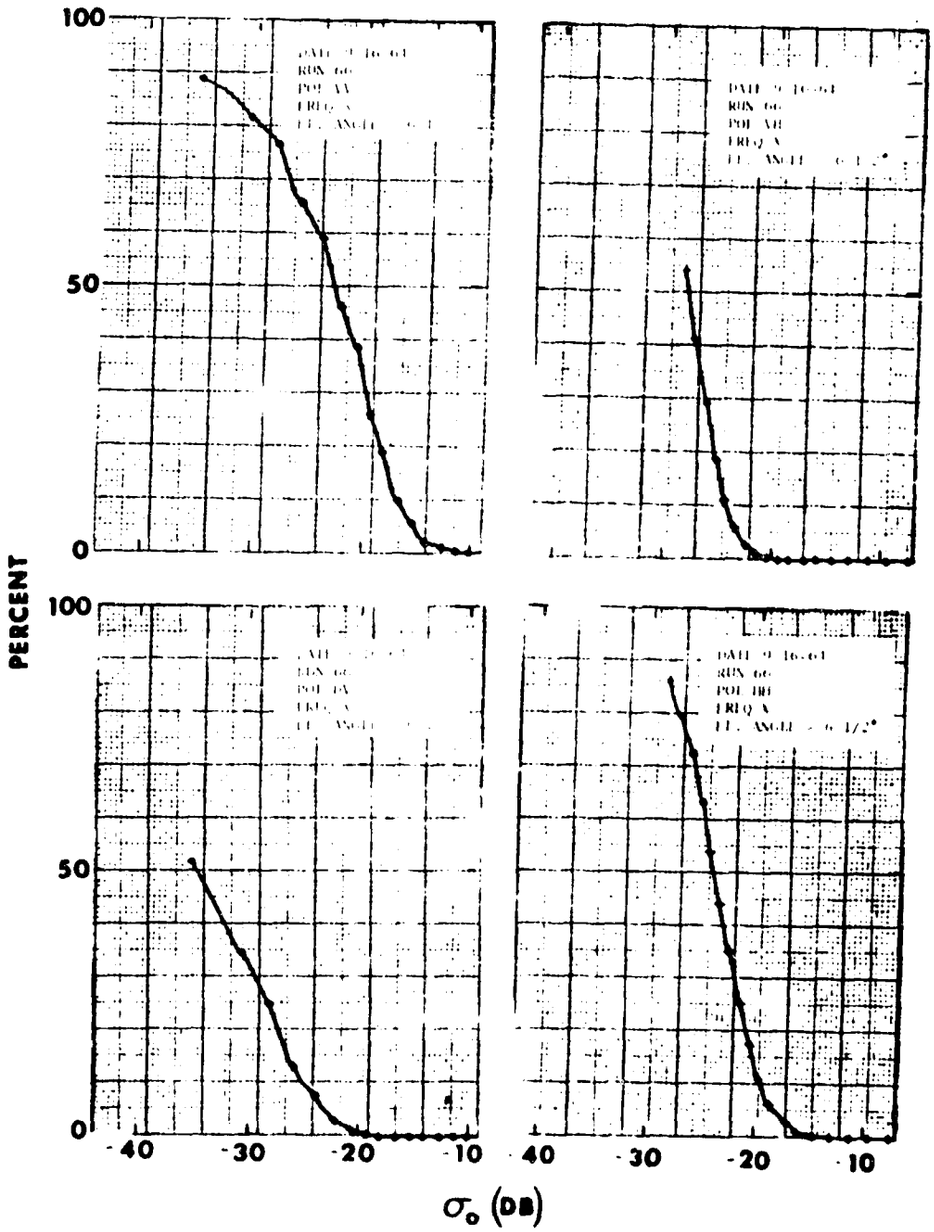

FIGURE 10f - Percentage Variation of σ_o, Angle = 6-1/2 Degrees, Run 66

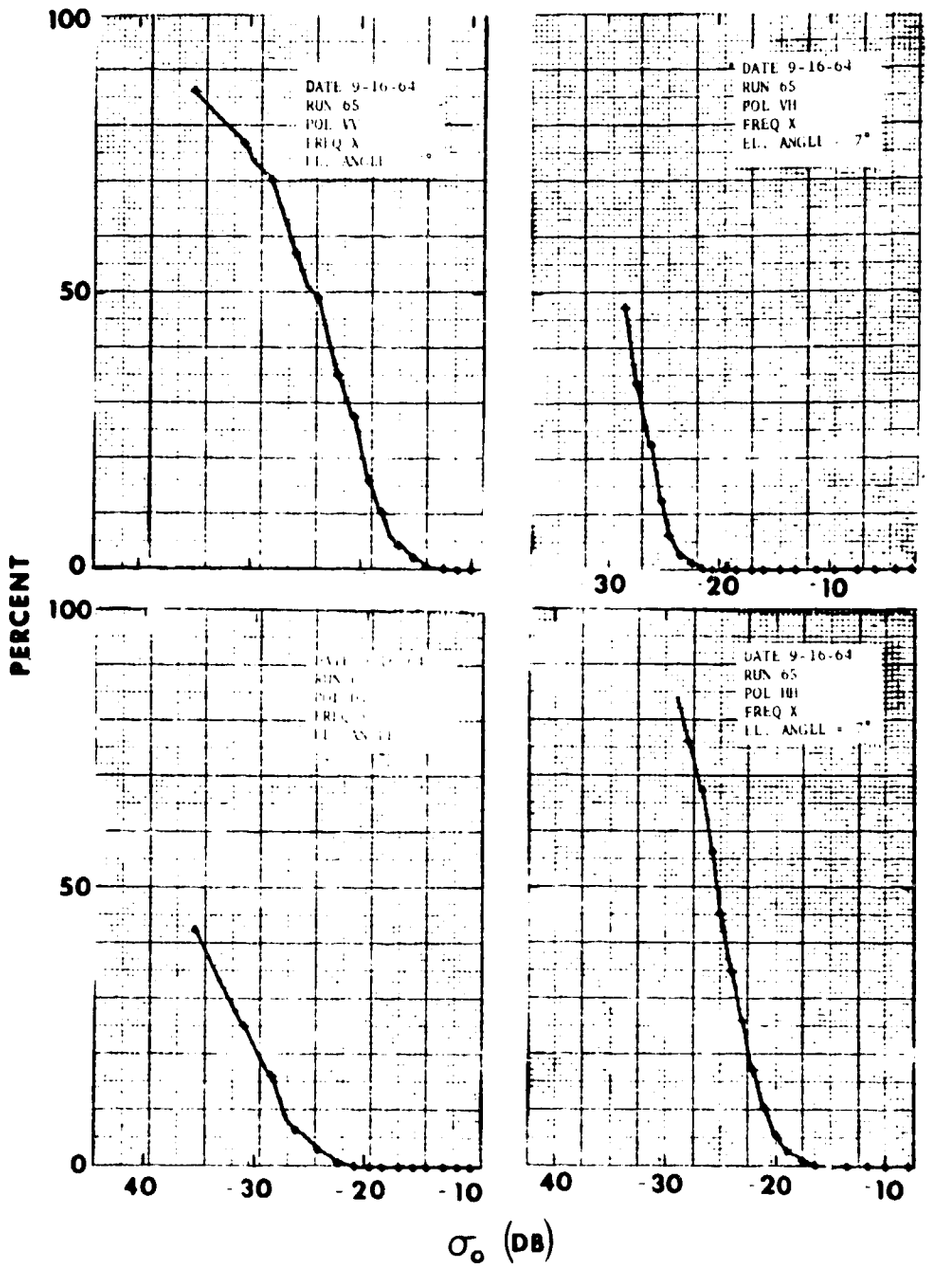

FIGURE 10g - Percentage Variation of σ_o, Angle = 7 Degrees, Run 65

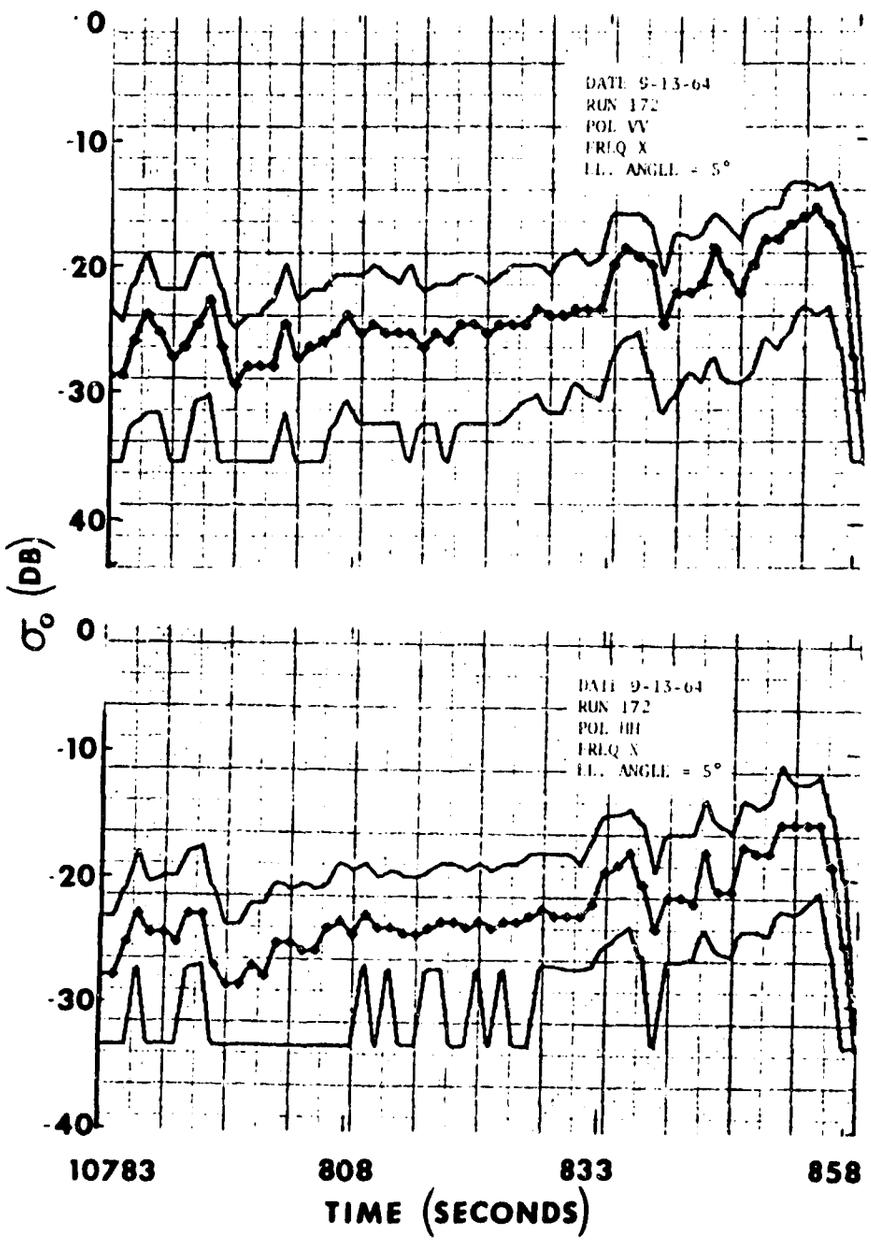

FIGURE 11a - Variation of σ_o With Time for Ground Return, Angle = 5 Degrees, Run 172

