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AN UNCONVENTIONAL APPROACH TO IMAGING RADAR CALIBRATION

R. G. FENNER and S. C. REID
NASA LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TEXAS

G. G. SCHABER
U.S. GEOLOGICAL SURVEY
FLAGSTAFF, ARIZONA

SUMMARY

Absolute calibration of radar return signals has been a goal of radar system engineers almost since radar was invented. A large degree of success has been obtained in the development of calibration techniques for instrumentation and fire control radar systems.

However, calibration of imaging radar systems has proven more difficult. Most past attempts to provide calibration to such systems have consisted of sampling the transmitted signal, and re-inserting this signal into the receiver in known quantities. This approach has had limited success, and does not address the question of end-to-end calibration.

This paper will present an unconventional approach in that it considers the entire system, including the imaging processing as a measurement instrument to be calibrated. The technique makes use of a calibrated aircraft scatterometer as a secondary standard to measure the backscatter (sigma zero) of large units of constant roughness. These measured roughness units when viewed by an imaging radar system can be used to provide gray-scale level corresponding to known degrees of roughness.

To obtain a calibrated aircraft scatterometer, a homogeneous smooth surface was measured by both the aircraft scatterometer and a sphere calibrated ground system. This provided a measure of the precision and accuracy of the aircraft system. The aircraft system was then used to measure large roughness units in the Death Valley, California area. Transfer of the measured roughness units to radar imagery was demonstrated.

1.0 INTRODUCTION

Absolute calibration of radar return signals has been a goal of radar system engineers almost since radar was invented. A large degree of success has been achieved in the development of calibration techniques for instrumentation and fire control radar systems.

However, calibration of imaging radar systems has proven more difficult. Most past attempts to provide calibration to such systems have consisted of sampling the transmitted signal, and re-inserting this signal into the receiver in known quantities.

One such use and evaluation of this technique was reported by the Environmental Research Institute of Michigan (ERIM) in 1973[1]. This approach has had limited success, and does not address the question of end-to-end calibration.

Imaging radar was originally developed to provide information for mapping and target recognition.

In the mid-1960's, the Department of Defense (DOD) developed techniques and ranges for evaluation of imaging radar systems. A summary of the DOD effort was presented by Marden in 1967[2]. The DOD effort was related to detection of cultural targets in various types of backgrounds and evaluation of geometric fidelity.

In the late 1960's and early 1970's as investigators started using radar imagery in Earth Resources investigations, the lack of end-to-end system calibration quickly became apparent. Most early imaging radar systems used optical recording and correlation techniques. Procedures and techniques for control of image quality during recording and correlation have been developed. Control of image processing will provide a uniform image output, but in no way addresses the end-to-end calibration problem. Variations in imaging radar systems performance, unknowns about the antenna characteristics, and atmospheric effects all must be accounted for to ensure end-to-end calibration.

At the Johnson Space Center, studies of the potential use of imaging radar in Earth Resources investigations were begun in the late 1960's. The results of one of these early studies by Stafford[3] outlined a concept of a large radar target range with varying degrees of known roughness. This target would be overflown frequently to give a means of relatively known image roughness to unknown image roughness.

The need for end-to-end calibration of imaging radar systems for Earth Resources investigations was not clearly established until the mid-1970's when investigators working in the fields of water resources and soil moisture areas began to realize the importance of radar backscatter data in their investigations. The inadequate performance of imaging radar systems with regard to end-to-end calibration have hindered meaningful investigations in these two important areas of Earth Resources.

2.0 END-TO-END RADAR CALIBRATION CONCEPT

Traditional approaches to imaging radar calibration generally involve the independent measurement of subsystem parameters, the calculation of total system transfer function and prediction of error bounds. Unfortunately, the error bounds associated with this approach may range as high as ±3db[1] which is excessive for a number of applications investigations using extended scene radar signatures. In addition to the difficulty of obtaining absolute calibration with reasonable error bounds, the problem of determination of the precision of the measurement exists.

In 1976, Johnson Space Center (JSC) initiated a program to establish the precision and accuracy of 1.6 GHz and 13.3 GHz scatterometers flown on the Airborne Instrumentation Research Program (AIRP) C-130 aircraft. This program as initially conceived involved the following:[4]

(1) Creation of a known sigma zero (σ_0) scene by performing in situ measurements over a smooth homogeneous surface using a sphere calibrated ground scatterometer system operating at 1.6 GHz and 13.3 GHz.

(2) Overflight of this scene with the aircraft 1.6 GHz and 13.3 GHz scatterometers.

(3) Determination of the aircraft systems precision and accuracy by analysis of the data gathered on the flights over the known sigma zero scene (calibration site).

In the course of determining how to evaluate the precision and accuracy of the aircraft scatterometer systems, the question of how pure roughness and its effect on sigma zero could also be evaluated, was addressed. A paper by Schaber, Berlin, and Brown in 1976[5] presented data indicating that sufficient studies and ground truthing of the roughness units in the Death Valley Area of California had been performed to allow it to be used for evaluation of roughness. However, gathering of ground scatterometers data for sigma zero verification would be extremely difficult.

A comparison of the terrain features and soil characteristics of the site chosen for the precision and accuracy evaluation (Northrop Strip, White Sands Missile Range, New Mexico) and the Badwater Basin region of Death Valley indicated many similar characteristics. This lead to the concept of extending calibration from a known and tested ground site to a training site, via aircraft scatterometer systems. The training site would contain roughness units varying in roughness from smooth to extremely rough.

A concept of end-to-end radar calibration as shown in Figure 1 was derived. This concept would function as follows:

Step #1: The calibration site sigma zero curves for a smooth homogeneous surface would be derived by performing measurements with a calibrated ground scatterometer system.

Step #2: This site would then be overflown with the airborne scatterometers and the precision and accuracy of the aircraft systems established.

