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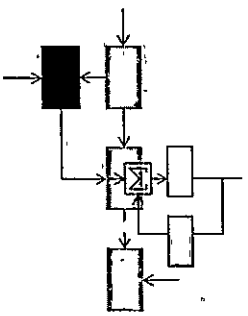

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FLIGHT TESTS OF A RADAR SCATTERING-COEFFICIENT MEASURING INSTRUMENT

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Department of Electrical Engineering

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FLIGHT TESTS OF A RADAR SCATTERING-COEFFICIENT MEASURING INSTRUMENT

PART I - SUMMARY

by

J. F. Reintjes, J. R. Sandison, J. A. Bosco,
and L. W. Counts

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ABSTRACT

A summary report of flight tests of a radar scattering-coefficient measuring instrument is presented. The report includes a brief description of the instrument, and its installation in the flight-test vehicle, a CV-990 aircraft. Representative values of scattering coefficients measured for normal incidence of the X-band radiation and for incidence angles of 75° and 60° angles are given. The targets chosen for illustration are water, mountainous areas, lava beds, flat land and farm land.

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ACKNOWLEDGEMENT

We wish to acknowledge the cooperation we have received from our sponsor, the Lunar and Planetary Programs Branch of the Office of Space Science and Applications, NASA. The transmitter tube used in our equipment was developed under a program sponsored by the E/M Microwave Radiation Laboratory at the Electronics Research Center, NASA. We also wish to express our appreciation to the personnel at the NASA Ames Research Center who provided facilities for flight testing.

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I. INTRODUCTION

Contained in this report are preliminary results obtained from flight tests of a radar scattering-coefficient measuring instrument during the period October 10 - 12, 1967, at the NASA Ames Research Center, Moffett Field, California. A detailed report which includes a more exhaustive analysis of the flight testing will be made later after all data have been reduced and examined.

The radar instrument under test is designed to measure electromagnetic scattering characteristics of reflecting surfaces and is directed toward use in satellites and spacecrafts for the purpose of measuring the scattering coefficients of planetary bodies. Such measurements should be particularly informative in the case of the Planet Venus, where the surface is cloud-covered and not directly observable by optical means.

The purpose of the October 10 - 12, 1967, flight tests was twofold:

1. To evaluate the performance of the radar as an instrument for measuring scattering coefficients, and

2. To observe relationships between types of terrain and the scattering coefficients which are associated with the terrain.

DESCRIPTION OF THE MEASURING INSTRUMENT AND THE MEASUREMENTS

The quantity measured in the experiment is the scattering coefficient $\Gamma(\theta)$, defined as the ratio of the energy scattered by a surface patch to that which would be scattered by a perfectly reflecting, hemispherically isotropic scatterer. In terms of the quantities involved in the measurement

$$\Gamma(\theta) = \frac{2\pi R^2 W_r}{A_e W_t}$$

where

$\Gamma(\theta)$ is the average scattering coefficient of the surface patch illuminated by the antenna beam

R is the slant range between radar instrument and scattering surface

W_t is the energy transmitted

W_r is the energy received in the echo pulse

A_e is the effective receiving area of the antenna

θ is the angle between the horizontal plane representing the illuminated surface patch and the antenna boresight axis

The radar instrument is designed to measure the quantities R, W_r, and W_t, and to store them on paper tape in digital form. The instrument also measures and stores digitally a quantized automatic gain control (agc) signal of the receiver. This quantity is necessary in order to interpret the magnitude of received energy correctly.

The waveform transmitted by the radar consists of a burst of four, 40-microsecond, X-band, r-f pulses spaced 20 milliseconds apart, followed by a quiescent interval of approximately 8 seconds. The waveform is drawn in Fig. 1.

Since flight tests were conducted at an altitude of approximately 40,000 feet, the leading edge of each echo pulse is received approximately 80 microseconds after occurrence of the leading edge of the corresponding transmitter pulse. The first of the four echo pulses in

a sequence is used to set the gain of the receiver; range and received energy are then measured for the three remaining echo pulses at constant gain setting. The energy in all transmitter pulses is recorded.

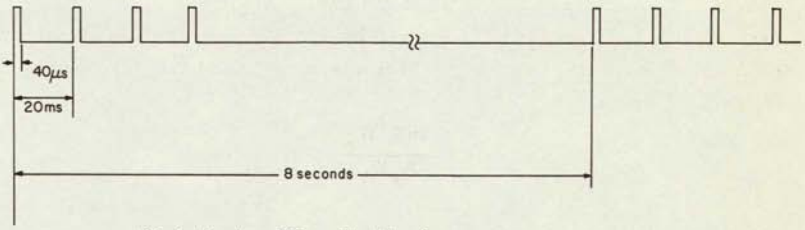

Fig. 1 Envelope of Transmitter Waveform

A horn antenna, having a beamwidth of 8 degrees at the 3-db points in the E and H planes, was mounted in the underbelly of the aircraft, and the antenna axis was aligned parallel to the aircraft yaw axis. The earth-surface area illuminated within the half-power points of the beam with the antenna pointing vertically downward was a circular patch approximately one mile in diameter at an aircraft altitude of 40,000 feet. At the average ground speed of the aircraft, 450 mph or 15 feet in 20 milliseconds, three overlapping measurements were taken during each burst. During the eight-second interval between bursts, the plane traveled approximately one mile, thus allowing the next three measurements to be taken on a ground patch which was contiguous with the previous area.

A camera was mounted in the aircraft adjacent to the antenna, and its pointing axis was aligned parallel to the antenna pointing axis. The camera was slaved to the radar, and camera triggering was arranged so that one photograph was taken for each set of four transmitter pulses. Synchronization was such that the camera was triggered between 50 and 100 milliseconds after occurrence of the leading edge of the transmitter pulse. The camera viewing angle was approximately three times the antenna beam angle. Figure 2 shows the radar installation in the main cabin, and Fig. 3 shows the horn antenna and camera installation.