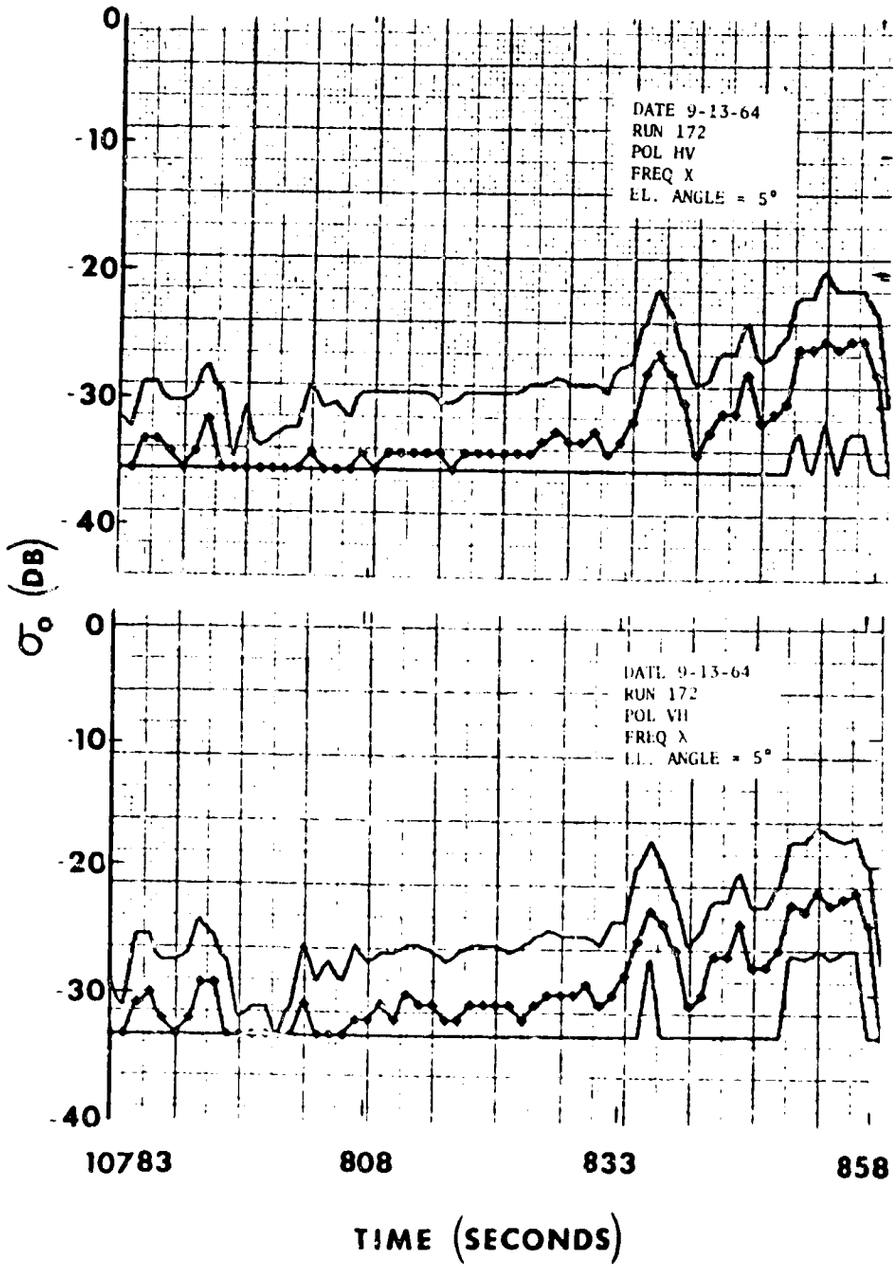

FIGURE 11b - Variation of σ_0 With Time for Ground Return, Angle = 5 Degrees, Run 172

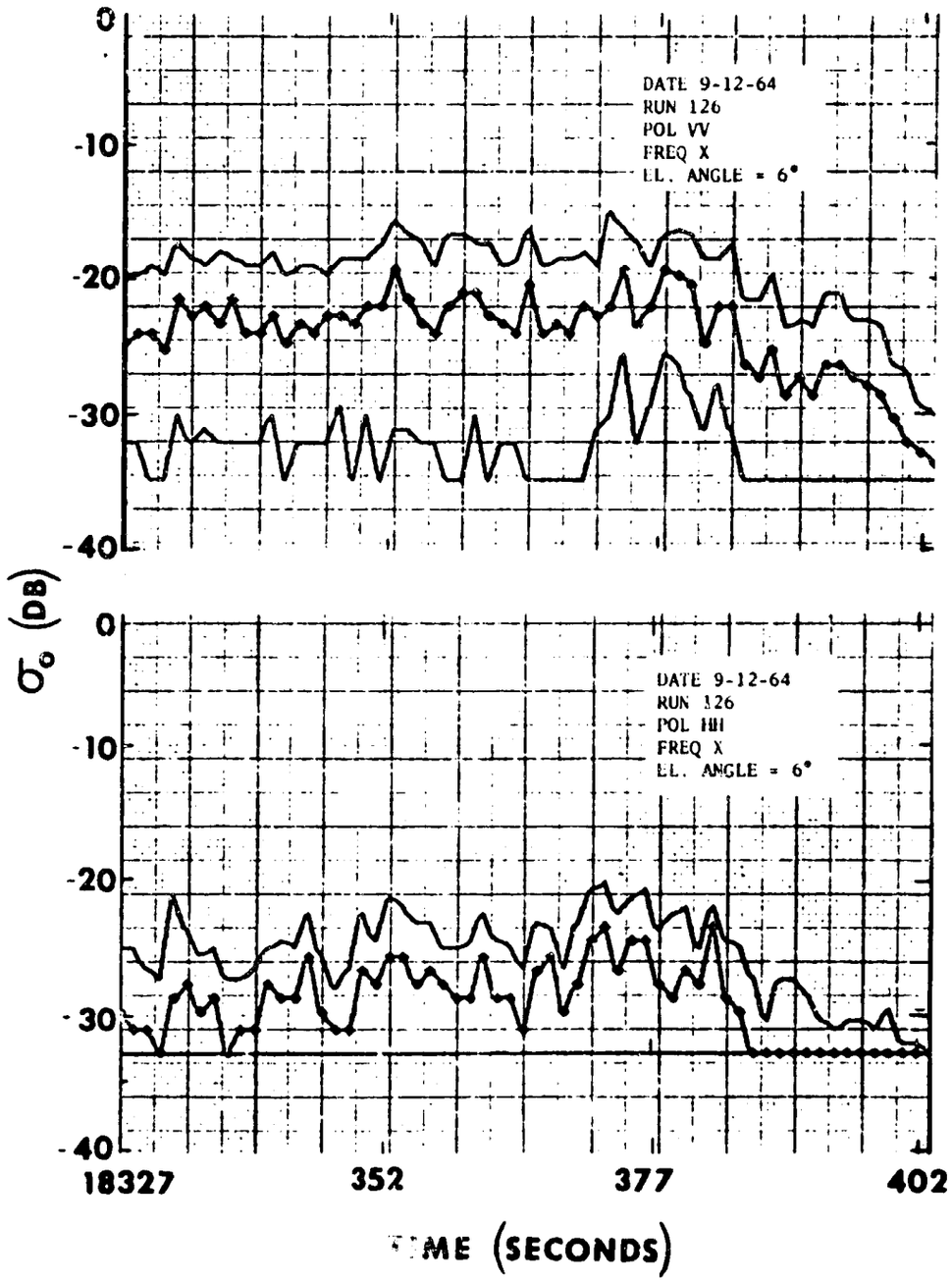

FIGURE 11c - Variation of σ_o With Time for Ground Return, Angle = 6 Degrees, Run 126

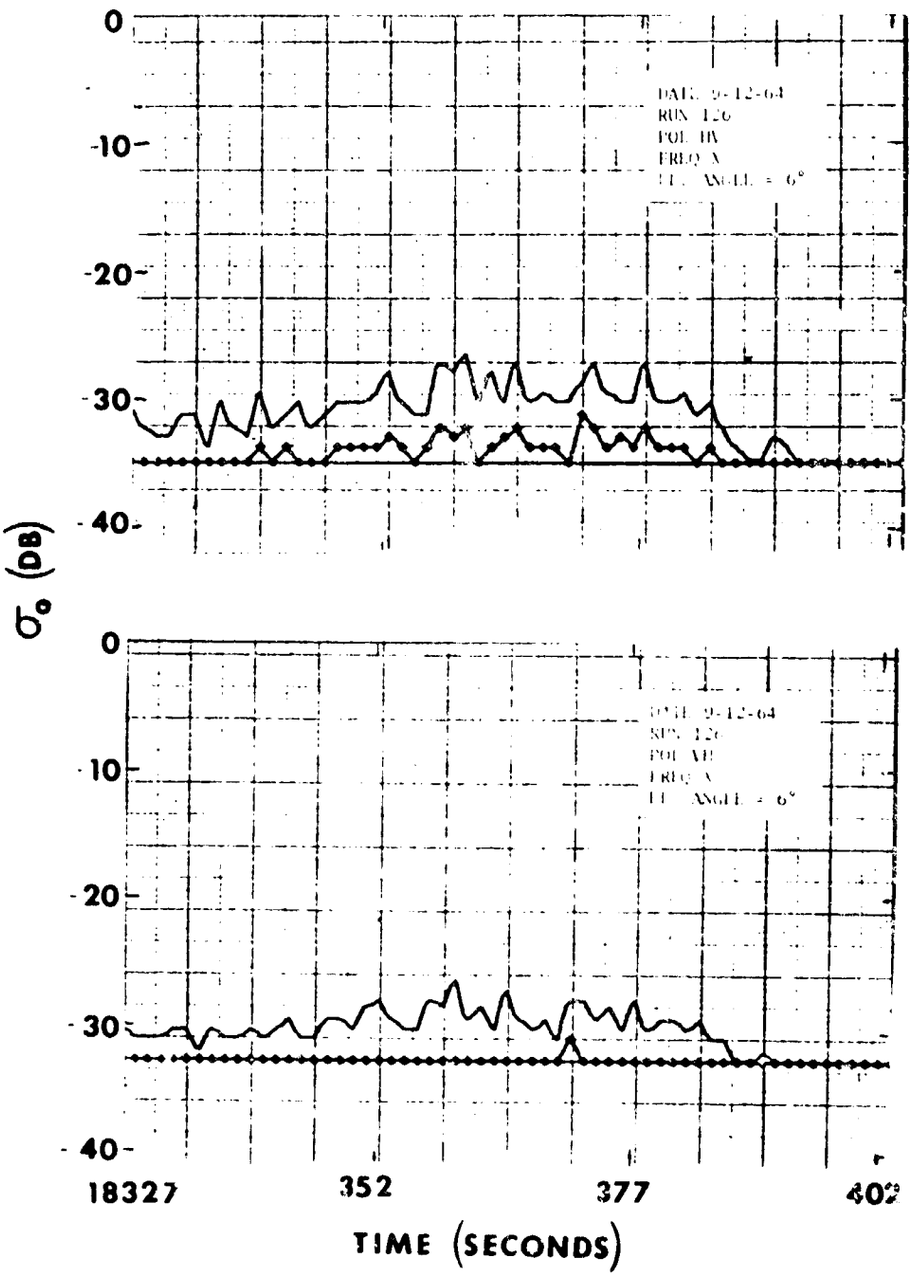

FIGURE 11d Variation of σ_o With Time for Ground Return, Angle = 6 Degrees, Run 126

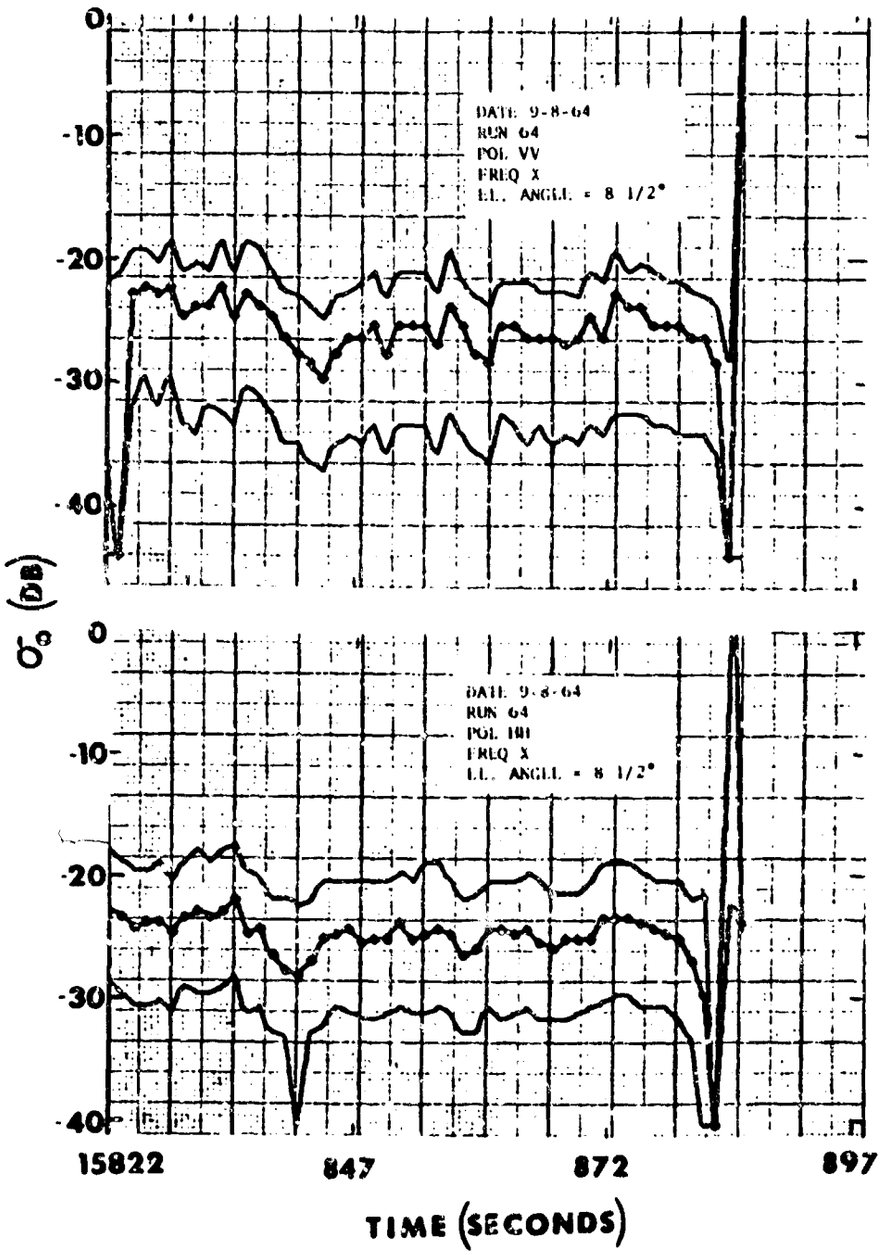

FIGURE 11e - Variation of σ_o With Time for Ground Return, Angle = 8-1/2 Degrees, Run 64