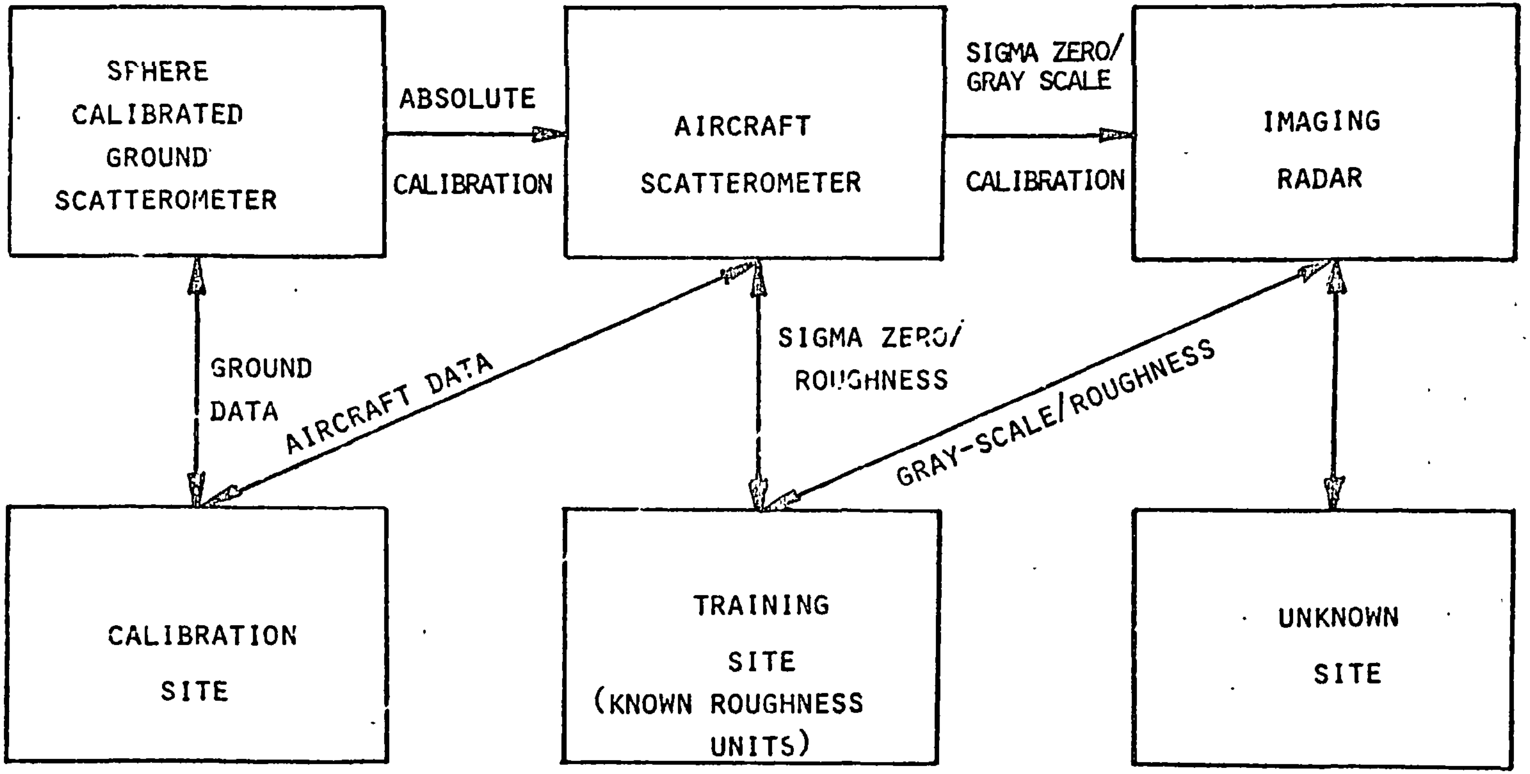

FIGURE 1

END-TO-END RADAR CALIBRATION CONCEPT

<u>Step #3</u>: The training site would be overflown with the aircraft scatterometer systems and sigma zero curves for the pure roughness units in the test site derived.

<u>Step #4</u>: The sigma zero curves derived for the test site would be used to relate gray-scale levels to roughness in imagery taken over the test site.

<u>Step #5</u>: The gray scale to roughness relation derived from imagery taken over the test site would be used to evaluate the amount of roughness and/or variations and deviations in roughness in radar imagery taken over unknown sites. Knowledge of the grey scale to roughness relation is an important piece of information in evaluating radar imagery.

Certain criteria must be applied to the sites selected for calibration and training sites. Each must be devoid of vegetation and have surface characteristics that are stable with time. Once measured, they must be controlled to ensure that manmade changes such as construction do not alter their characteristics.

On the calibration site, the surface must appear smooth at the highest frequency that data will be gathered at. The site must be accessible for ground scatterometer testing.

The training site must contain roughness units varying from a smoothness approaching the calibration site and increasing in roughness graduations to the largest degree of roughness available. These units must be large enough to provide sufficient independent samples for precise measurements. The sites chosen for the calibration and training sites meet all of these criteria.

3.0 CALIBRATION SITE

The site chosen for the calibration site is the Northrop Strip located on the White Sands Missile Range in New Mexico. Northrop Strip is a 10,000-foot long by 300-foot wide emergency landing strip built on a dry lake bed. The

TABLE I

MEAN VALUE OF MEASURED DIELECTRIC CONSTANT

NORTHROP STRIP, WSMR

	1968 (10.0 GHz)	June 1977 (13.3 GHz)	Nov. 1977 (13.3 GHz)
Real	4.12	4.76	5.31
Imaginary	3.01	2.37	1.63

surface is packed gypsum sand with a high alkaline content. This site was chosen for a number of reasons as follows:

(1) The entire area is naturally smooth with the runway surface graded and packed.

(2) The site is located in an arid area, devoid of vegetation and not subject to seasonal variations in surface moisture.

(3) The high alkaline content of the soil will tend to make it a highly reflective surface at the frequencies of interest.

(4) Radar reflectivity and soil dielectric constant data had previously been gathered on the site as part of the Apollo Lunar Reflectivity Program in 1968.[6]

(5) The runway is well marked with visual aids for repeatability of aircraft flight lines.

Ground truth data acquisition at the site was initiated in June of 1977 by taking a series of soil samples and measuring the dielectric constant in the same manner as reported by Dickerson.[6] Additional samples were taken in November 1977. Table I shows the average results of these samples. This data shows that there are no long-term (yearly) or short-term (seasonal) variations in the surface properties of the soil at the site.

To ground truth the site, a ground scatterometer utilizing the FM/CW approach reported by Bush and Ulaby in 1973[7] was constructed. Initial plans were to ground truth the site in June of 1977 coincident with the aircraft overflight, but mechanical difficulties with the antenna system prevented the ground measurements from being made until November of 1977.

4.0 TRAINING SITE

The use of known terrain scattering properties to provide a convenient method of calibrating airborne radar systems was first suggested in 1960 by Cosgriff et al[8]. Recent work by Schaber (1976) has delineated the characteristics of geologic units on radar images of Death Valley. The unique combination of large pure roughness units, unchanging electrical surface properties, and time constant roughness units makes Death Valley an ideal training site for imaging radar calibration. The well-documented characteristics of the region, the absence of rainfall and vegetation ensure the temporal stability of the backscatter coefficient obtained. For these reasons Death Valley was chosen as a potential training site.

A series of scatterometer flights were flown over Death Valley in June of 1977. Flight lines were chosen such that sufficiently large areas of constant roughness were overflown to ensure adequate sampling.