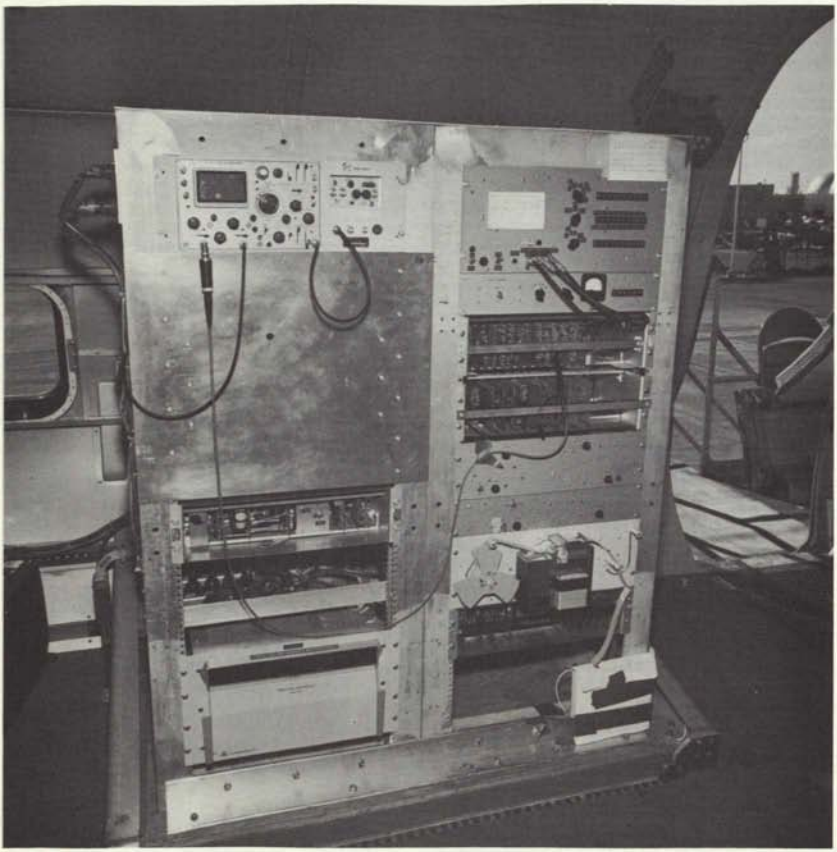

Fig. 2 Equipment Installed in Aircraft

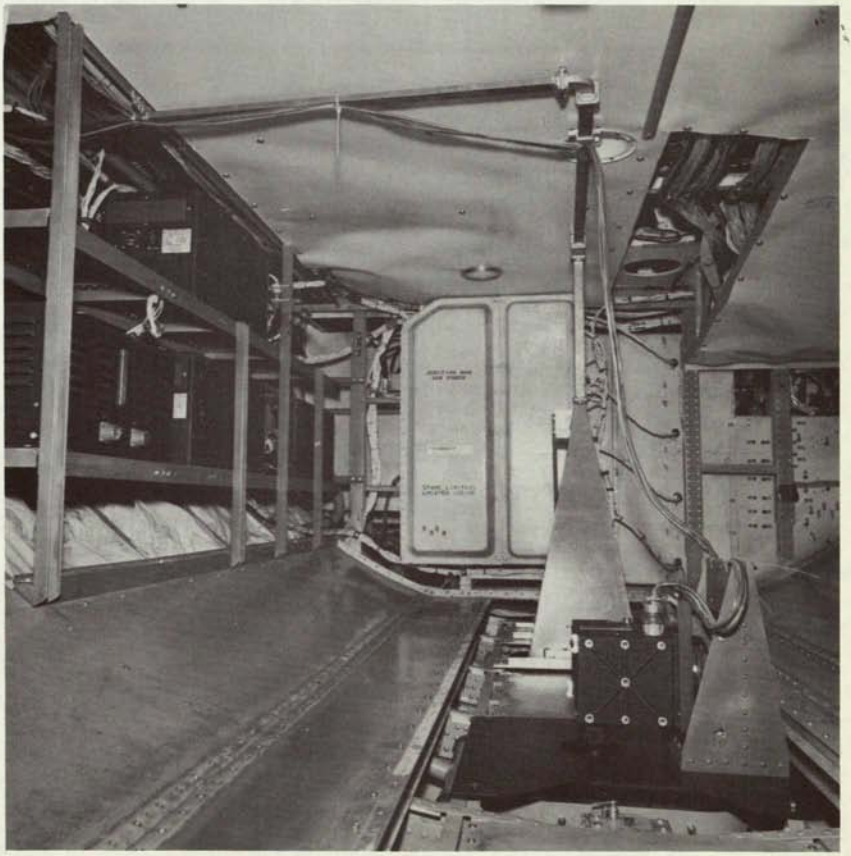

Fig. 3 Horn-Antenna and Camera Installed in Cargo Space

Data taken during flight tests were reduced by means of a PDP-7 and a 7094 computer, (the machines which were available to us for data reduction). The PDP-7 served to transfer the digitally encoded information from paper tape to magnetic tape, the input medium required by the 7094. The 7094 then calculated the scattering coefficients from the raw data and calibration information.

III. THE FLIGHT TESTS

Flight tests were conducted on October 10, 11, and 12, 1967. On October 10 and 12, we shared the flight with experimenters from the Jet Propulsion Laboratory and the University of Arizona, and the flight plan on each of these days was controlled by these groups. We were the principal experimenters on October 11 and the flight plan was specified by our group.