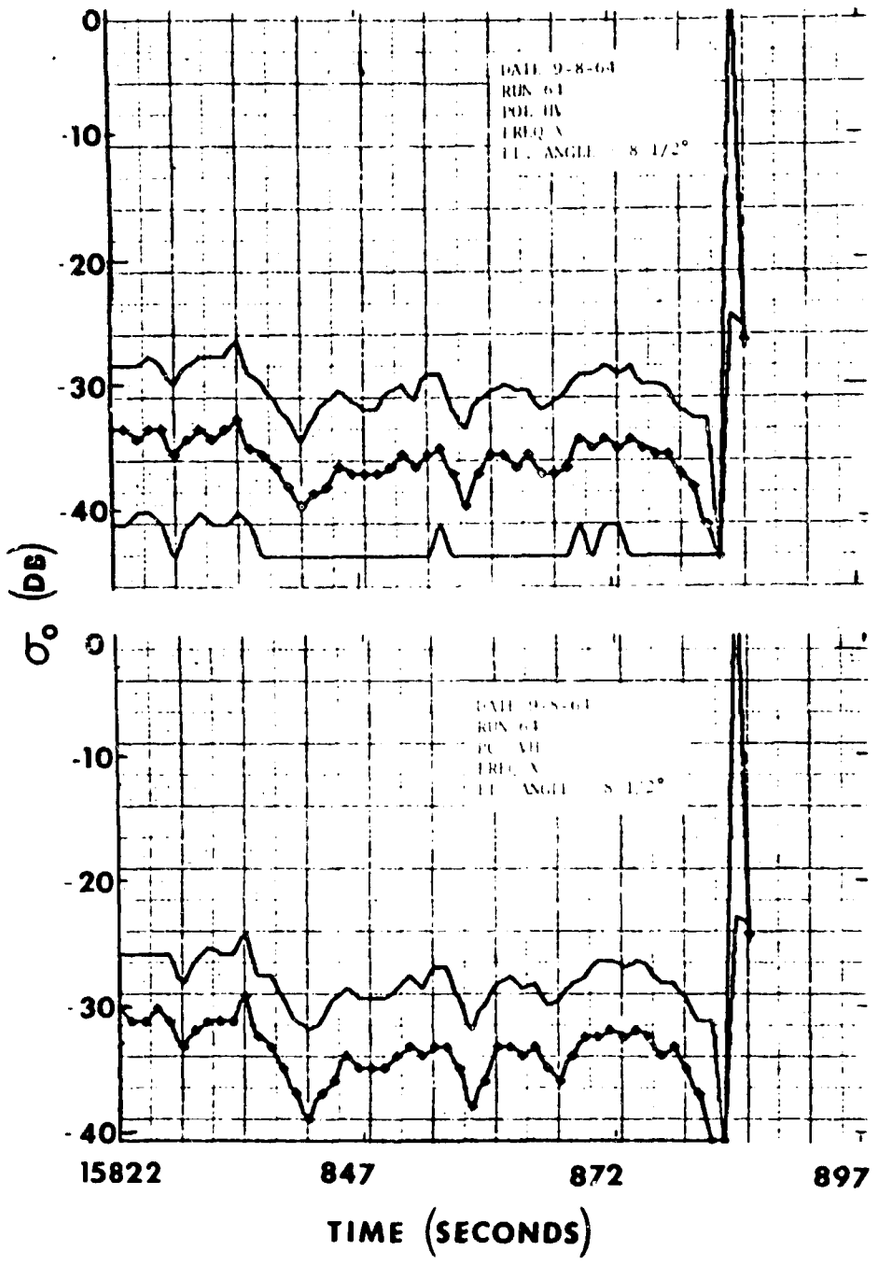

FIGURE 11f - Variation of σ_o With Time for Ground Return, Angle = 8-1/2 Degrees, Run 64

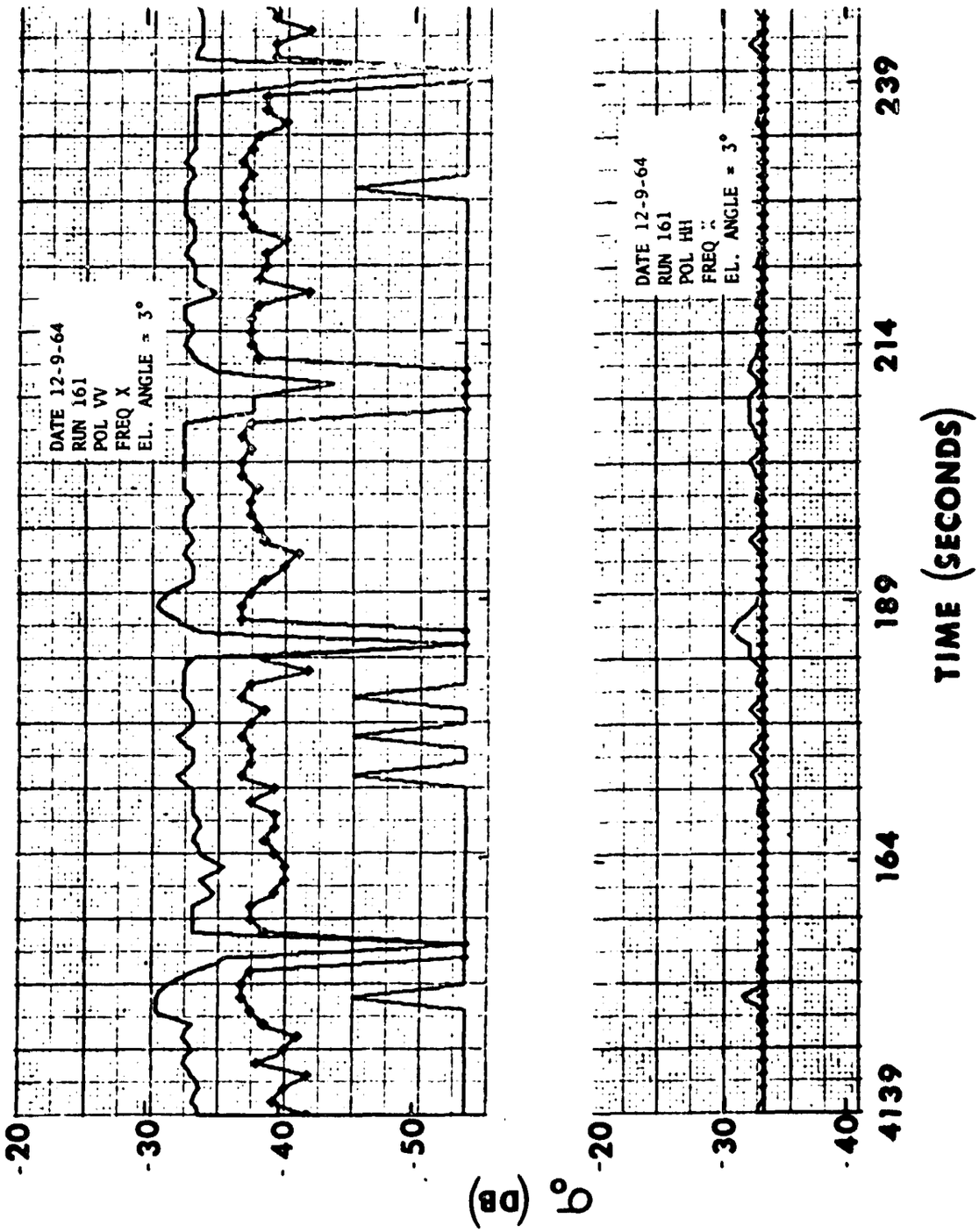

FIGURE 12a - Variation of σ_o With Time for Sea Return, Angle = 3 Degrees, Run 161

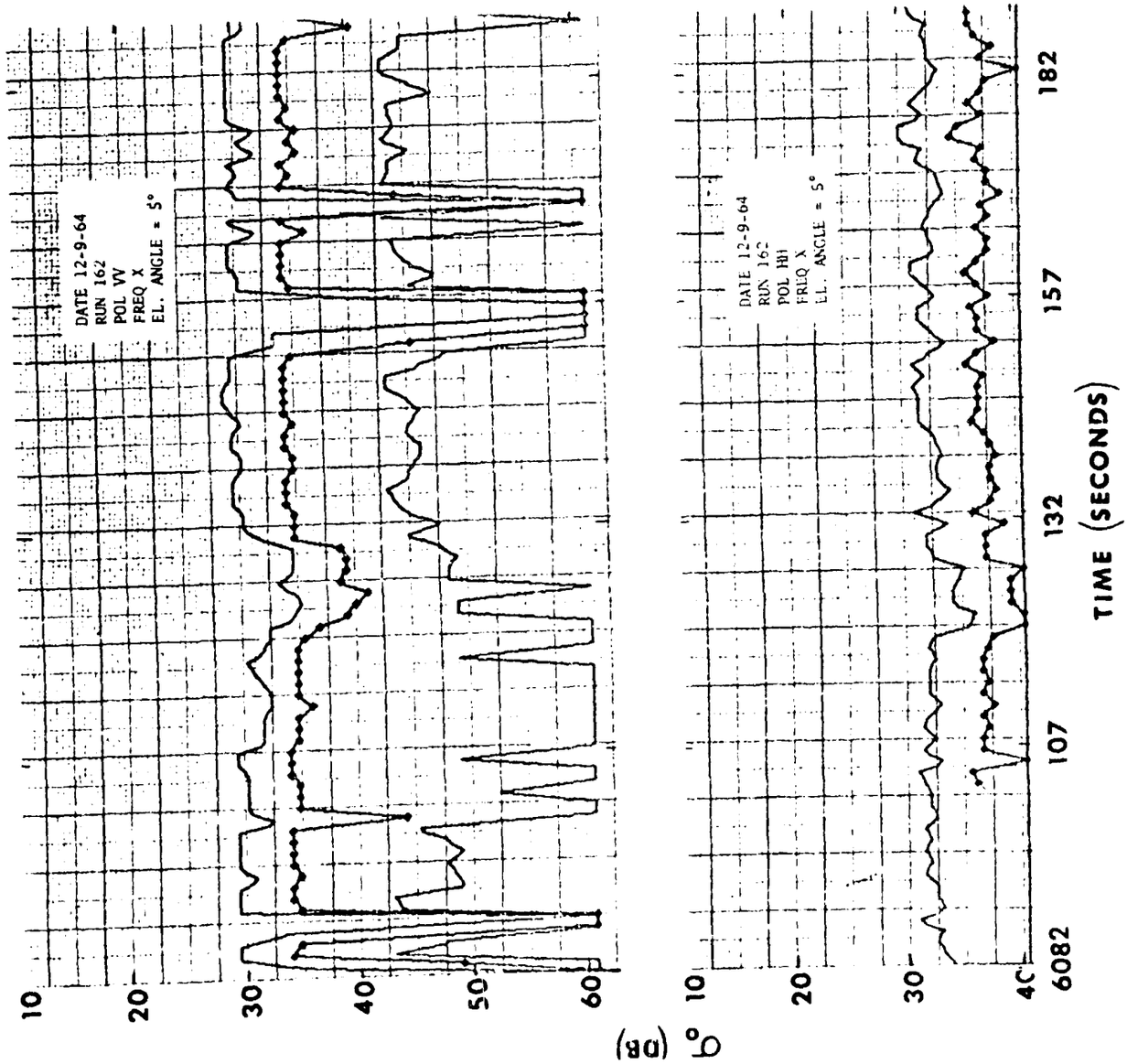

FIGURE 12b - Variation of σ_o With Time for Sea Return, Angle = 5 Degrees, Run 162