5.0 PROGRESS TO DATE

As stated previously, aircraft scatterometer data was gathered over the Northrop Strip, WSMR calibration site and the Death Valley, California test site in June of 1977. The calibration site ground scatterometer data was gathered in November of 1977.

Analysis of this data has progressed slowly because of difficulty in processing of the aircraft data. To date, only the precision or repeatabilities of the data sets has been addressed. Attempts to arrive at an accuracy estimate by comparison of ground and aircraft data sets has not proved completely successful.

Some of the differences between scatterometer data sets and the ground scatterometer data sets may be due to problems in the data reduction methods for the two systems. Analysis of the data reduction techniques is presently underway to resolve the differences.

The following paragraphs will discuss the results of the data analyzed to date:

5.1 DATA ACQUISITION

Ground scatterometer calibration site data was acquired for two frequencies (1.6 GHz and 13.3 GHz) at six locations spaced 500 feet apart along the Northrop Strip runway center line. This provided a 2500 foot long sample area. Azimuth rotation of the antenna systems provided multiple samples at each location. Incident angle data was acquired at 10, 20, 30, 40, 50, and 60 degrees.

The aircraft scatterometer data was acquired by multiple flights over the same sample area as used by the ground scatterometer. A total of 16 data runs were made on two successive days with four morning and four afternoon runs each day. Five data runs were made over the Death Valley training site to establish the relative magnitude of the radar reflectivity data from the wide range of surface roughness conditions available.

The aircraft flew at a 1500-foot altitude and a ground speed of 150 knots. The radar antenna footprints at this altitude were 225 feet and 75 feet for the 1.6 and 13.3 systems, respectively.

In order to gather 13.3 scatterometer samples only over the Northrop Strip runway, the aircraft flight had to satisfy the conditions of either being exactly over the runway centerline with a combined roll and drift of less than three degrees or be less than 100 feet off the centerline with no roll or drift. Photography obtained during the data runs was used to establish aircraft flight path relative to runway centerline. The LTN-51 inertial navigation system was used to determine aircraft roll and drift. For the 16 runs flown, these conditions were satisfied on ten runs thus defining the data set that was used for analysis.

5.2 DATA PROCESSING

Ground scatterometer data was reduced as it was gathered by the use of a Hewlett-Packard 9820 programmable calculator operating in conjunction with the scatterometer systems.

The aircraft scatterometer data is recorded on FM analog recorders and returned to JSC for playback, analog to digital conversion and digital processing. The data processing is accomplished on a PDP-11/70 minicomputer using the algorithms developed by Krishen.[9]

The program output is in the form of time correlated sigma zeros at angles of 5, 10, 15, 20, 30, 40, 50, and 60 degrees off nadir. The sampling times used were 0.42 seconds and 0.1 seconds for the 1.6 and 13.3 systems repectively.

5.3 DATA ANALYSIS RESULTS

5.3.1 Northrop Strip

5.3.1.1 Ground Scatterometer

Figures Two and Three are plots of mean and standard deviations of the data gathered by the ground system. Mean standard deviation for the 1.6 GHz data is 0.77 db. Mean standard deviation for the 13.3 GHz data is 1.0 db. This is a limited data set since the sigma zero values for angles of 10° and 20° represent a small number of statistically independent samples.

5.3.1.2 Aircraft Scatterometers

Curves of relative mean radar reflectivity versus incidence angle have been developed to illustrate the precision of measurement obtained. Figures 4 and 5 represent mean values for 1.6 GHz VV and HH data acquired on four runs over two successive days. Figure 6 represents mean values for 13.3 GHz data acquired on ten runs over two successive days. The day-to-day repeatability of the aircraft systems is excellent as indicated by the less than 1 db standard deviation of all data acquired.

The data standard deviations within a run and between runs on the same day provided in Table II are lower than those obtained when considering data acquired on different days. This should be expected since the conditions under which the data was gathered could not be rigidly controlled from day to day, hence the mean values of the data sets are different.

5.3.2 Death Valley

Data acquired over the Death Valley site has not yet been processed, however, analog time histories provide information on the dynamic range available at this site. Figures 7 and 8 are radar reflectivity time histories illustrating the changes present at the transition from the roughest geological