The data presented here apply only to the October 11 flight. A map of the flight path is shown in Fig. 4. The five target areas were chosen to be representative of a variety of surfaces. The area in the vicinity of Malad, Idaho, is mountainous terrain with peaks from 3000 to 9000 feet above sea level; Carson Sink, Nevada, is a flat dry lake area; and the areas near Yuba City and Merced, California, are farmland and rolling hills. In addition, measurements were made over and near Great Salt Lake, Utah, and over lava beds in Idaho. At each target area, except the lava beds, the aircraft made a straight, level run followed by two circular courses at bank angles of 15° and 30°.

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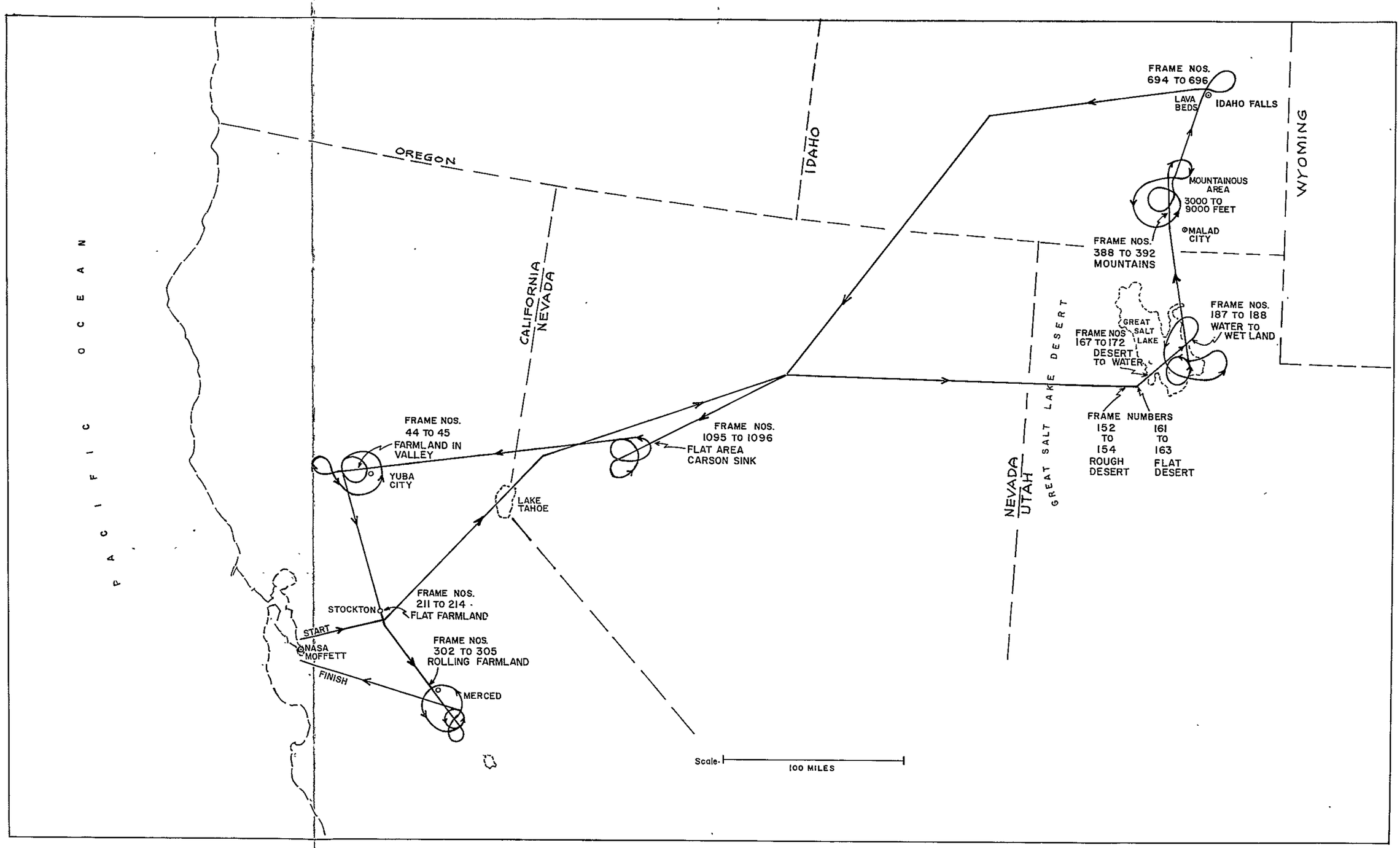

Fig. 4 Map of Flight Path for Measurement of Scattering Coefficients
October 11, 1967

FOLDOUT FRAME 8-A

FOLDOUT FRAME 8-B

IV. TEST RESULTS

A. MEASUREMENTS

The earth patches shown in the aerial photographs in Figs. 5 through 12 are representative of the classes of surfaces for which measurements were taken during the October 11, 1967 flight tests. As explained previously, each photographic frame is associated with a burst of four r-f pulses. The frame number is indicated below each picture. A time-code generator and light marker were used to relate each set of four pulses to its corresponding frame.

The location of the terrain and its classification are also given for each picture. Each frame number shown in Figs. 5 through 11 is also labeled on the flight-path map of Fig. 4 for identification of geographic location. Examples of rolling and flat farmland, rough and flat desert, mountains, lava beds and water have been chosen for illustration. Figures 5-11 apply to data taken during straight, level runs only; Fig. 12 applies to circular courses as well as straight, level flights.

The radar scattering coefficients $\Gamma(\Theta)$ calculated from measurements made by the radar instrument are plotted on a logarithmic scale beneath each picture in Figs. 5-11. Since three measurements were taken during each burst of four pulses, three values of $\Gamma(\Theta)$ appear in each plot, except in cases where a missing piece of data prevented a calculation. Calculated values of $\Gamma(\Theta)$ are plotted in time sequence, from left to right. The aircraft traveled approximately 15 feet between each measurement in a set of three.