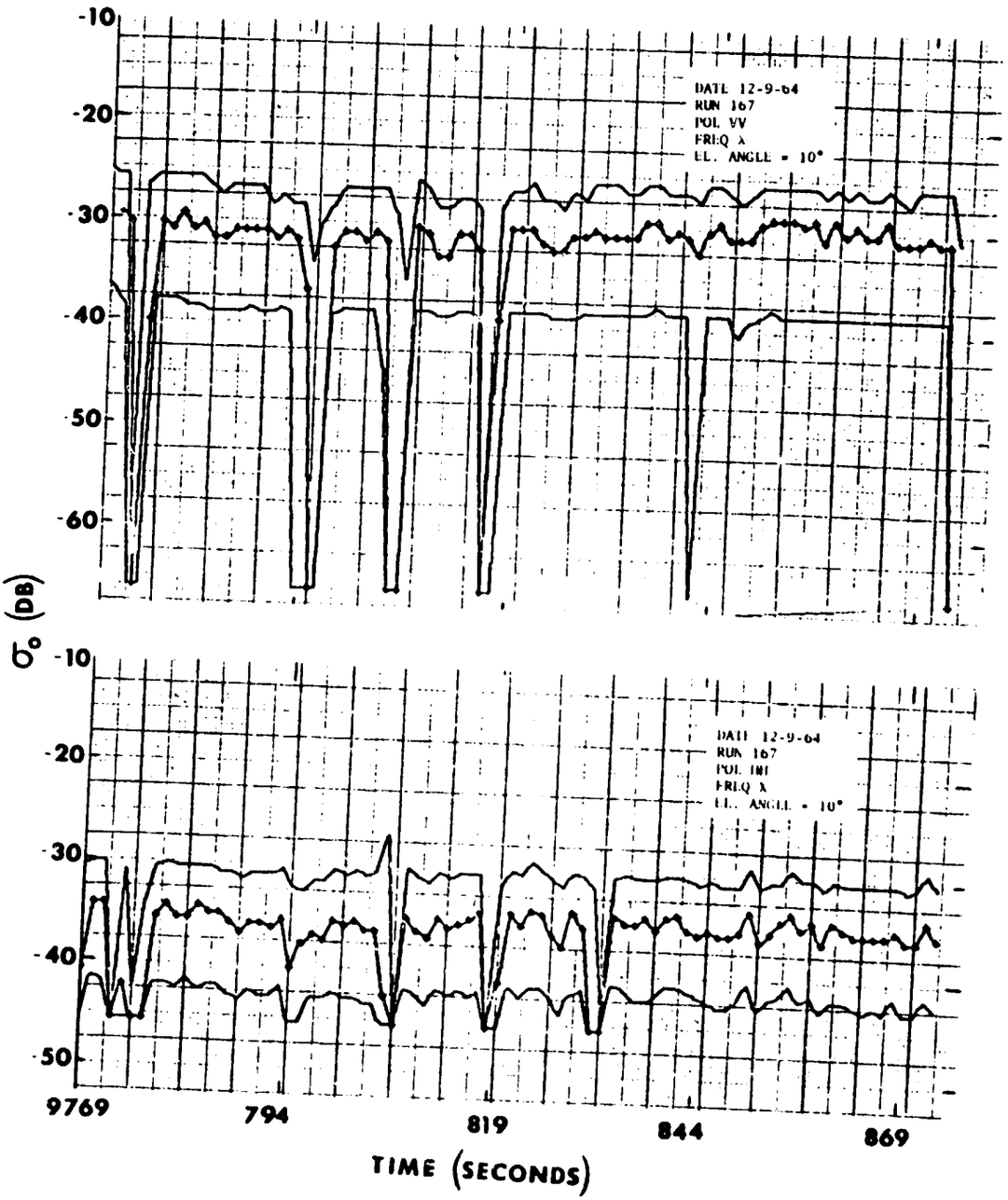

FIGURE 12c - Variation of σ_o With Time for Sea Return, Angle = 10 Degrees, Run 167

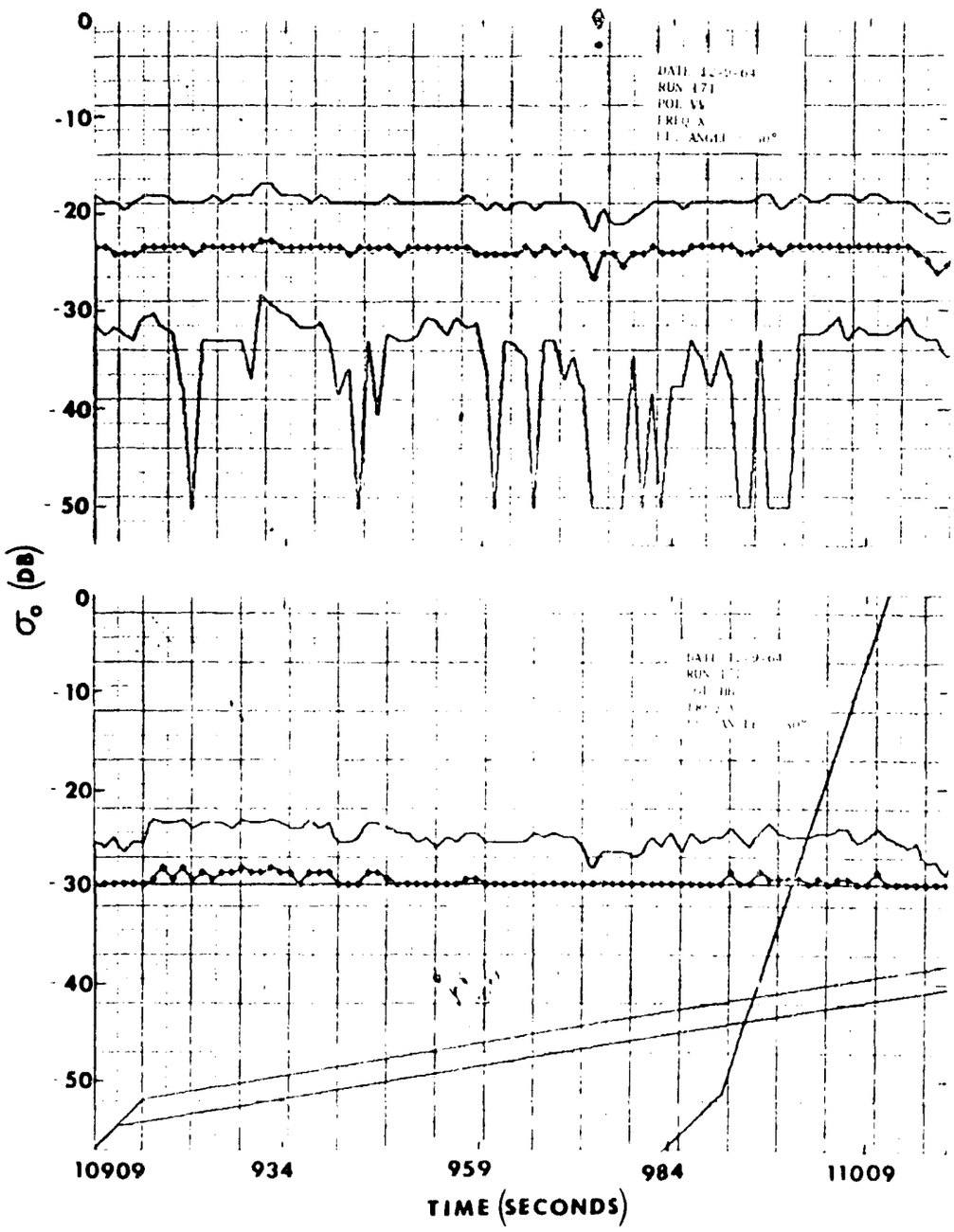

FIGURE 12d - Variation of σ_o With Time for Sea Return, Angle = 30 Degrees, Run 171

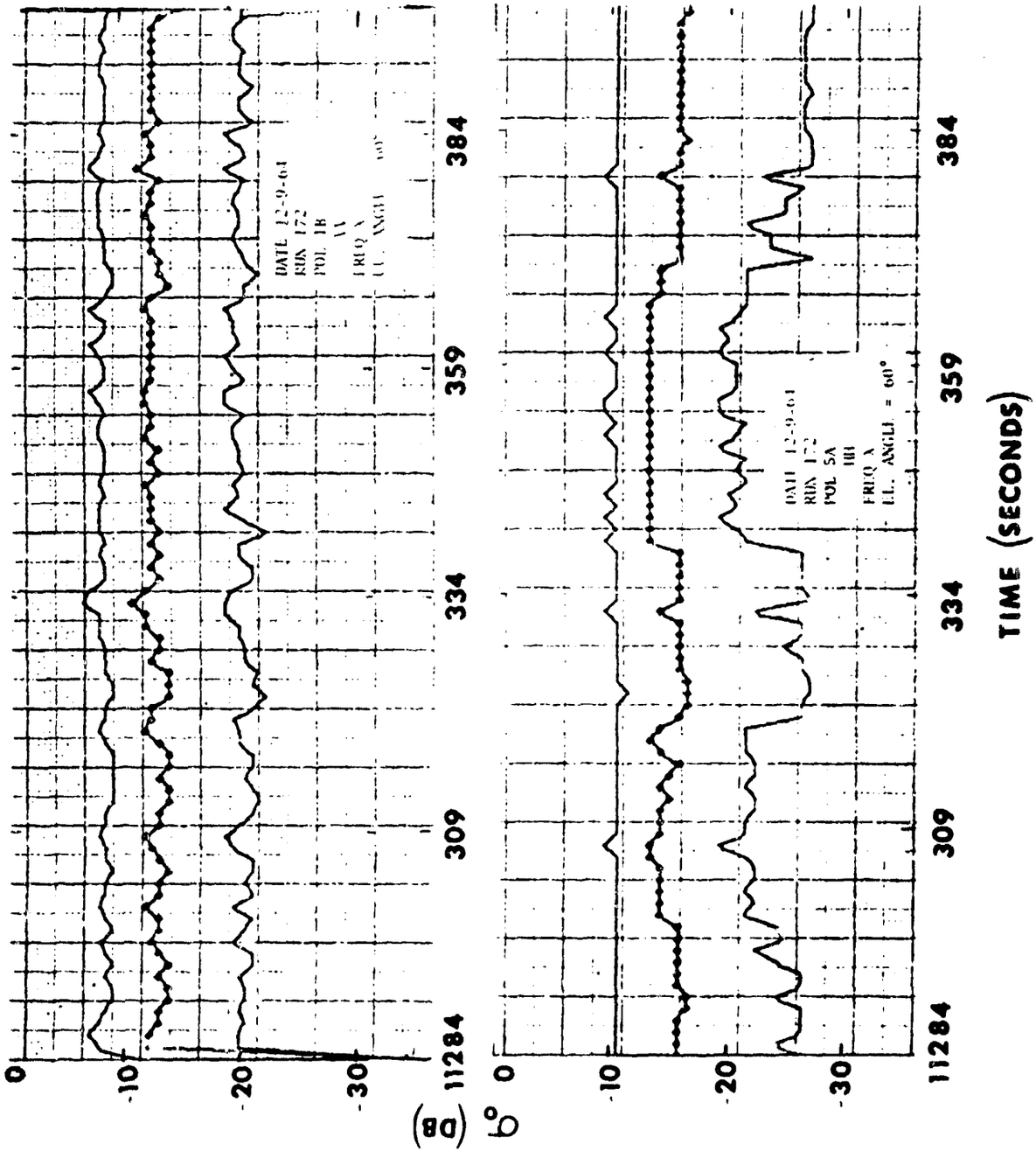

FIGURE 12e - Variation of σ_o With Time for Sea Return, Angle = 60 Degrees, Run 172

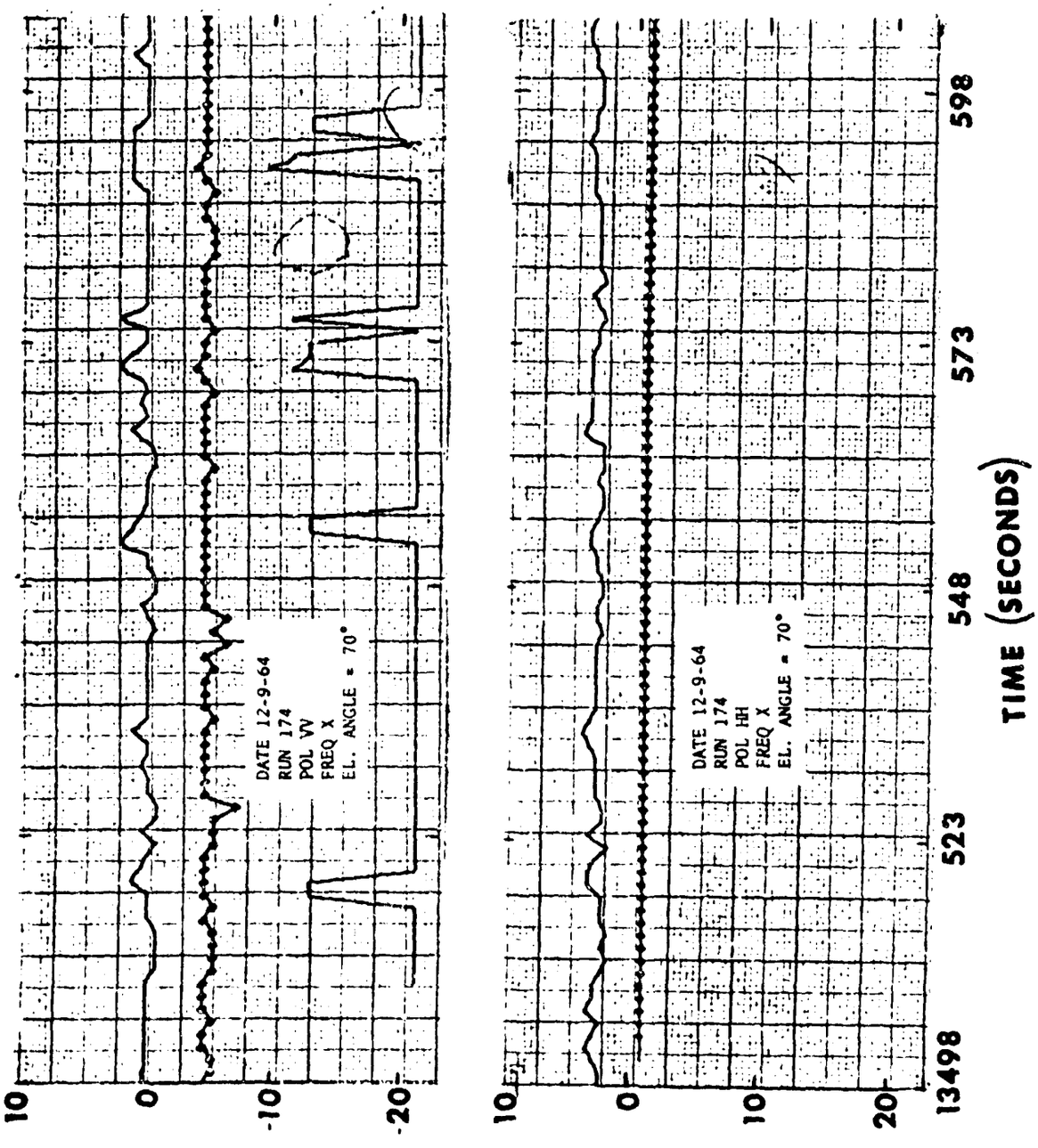

FIGURE 12f - Variation of σ_o With Time for Sea Return, Angle = 70 Degrees, Run 174