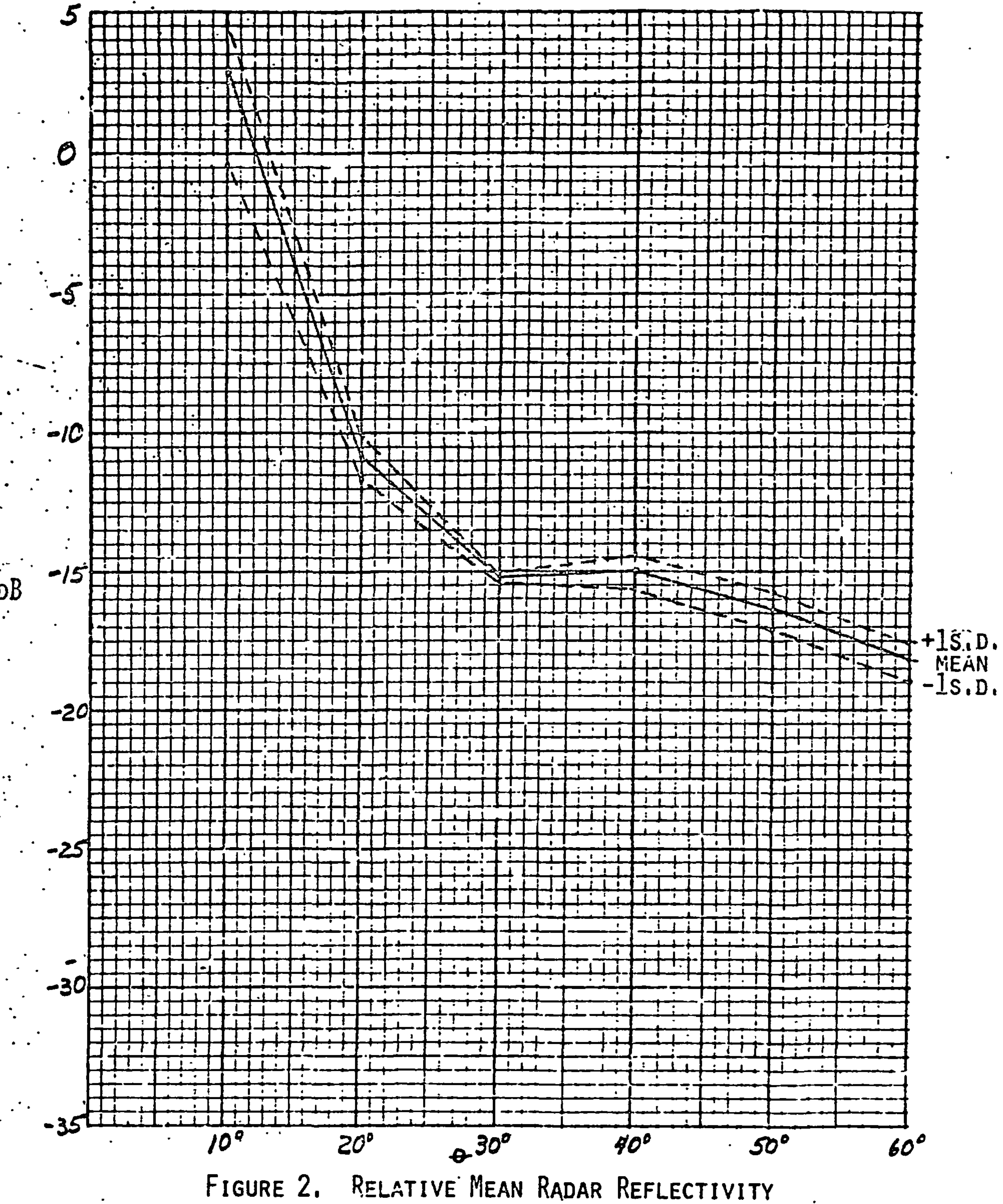

FIGURE 2. RELATIVE MEAN RADAR REFLECTIVITY - GROUND 1.6 GHz VV - WHITE SANDS

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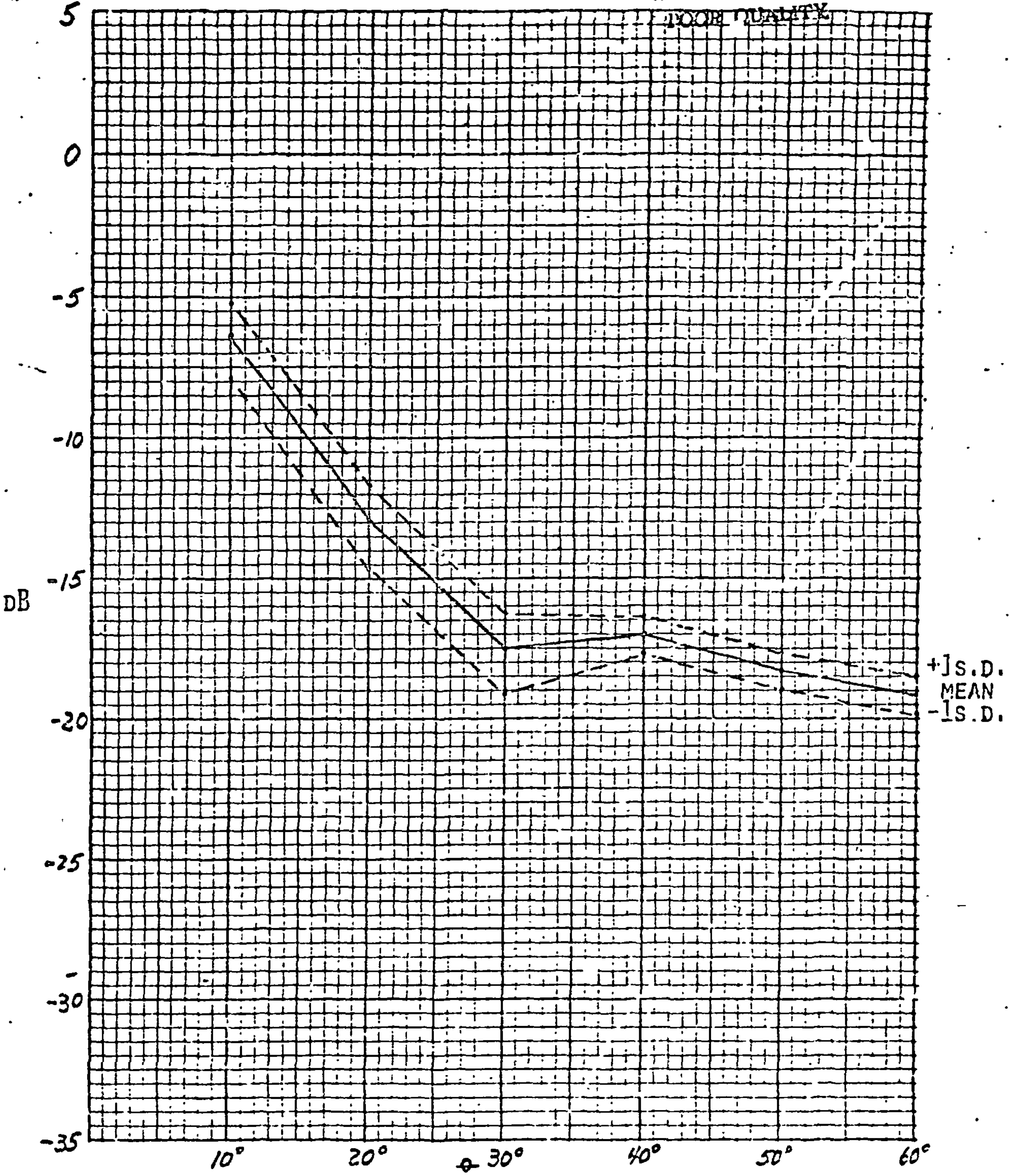