The following observations for scattering coefficients at normal incidence can be made from the data presented. It is emphasized that the observations here apply only to the data included in Figs. 5 through 11.

> The maximum value of scattering coefficient illustrated is 8, measured over Great Salt Lake (frame 171), and the minimum value is 0.003, measured over Great Salt Lake desert (rough terrain, frame 153). Thus, the maximum spread of the measurements from smooth surface to rough surface is of the order of 2,500 to 1.

The values of $\Gamma(90^{o})$ over water range from 8 (frame 171) to 0.9 (frame 170), a ratio of 9 to 1.

Scattering coefficients for surfaces that have been categorized as mountainous vary from 0.005 to 0.06, as may be seen from frames 388 and 390. Again a ratio of 9 to 1 is observed.

Farmland gave scattering coefficients that were somewhat higher than the coefficients for mountainous terrain, although measurements of comparable values were obtained for both types of target. (See frames 44, 45, 303, 304.)

Within the 20-millisecond time period of two closely spaced measurements, the values of scattering coefficients may differ by a ratio of the order of 8 to 1. See, for example, the measurements for frames 696 and 44. Although the vehicle has moved only 15 feet in the 20-millisecond interval, the returns from the huge number of elementary scatterers that comprise the composite scattering surface have combined in a sufficiently different manner to yield a large change in energy returned in the direction of the aircraft.

Although the above observations are based only on the measurements included in this summary report, our preliminary examination of a much larger volume of data indicates the observations are qualitatively similar.

Figure 12 illustrates the effect on scattering coefficient of illuminating the surfaces at oblique incidence as well as at normal incidence. The circular courses flown at 15-deg. and 30-deg. bank angles permitted data to be gathered at incidence angles of 75 deg. and 60 deg. Two examples have been chosen in order to show comparative effects when the surface is highly reflecting and when the surface is a diffuse scatterer. Figure 12a is a photograph taken over Great Salt Lake. The corresponding scattering coefficients for normal incidence and for 75-deg. and 60-deg. incidence angles are plotted beside the picture. Several measurements for each angle are included except for the 60-deg. angle. As might be expected over a highly reflecting surface, the scattering coefficient falls off rapidly with increasing angles of incidence away from the normal.

In contrast, Fig. 12b shows the mountainous region near Malad, Idaho. Note in the corresponding plot the scattering coefficients are relatively independent of the viewing angle.

B. EQUIPMENT OPERATION

In general, the radar instrument functioned acceptably well. Because of an intermittent malfunction and also because the receiver design was based on an invalid assumption, only about 10 percent of the data taken is useful. Nevertheless, this yield has resulted in nearly 1,000 useful measurements and an additional 1,000 or more can be interpreted with confidence by making valid substitutions for a missing quantity.

The intermittent malfunction appears to have been caused by randomly occurring noise signals on a lead which carries the paper-tape punch trigger. The punch therefore was triggered incorrectly in the presence of these unwanted signals.

A more fundamental point which we discovered is that our receiver agc circuit is incorrectly designed. We assumed that the echo signal returned in each burst of four r-f pulses would be approximately the same amplitude and that we could, therefore, set our agc voltage at a level determined by the amplitude of the first received pulse in a set of four. This turned out to be an invalid assumption. Echo signals varied widely on occasion from pulse to pulse with the result that the receiver was frequently saturated by the echo signals. Obviously the receiver design must be reexamined and the design flaw corrected.

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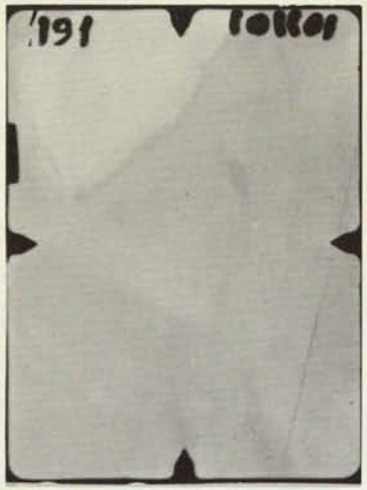
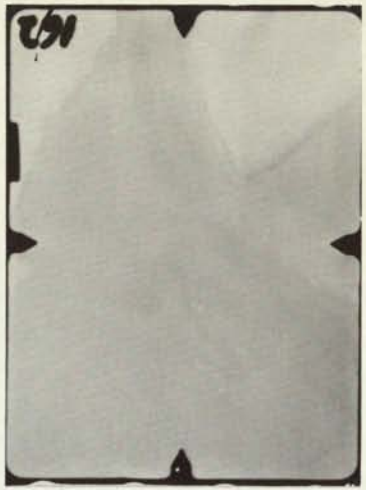
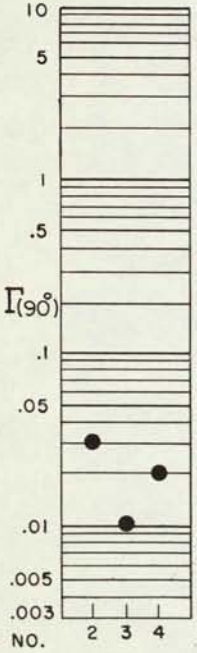



FRAME NO. 152 153 154 161 162

LOCATION: (GREAT SALT LAKE DESERT, UTAH) ROUGH DESERT FLAT DESERT



PULSE NO.