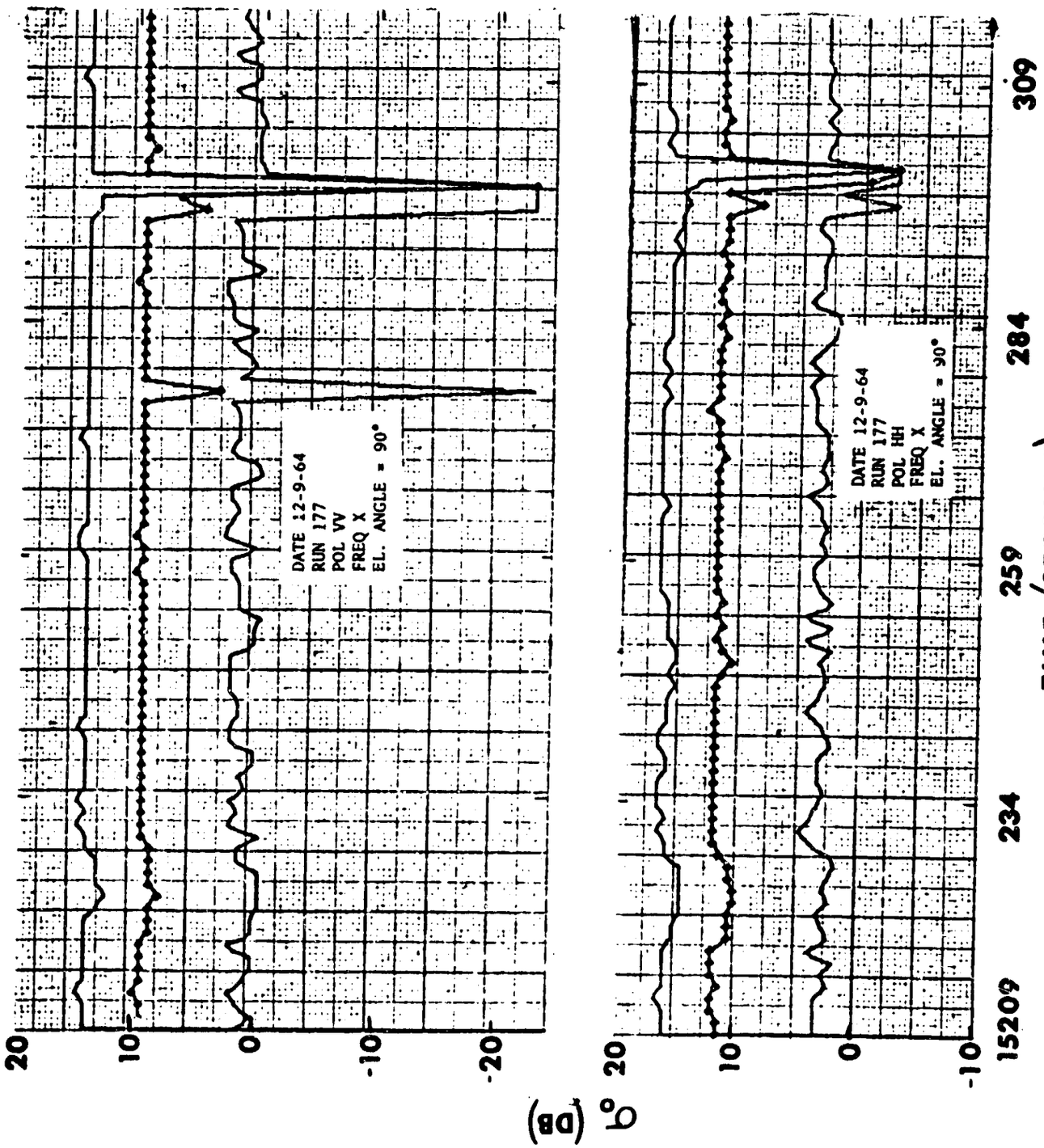

FIGURE 12g - Variation of σ_o With Time for Sea Return, Angle = 90 Degrees, Run 177