FIGURE 3. RELATIVE MEAN RADAR REFLECTIVITY - GROUND 13.3 GHz VV - WHITE SANDS

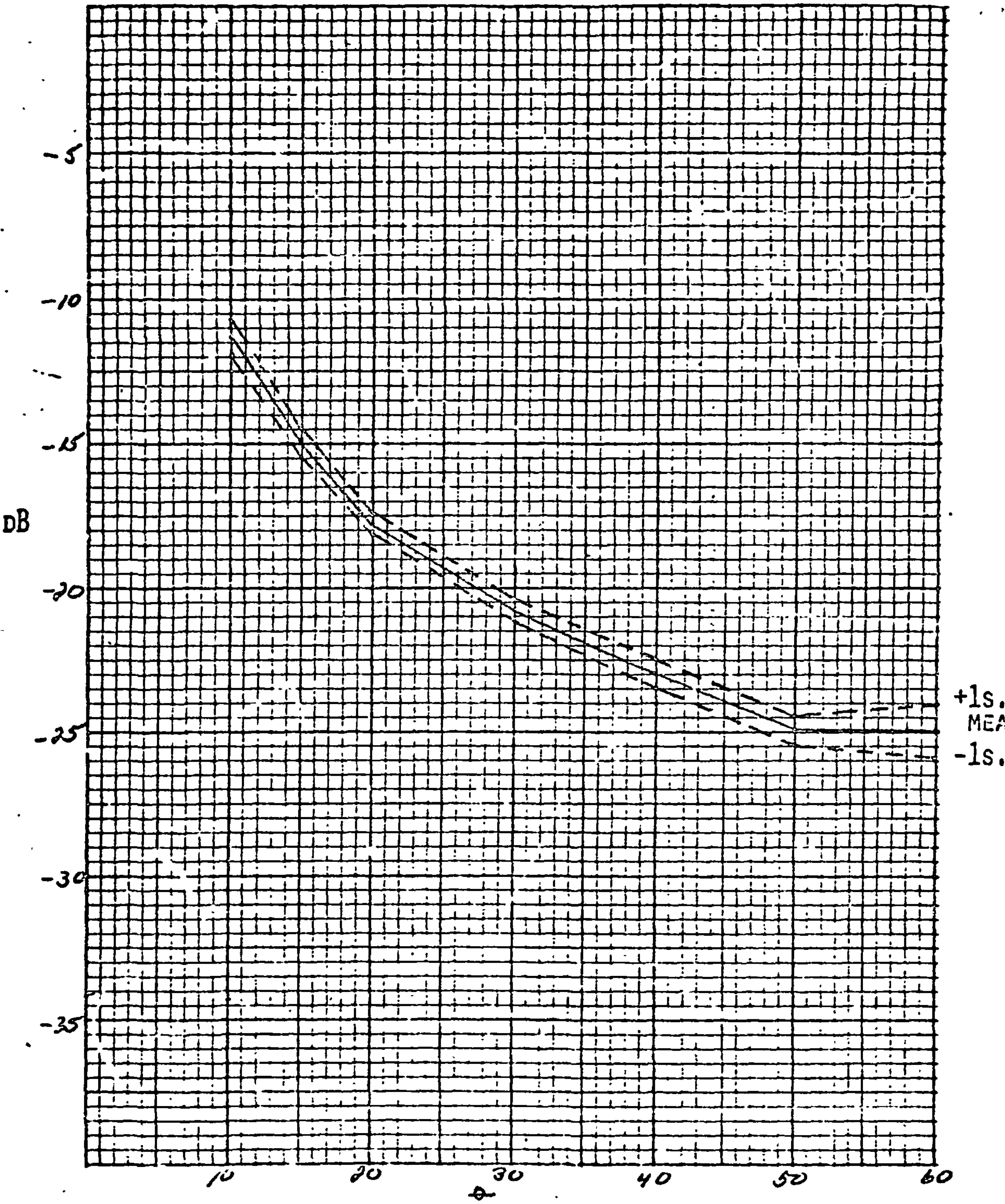

FIGURE 4. RELATIVE MEAN RADAR REFLECTIVITY - A/C 1.6 GHz VV - WHITE SANDS

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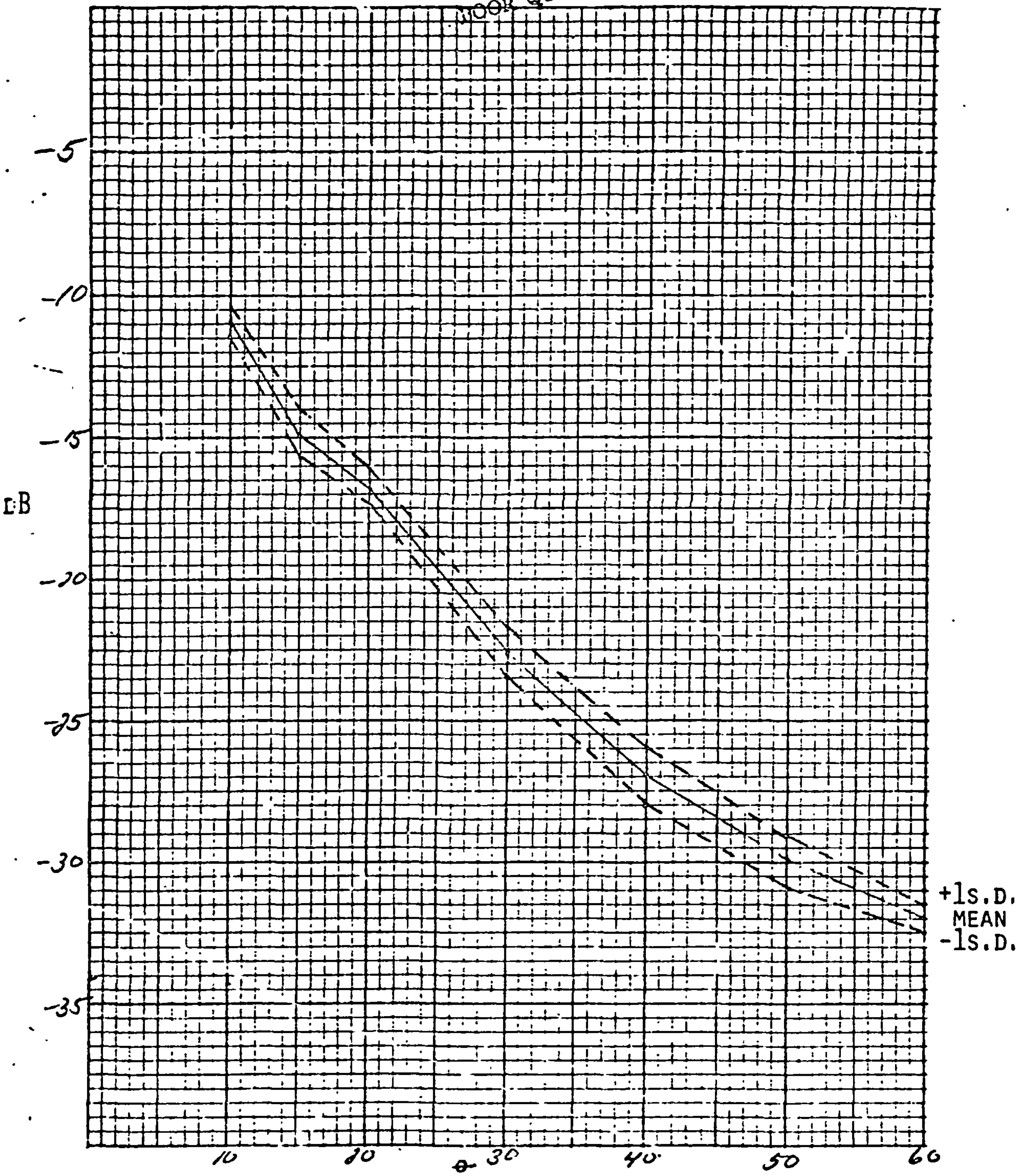