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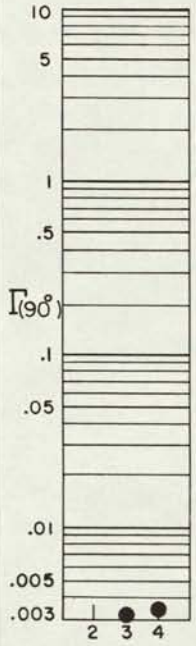
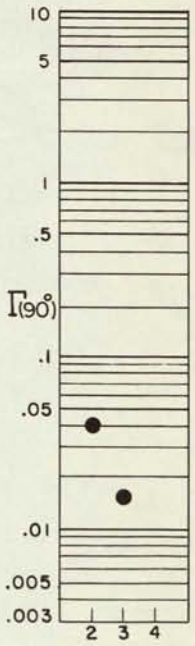
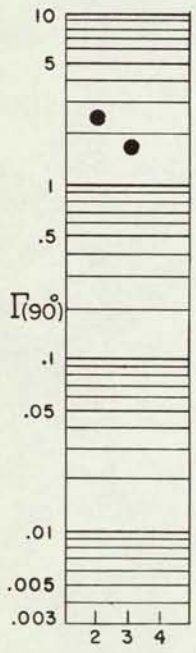


14-A





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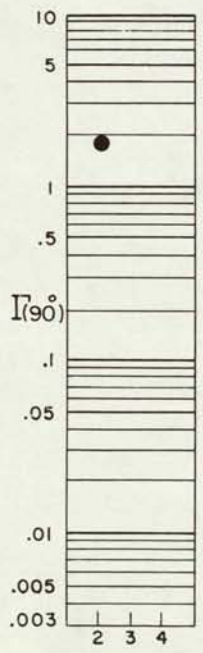
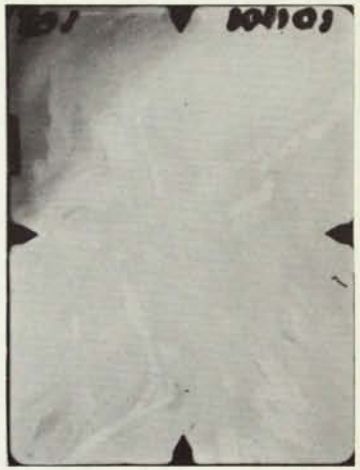