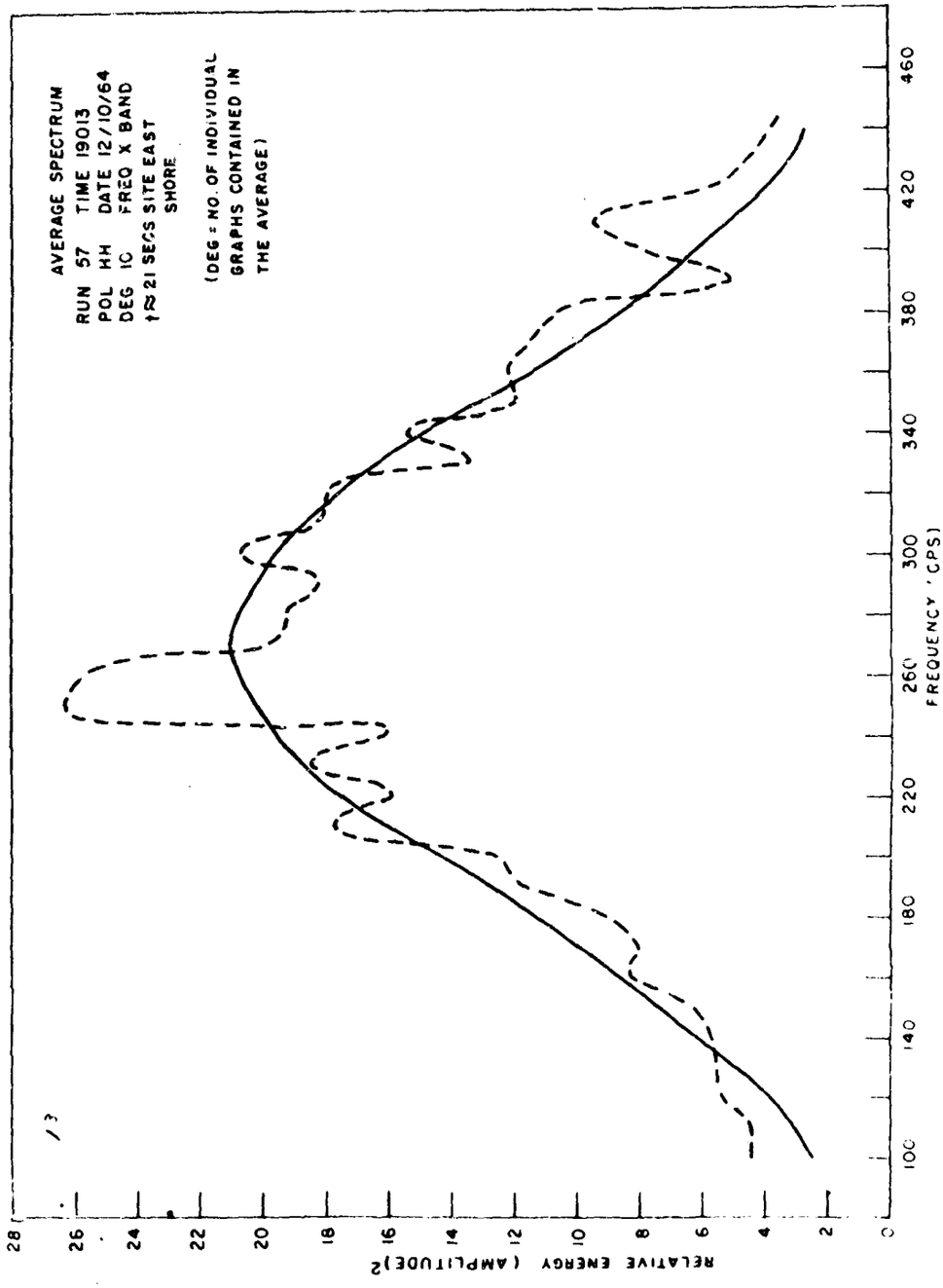

FIGURE 13 - Combined X-Band Average Spectrum for Horizontal Polarization

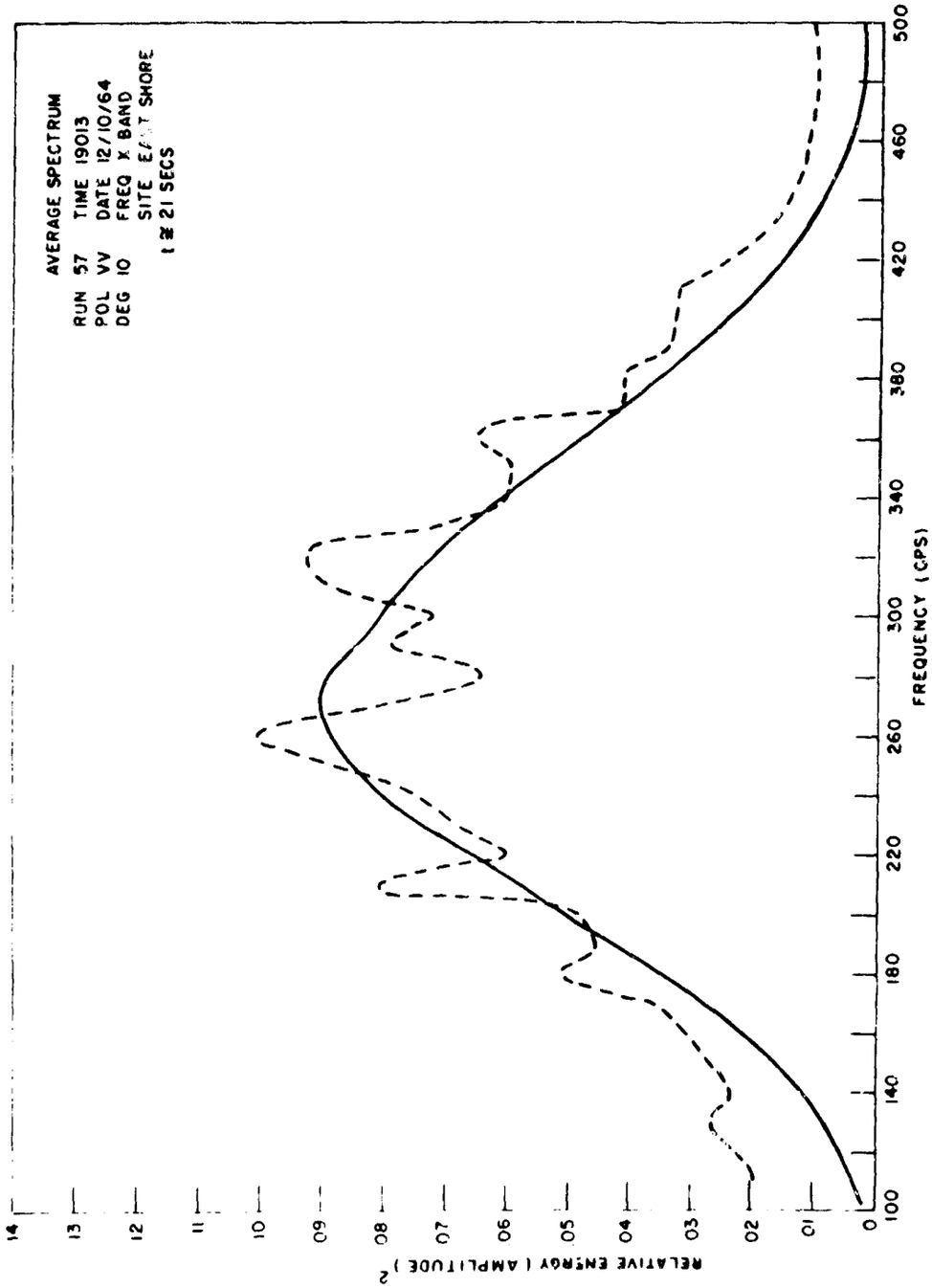

FIGURE 14 - Combined X-Band Average Spectrum for Vertical Polarization

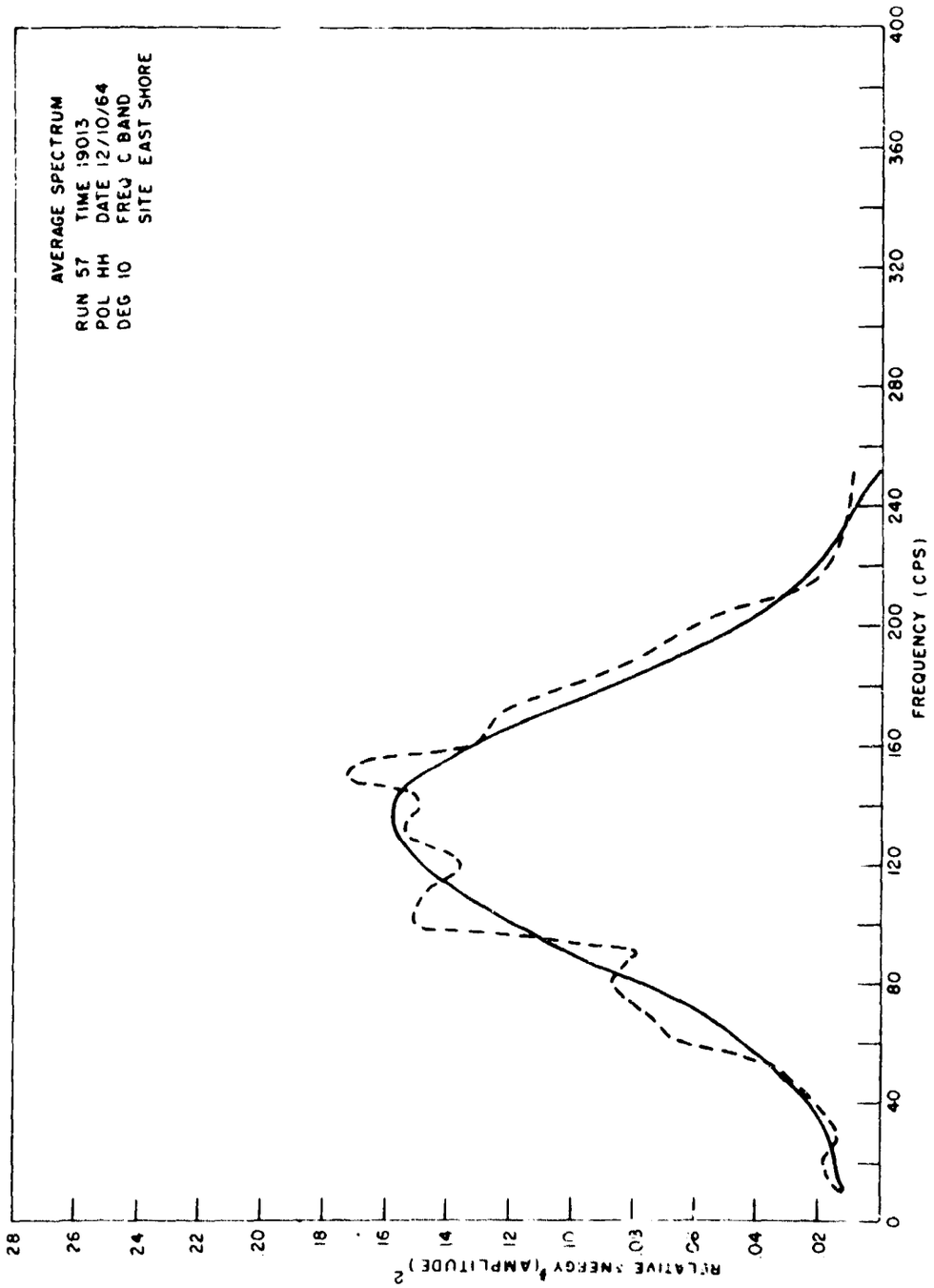

FIGURE 15 - Combined C-Band Average Spectrum for Horizontal Polarization

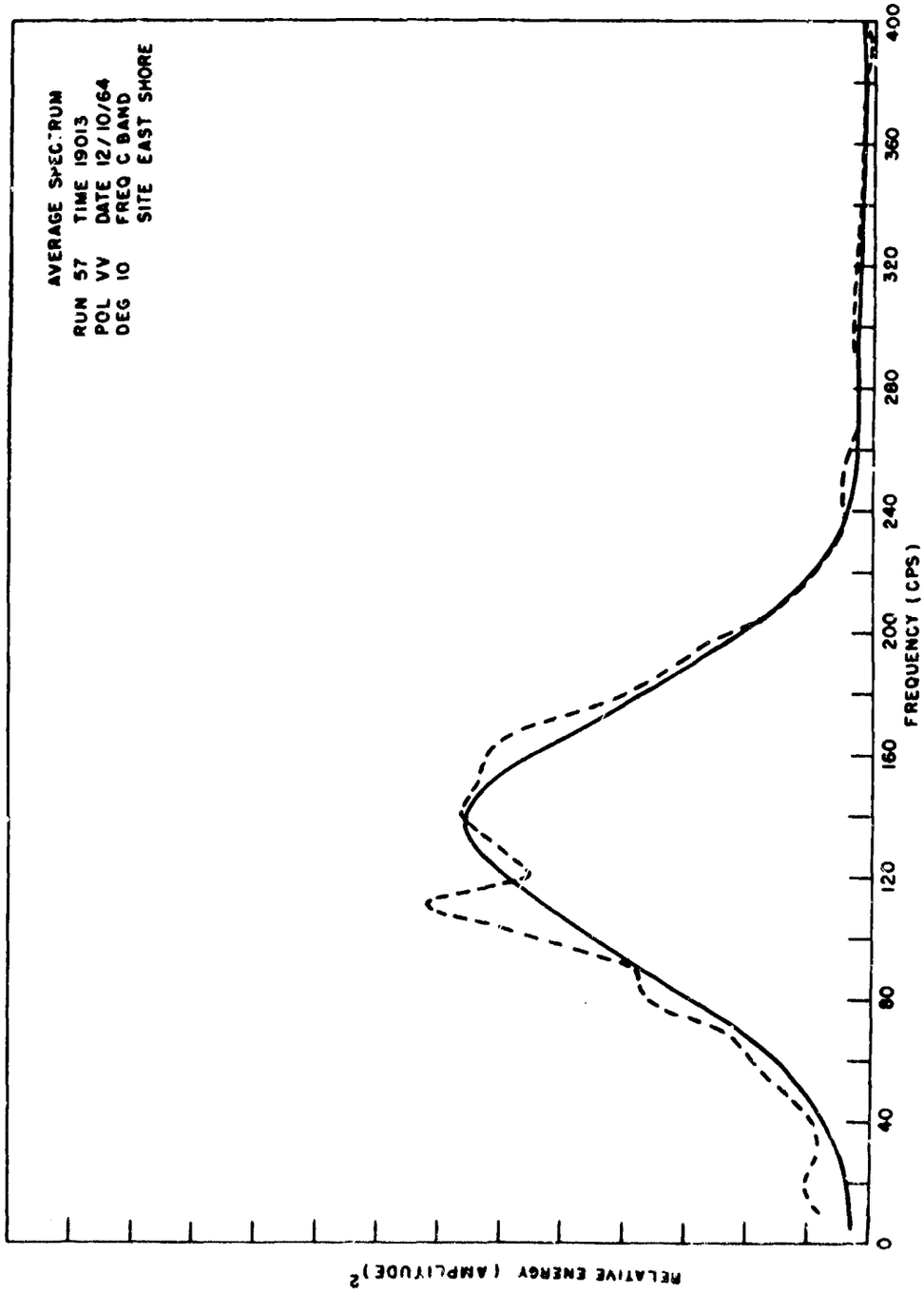