FIGURE 5. RELATIVE MEAN RADAR REFLECTIVUTY
- A/C 1.6 GHz HH - WHITE SANDS

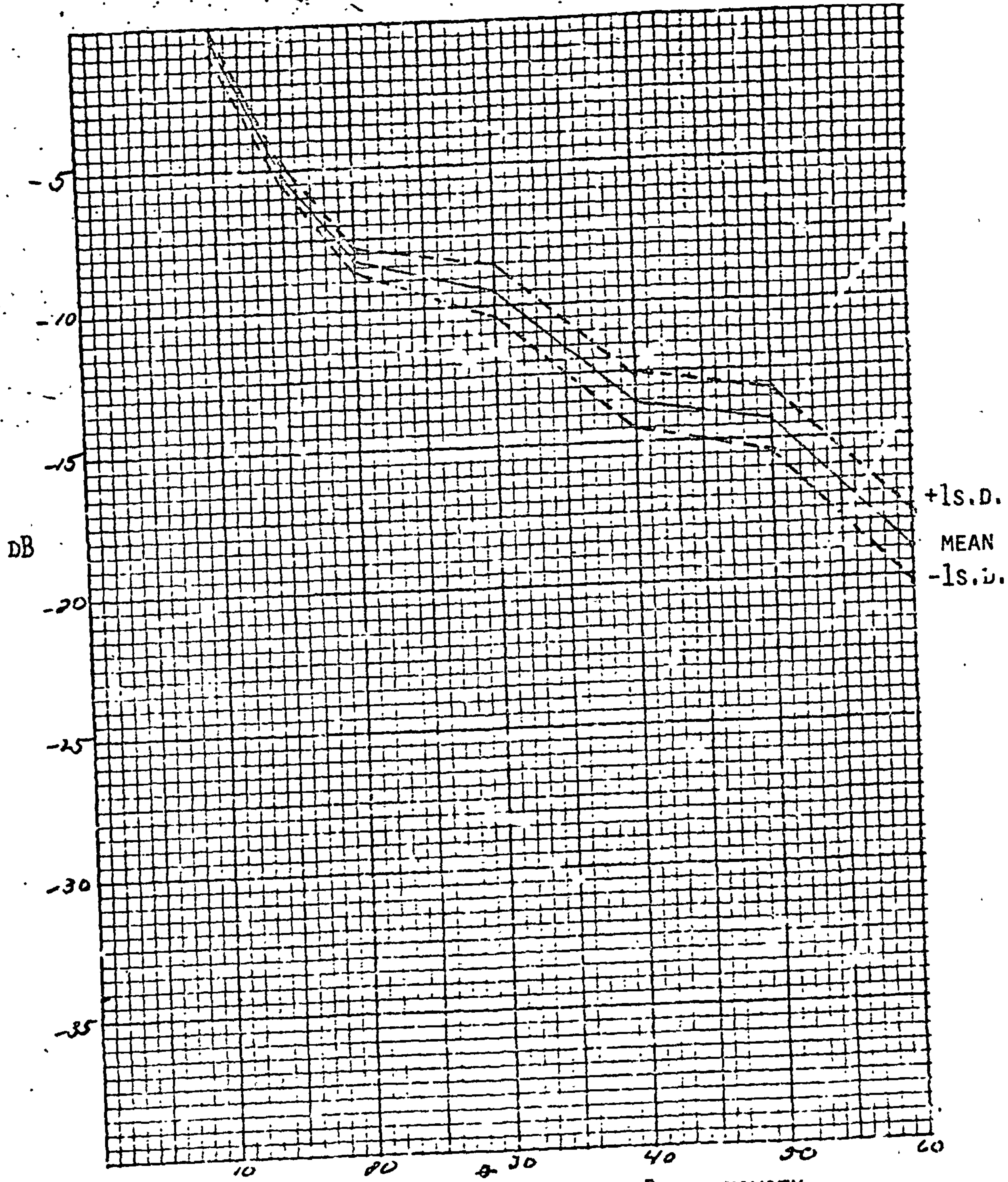

FIGURE 6. RELATIVE MEAN RADAR REFLECTIVITY
- A/C 13.3 GHz VV - WHITE SANDS

TABLE II

STANDARD DEVIATION OF A/C DATA

			10°	20°	30°	40°	50°
1.6 GHz	VV	WITHIN RUN	0.4	0.5	0.5	0.5	0.5
1.6 GHz	VV	RUN-TO-RUN SOME FLIGHT	0.6	0.5	0.7	0.8	0.7
- 1.6 GHz	VV	DAY-TO-DAY	0.8	0.9	1.0	0.7	0.8
1.6 GHz	HH	WITHIN RUN	0.3	0.3	0.4	0.5	0.5
1.6 GHz	HH	RUN-TO-RUN SOME FLIGHT	0.5	0.5	0.6	0.6	0.7
- 1.6 GHz	HH	DAY-TO-DAY	0.7	0.7	0.7	0.6	0.8
13.3 GHz	VV	WITHIN RUN	0.3	0.4	0.5	0.5	0.6
13.3 GHz	VV	RUN-TO-RUN SOME FLIGHT	0.4	0.4	0.7	0.7	0.9
- 13.3 GHz	VV	DAY-TO-DAY	0.5	0.5	1.0	1.0	1.1