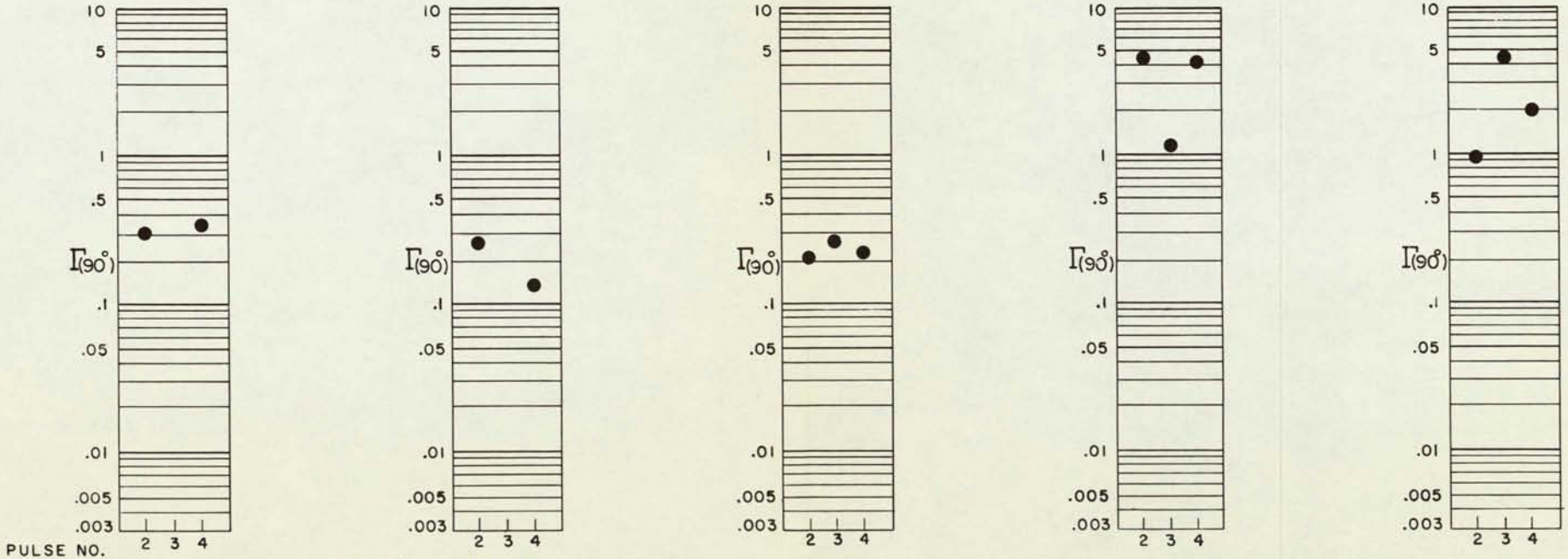
14-B

Fig. 5



FRAME NO. 163 167 168 169 170

LOCATION: GREAT SALT LAKE DESERT, UTAH TRANSITION GREAT SALT LAKE, UTAH



FOLDOUT FRAME 15-A

15-B FOLDOUT FRAME

Fig. 6

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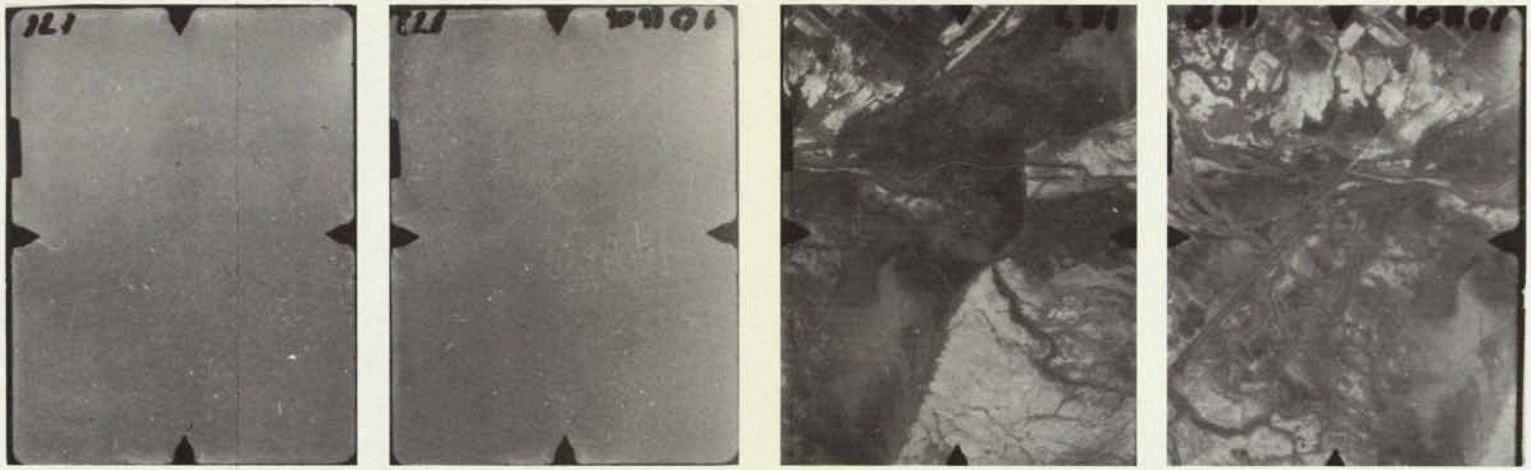
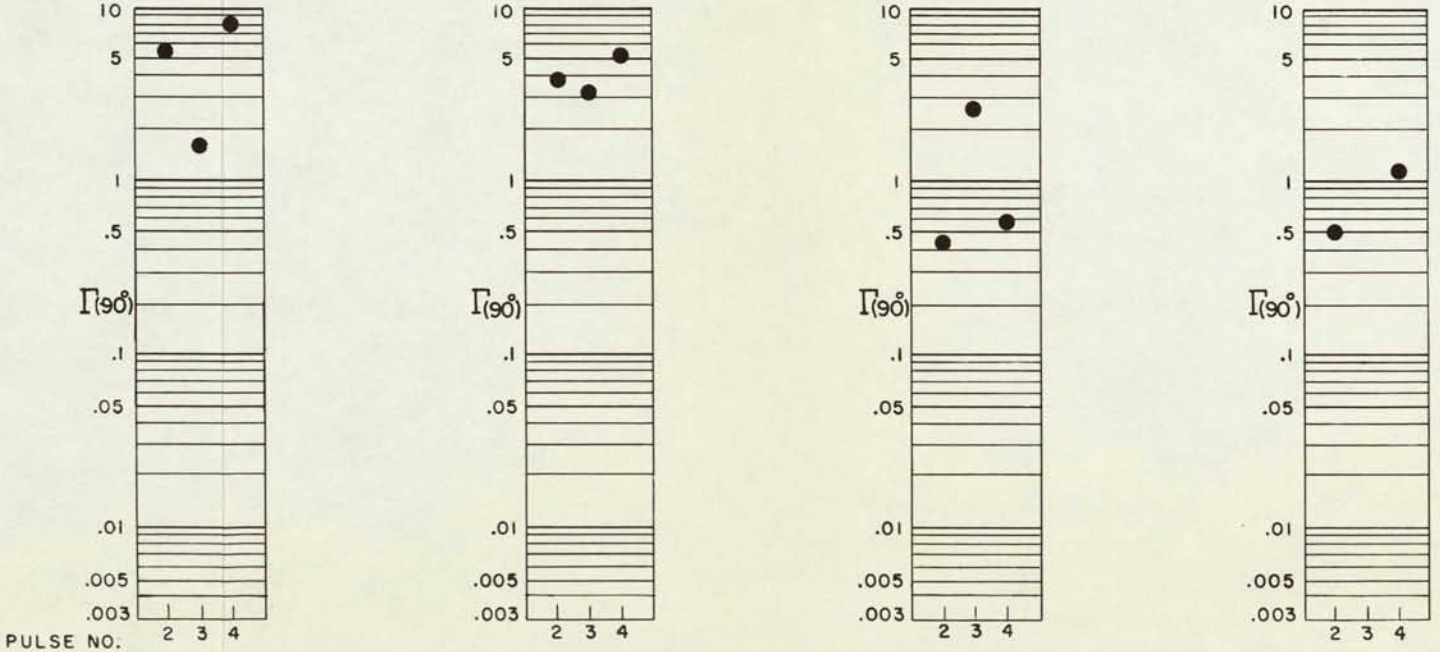