FIGURE 16 - Combined C-Band Average Spectrum for Vertical Polarization

GRAPHIC NOT REPRODUCIBLE

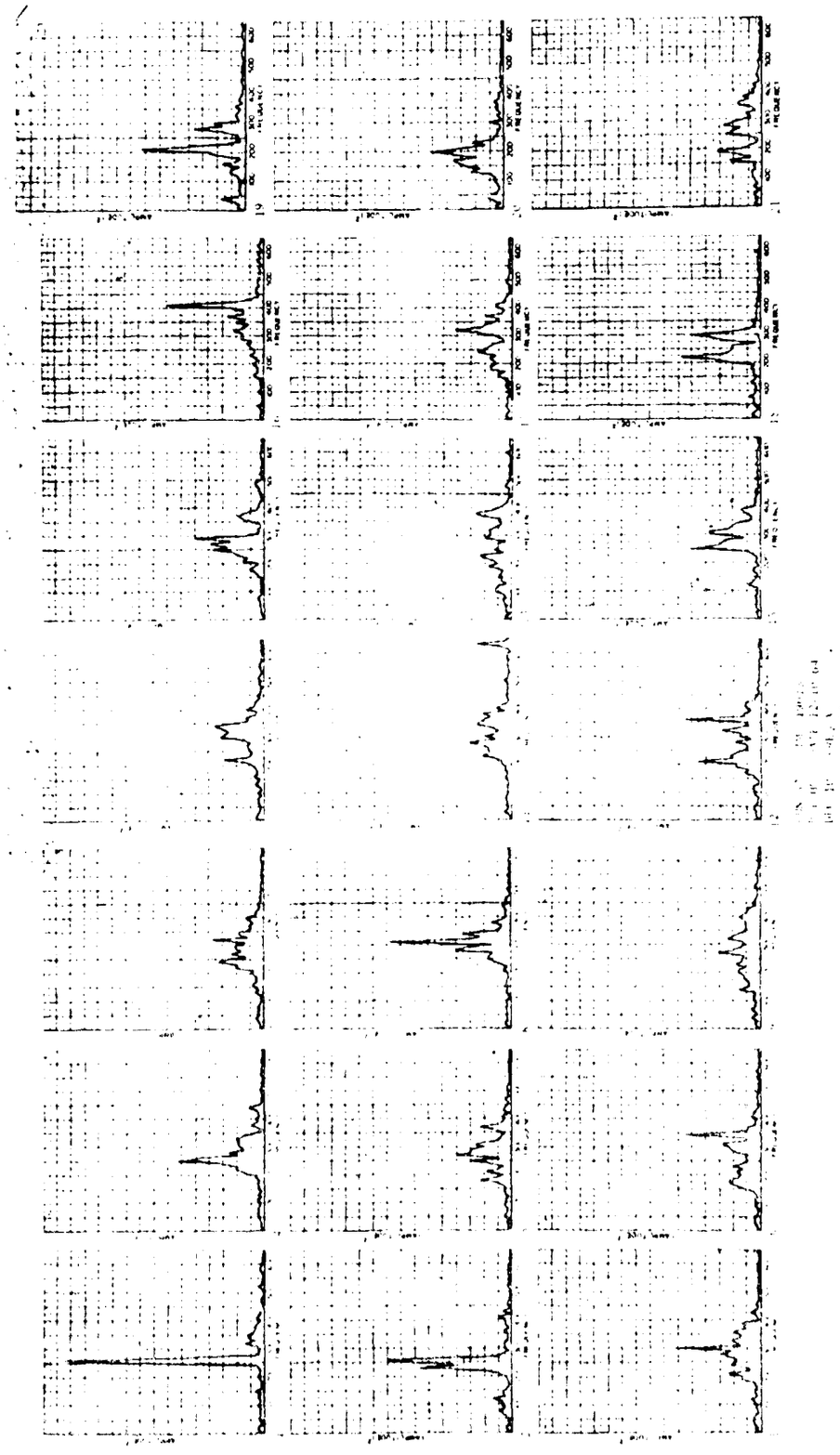

FIGURE 17 - X-Band Average Spectra for Horizontal Polarization

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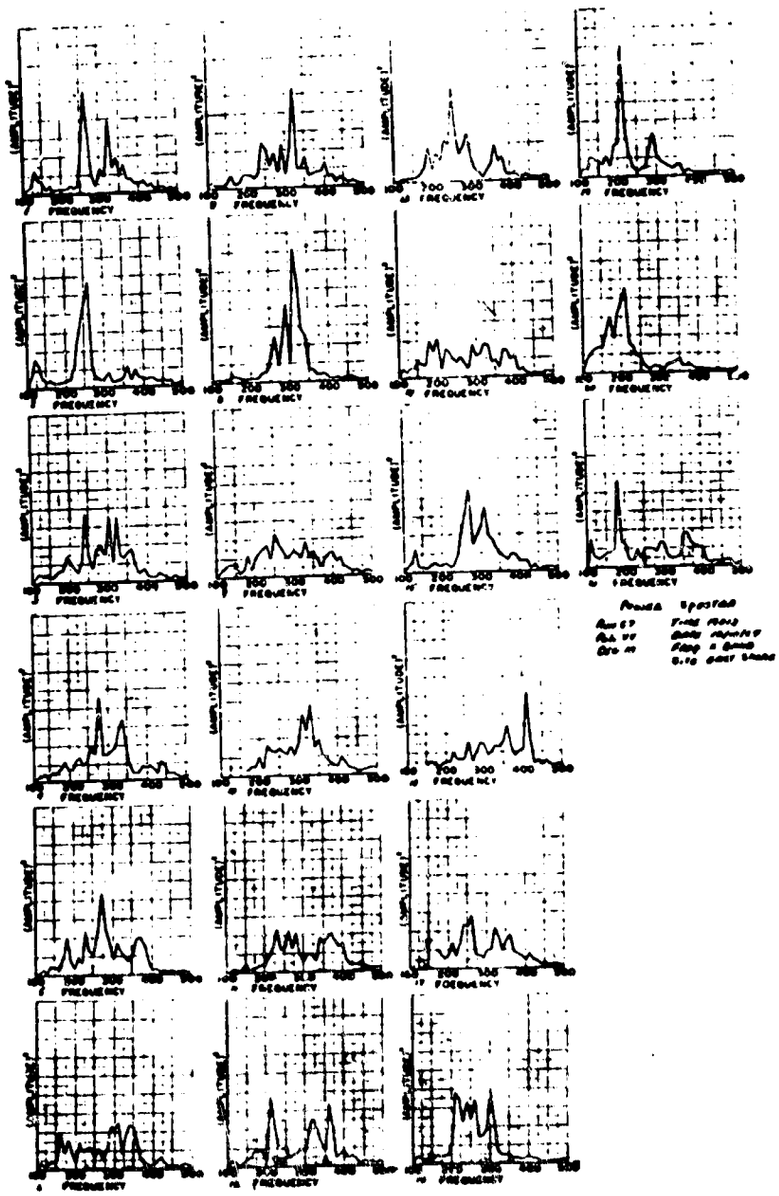


FIGURE 18 - X-Band Average Spectra for Vertical Polarization

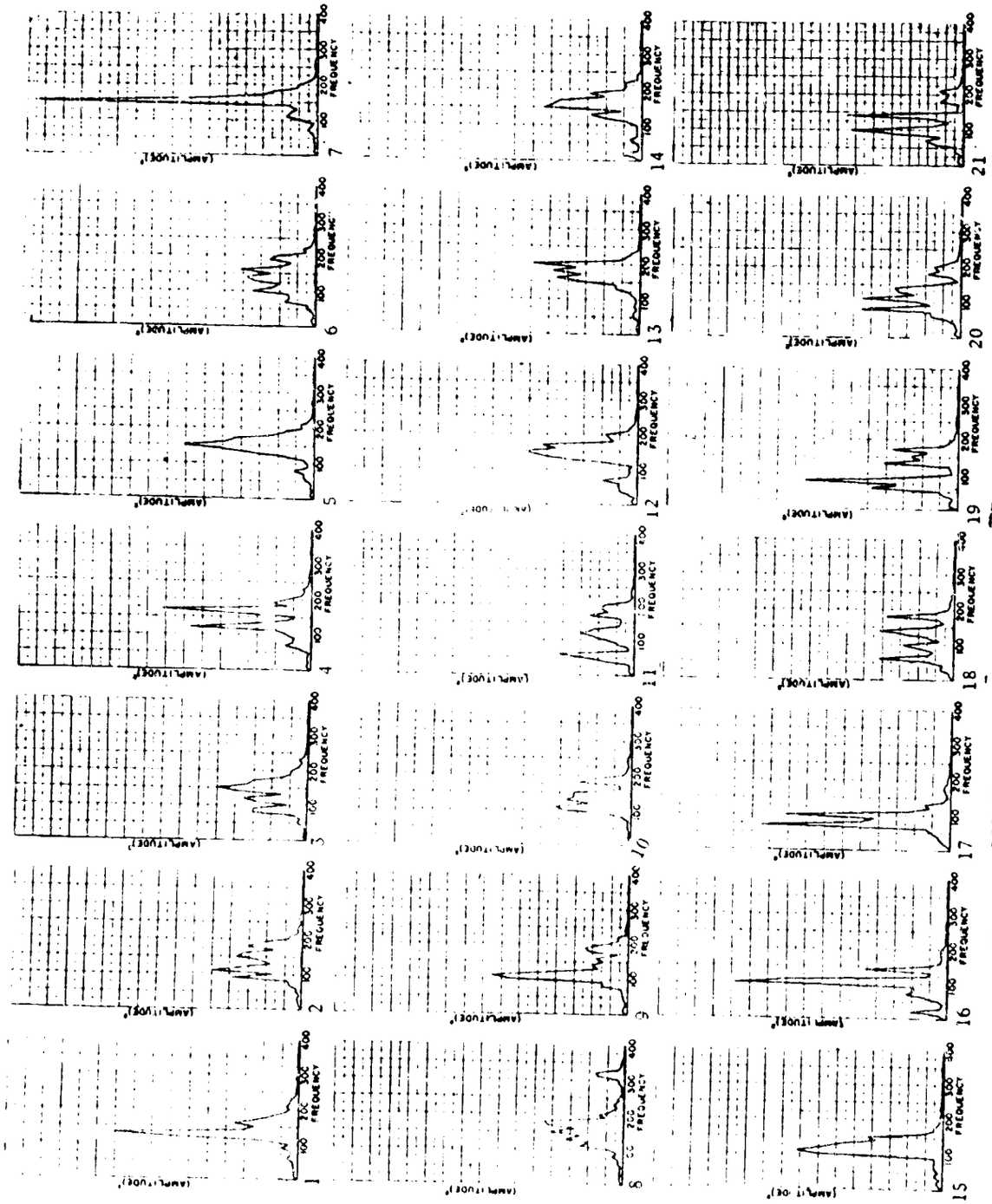
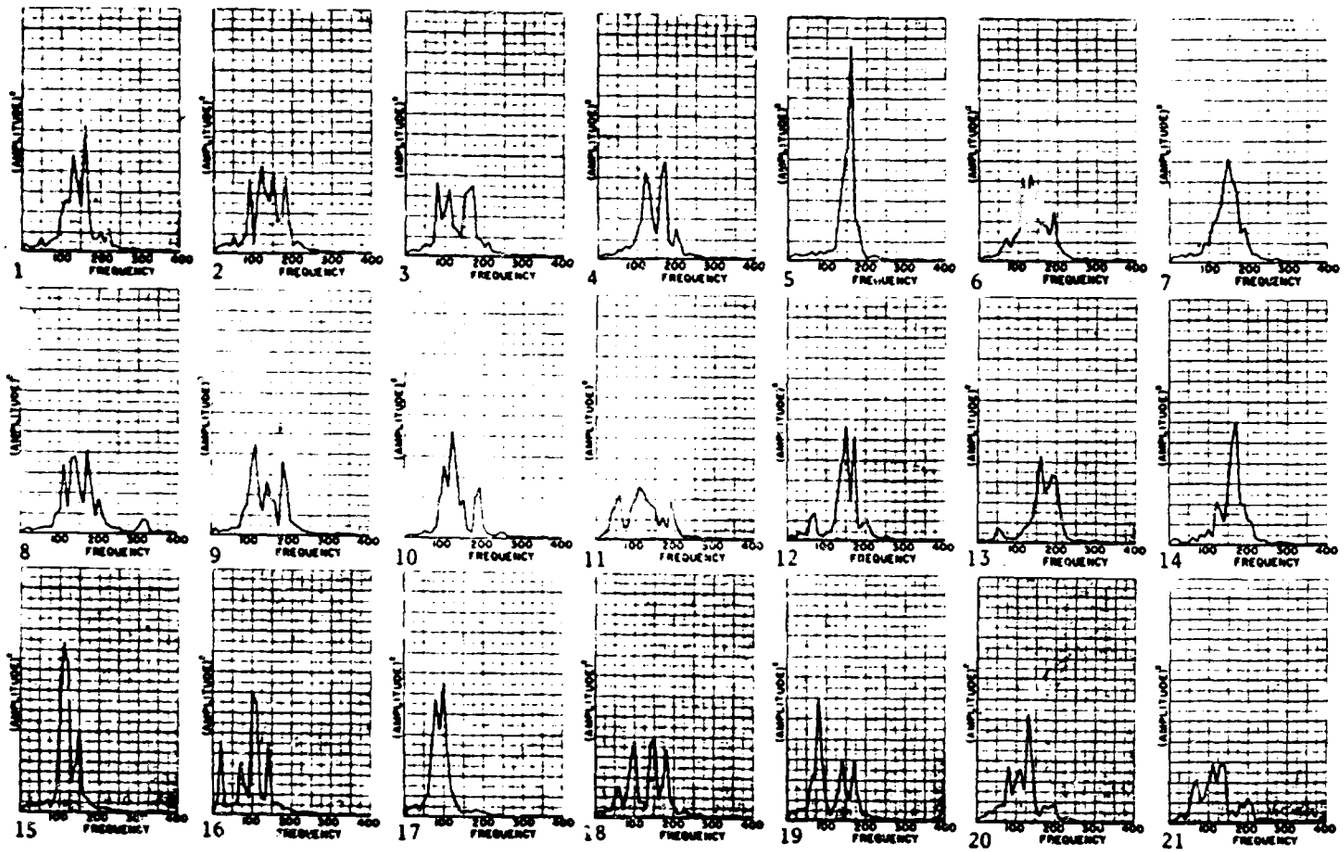