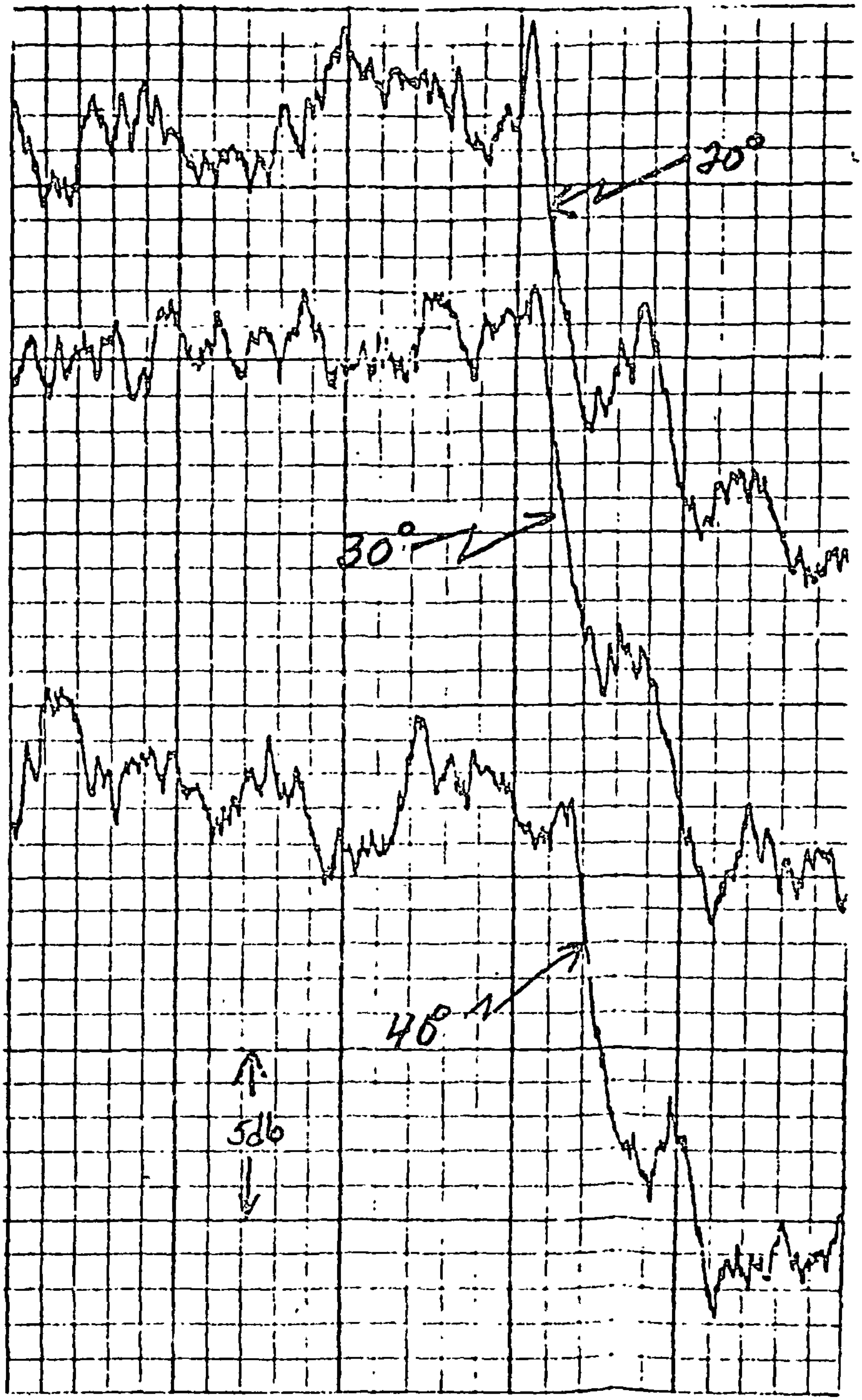

FIGURE 7. RADAR REFLECTIVITY TIME HISTORIES - 1.6 GHz VV - DEATH VALLEY

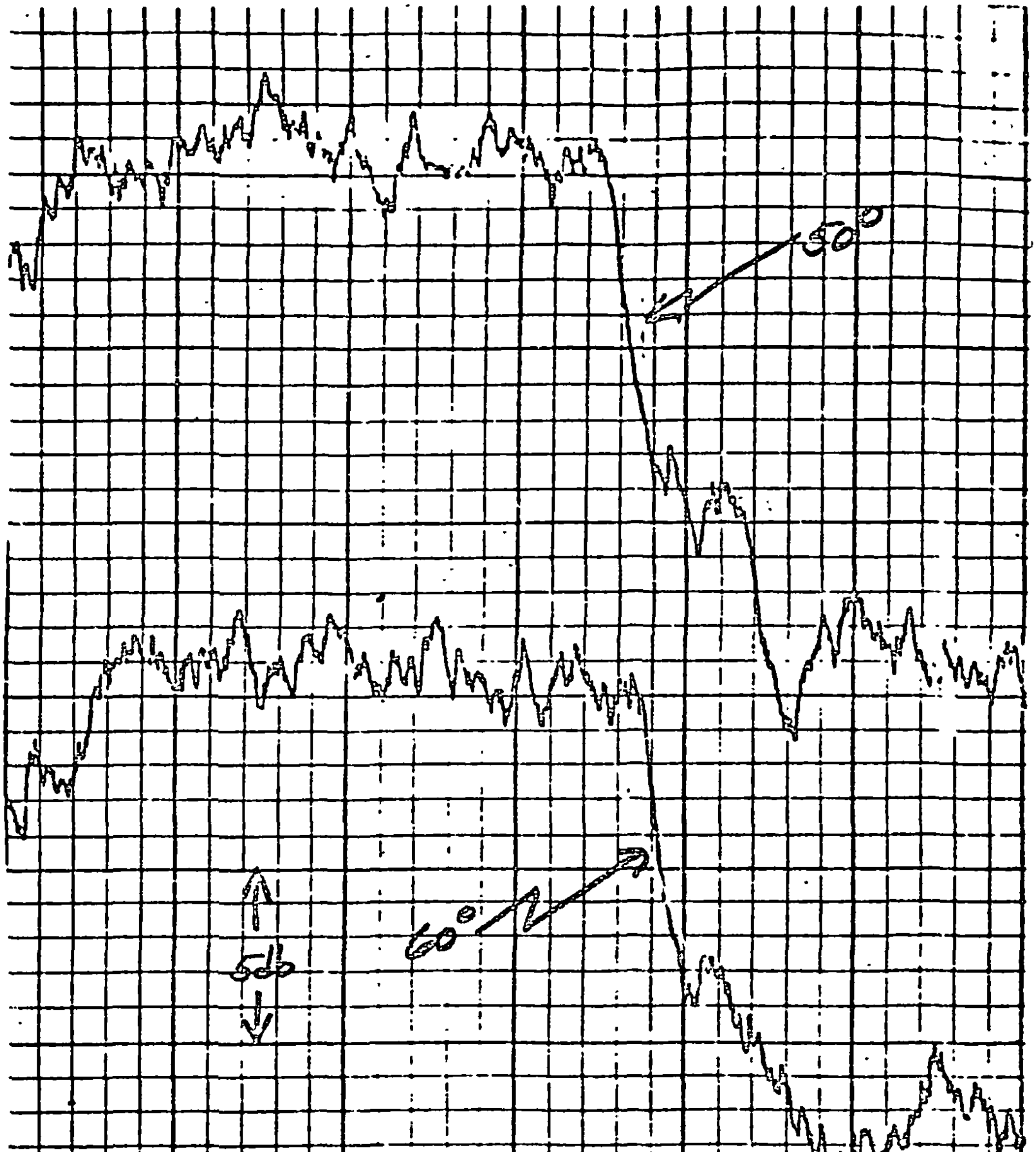

FIGURE 8. RADAR REFLECTIVITY TIME
HISTORIES - 1.6 GHz VV - DEATH VALLEY

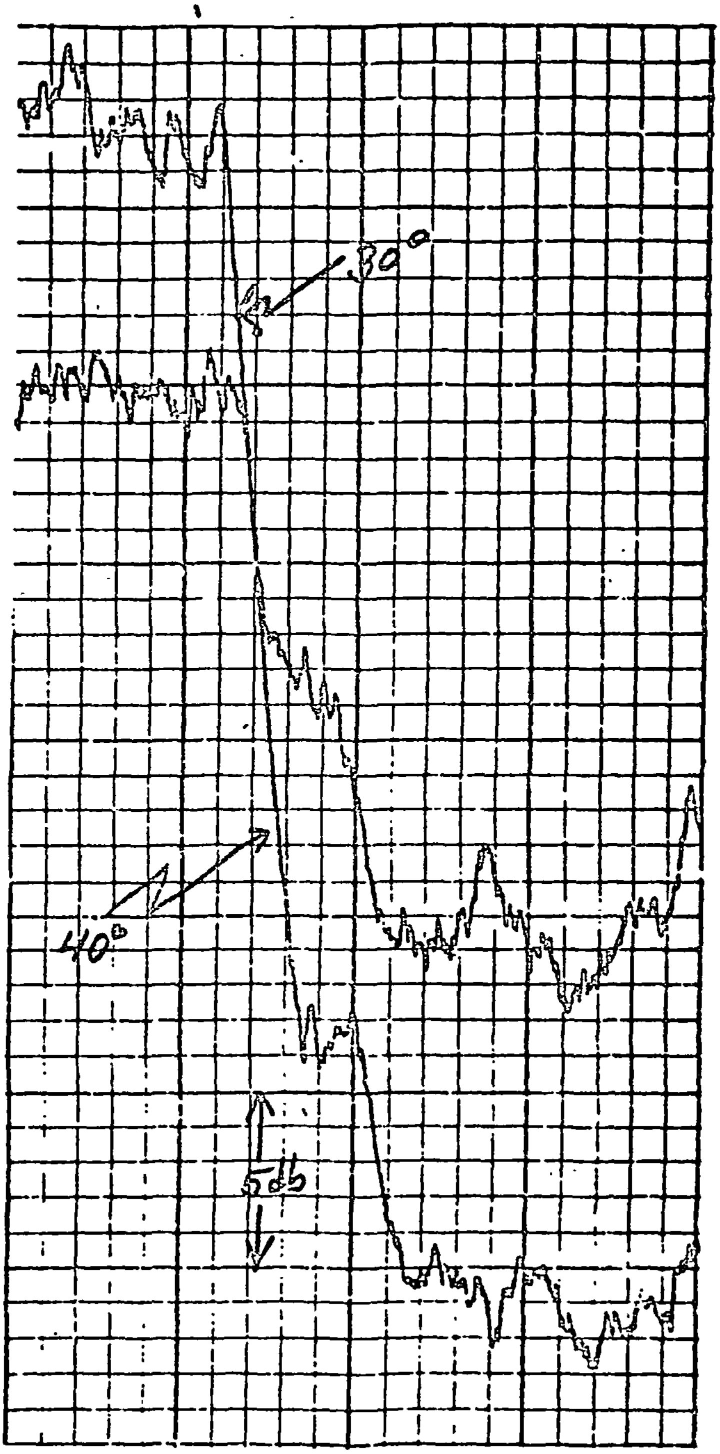

FIGURE 9. RADAR REFLECTIVITY TIME HISTORIES - 1.6 GHz VH - DEATH VALLEY

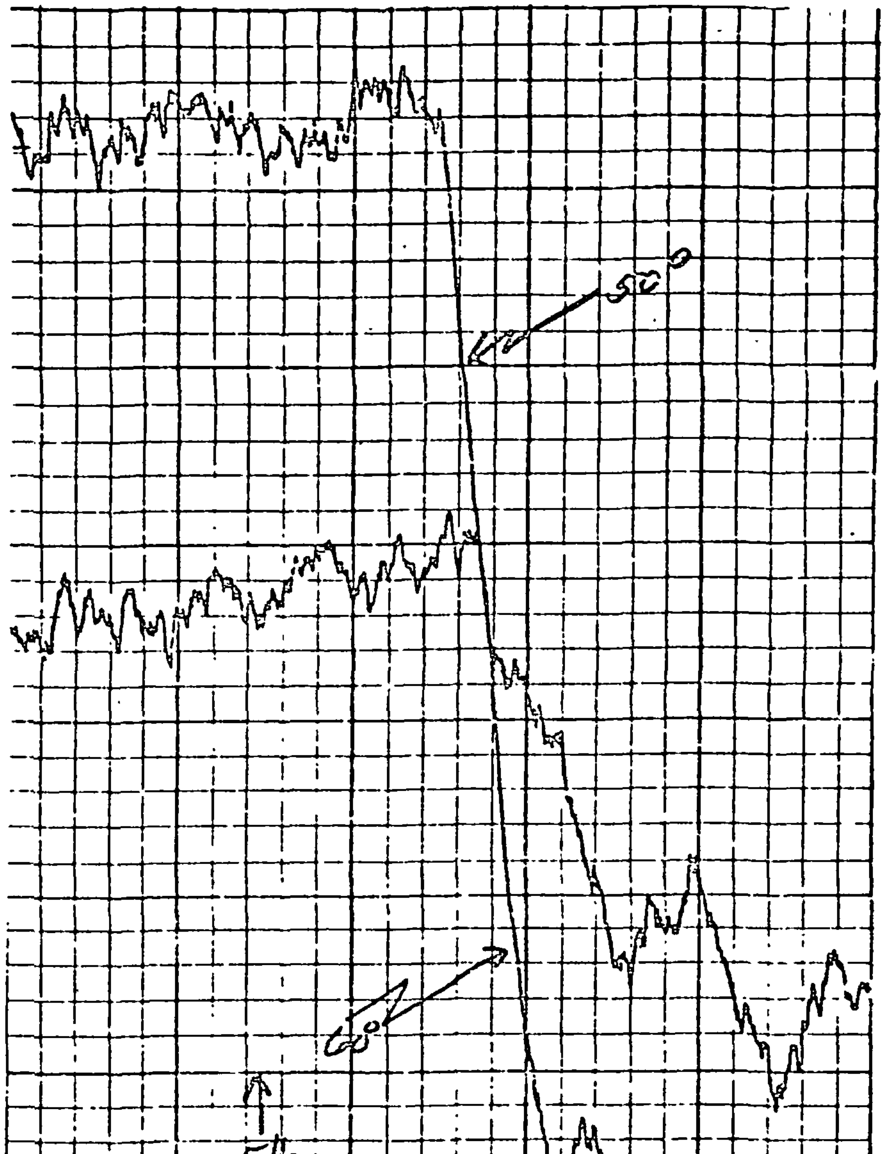

FIGURE 10. RADAR REFLECTIVITY TIME HISTORIES - 1.6 GHz VH - DEATH VALLEY

unit in Death Valley (Devil's Golf Course) to the smoothest (Badwater Basin). The linear polarized return changes by about 15 db at 50° incidence angle. An even more dramatic change, 25 db at 40°, is observed on the cross-polarized return as shown in Figures 9 and 10. The total system dynamic range indicated is in excess of 50 db.

It can be observed that no strong angular dependence is present for these extremes of random surface roughness.

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