FRAME NO. 171 172 187 188

LOCATION: GREAT SALT LAKE, UTAH WETLAND, EDGE OF GREAT SALT LAKE, UTAH



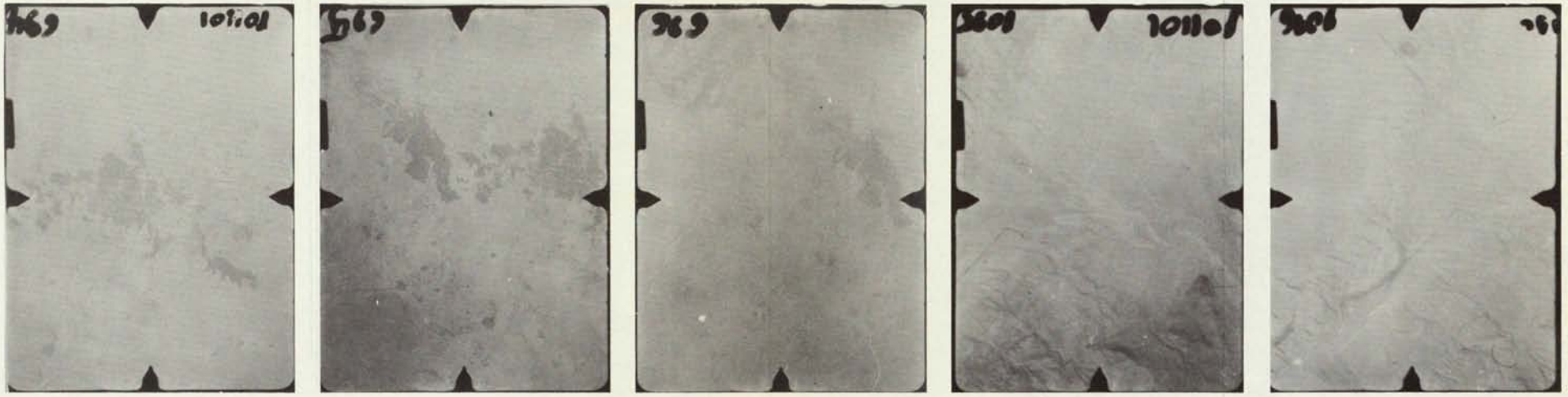
FOLDOUT FRAME

Fig. 7

-18-A

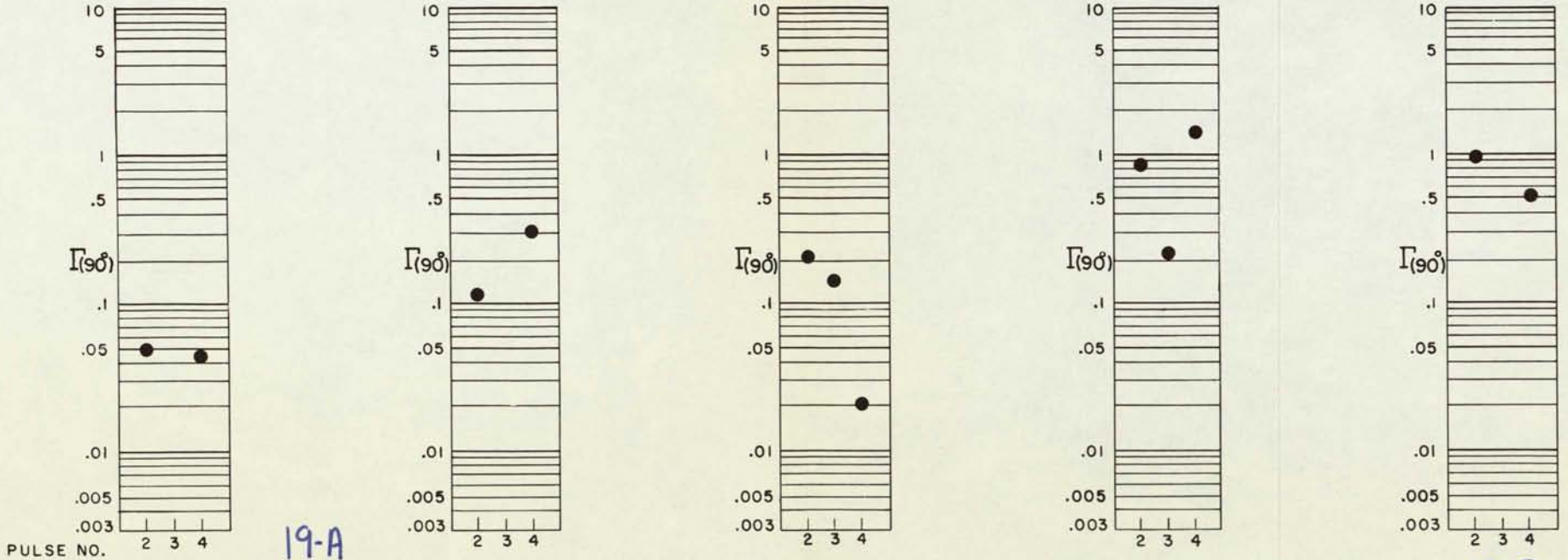
18-B

FOLDOUT FRAME



FRAME NO. 694 695 696 1095 1096

LOCATION: LAVA BEDS NEAR IDAHO FALLS, IDAHO CARSON SINK, NEVADA



19-A

FOLDOUT FRAME

FOLDOUT FRAME 19-B

Fig. 8

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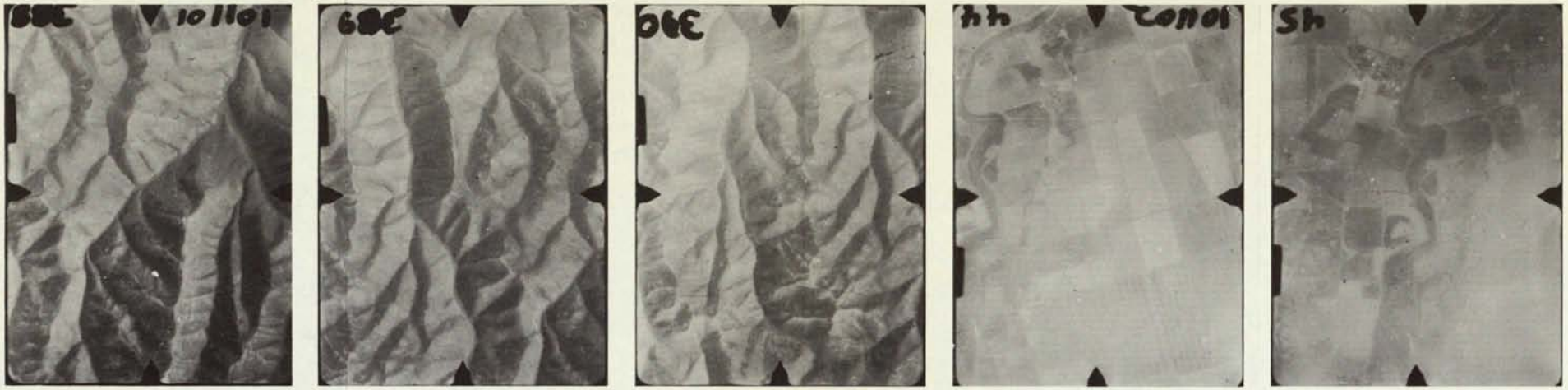