FIGURE 19 - C-Band Average Spectra for Horizontal Polarization

GRAPHIC NOT REPRODUCIBLE



RUN 57 TIME 19013
POL VV DATE 12/10/64
DEG 10 FREQ C
SITE EAST SHORE

FIGURE 20 - C-Band Average Spectra for Vertical Polarization

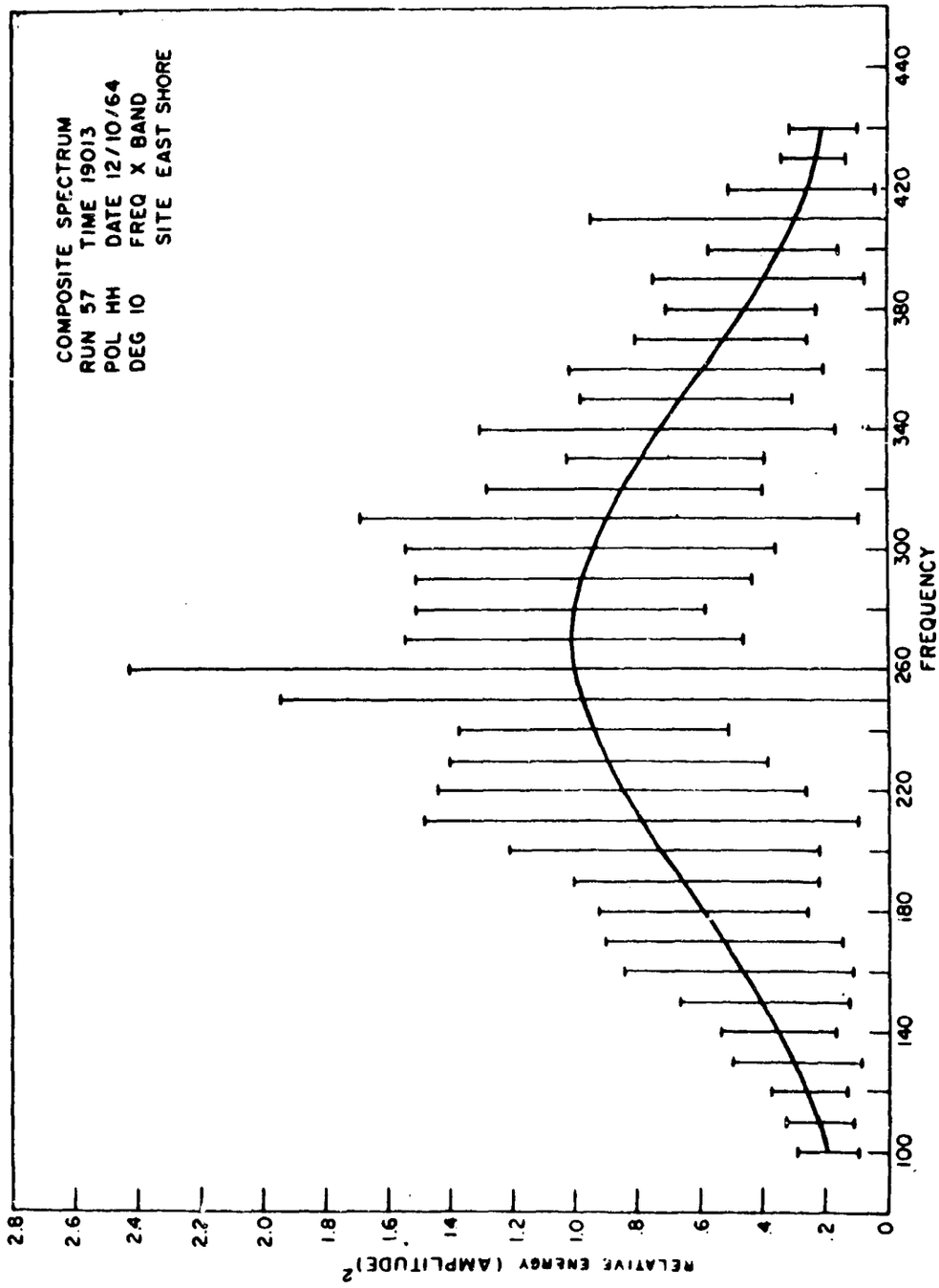


FIGURE 21 - Composite X-Band Spectrum for Horizontal Polarization

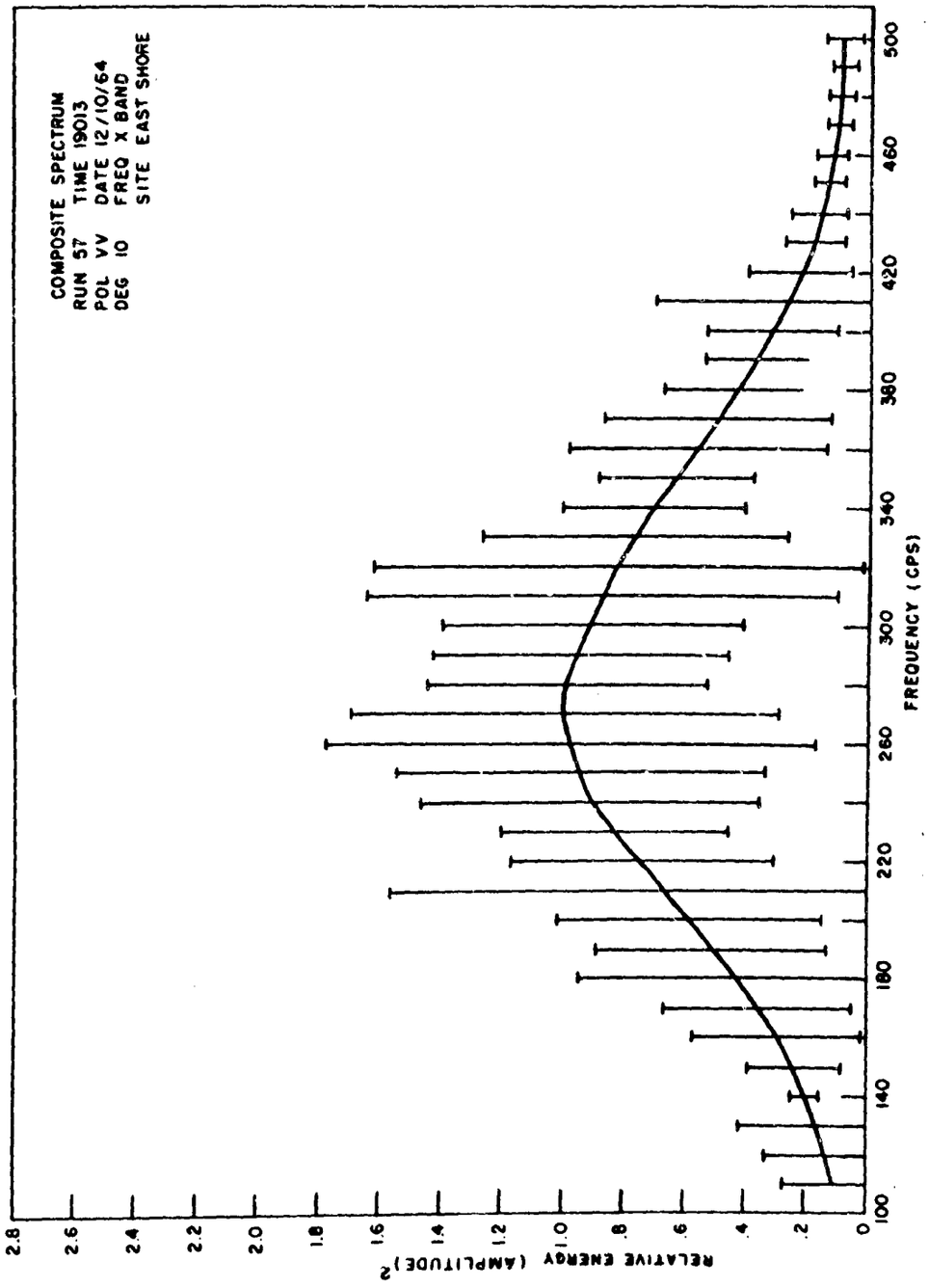


FIGURE 22 - Composite X-Band Spectrum for Vertical Polarization

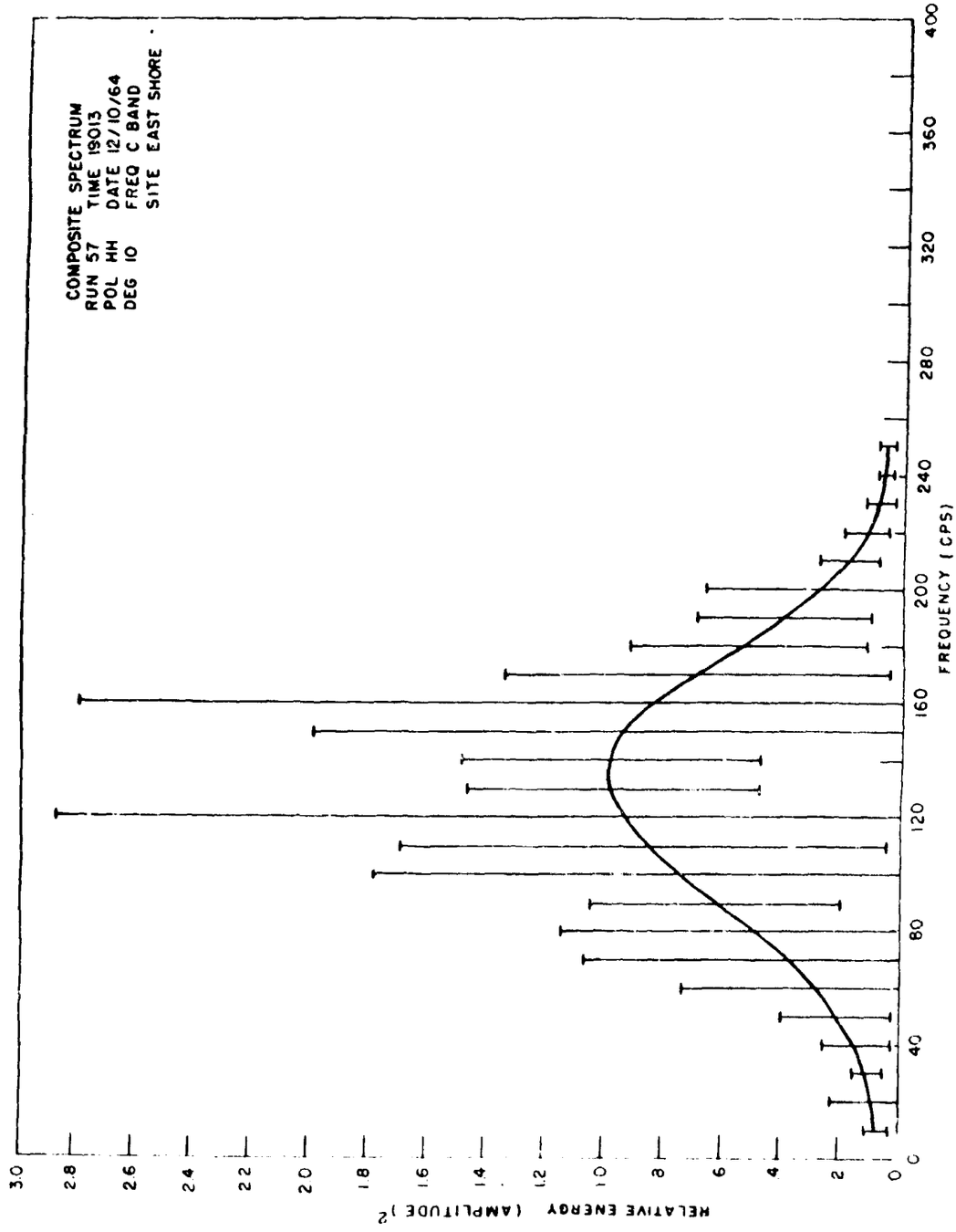


FIGURE 23 - Composite C-Band Spectrum for Horizontal Polarization

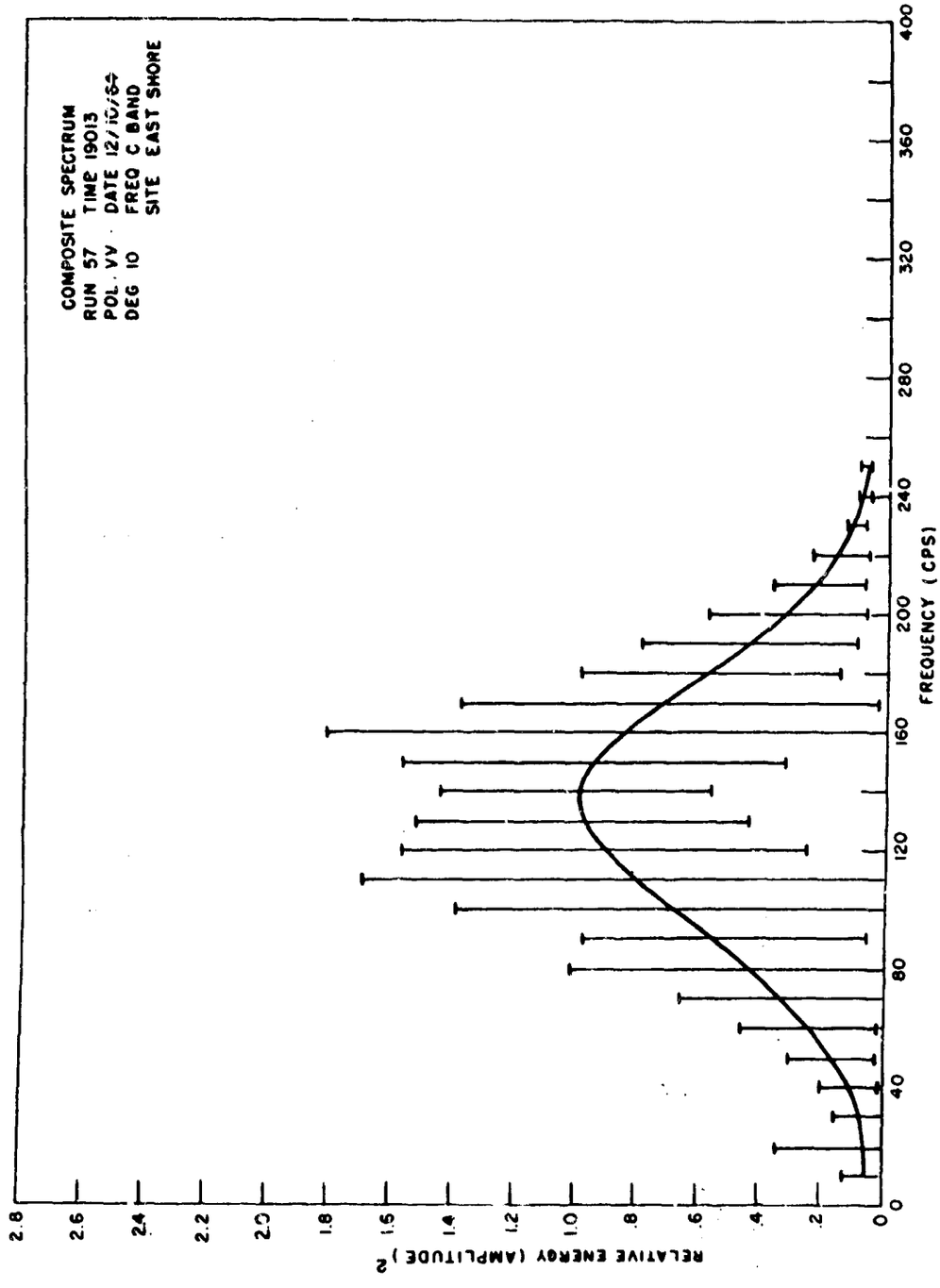


FIGURE 24 - Composite C-Band Spectrum for Vertical Polarization

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This report provides a clutter model based on currently available data, and is intended to be used in the design and evaluation of AEW radar techniques. It presents expected values of clutter amplitude, σ_o, as related to antenna depression angle, radio frequency, and polarization of the transmitting and receiving antennas. It also indicates typical doppler spectra.

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