FRAME NO. 388 389 390 44 45

LOCATION: MOUNTAINS NEAR MALAD, IDAHO FARMLAND IN VALLEY, YUBA CITY, CAL.

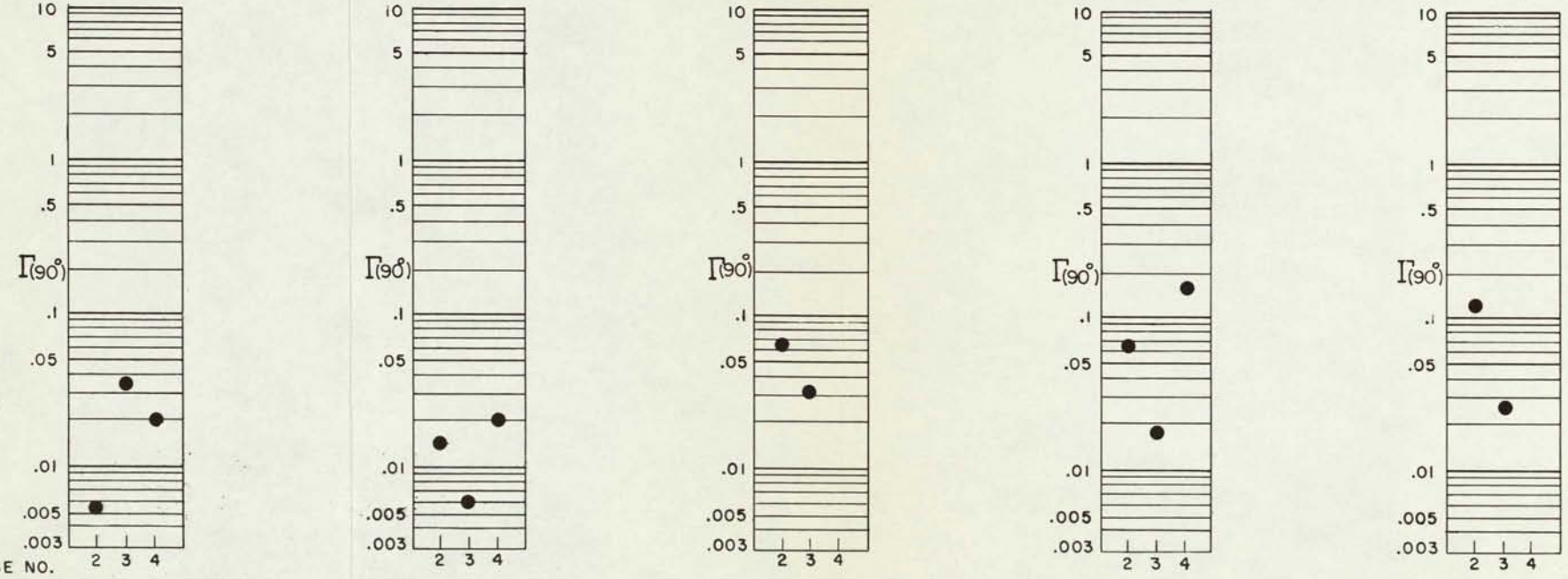


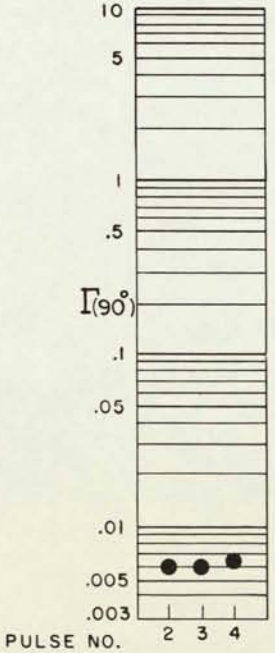
Fig. 9

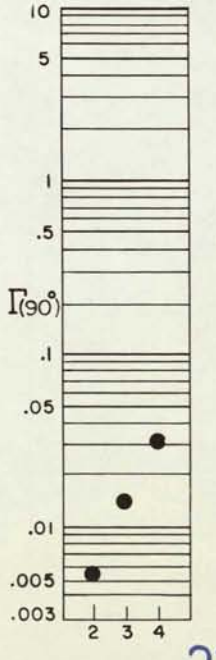
FOLDOUT FRAME 22-A

FOLDOUT FRAME 22-B

FRAME NO. 391 392 211 212 213

LOCATION: MOUNTAINS NEAR MALAD, IDAHO FLAT FARMLAND NEAR STOCKTON, CAL.





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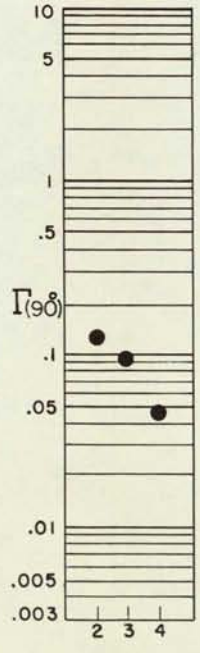
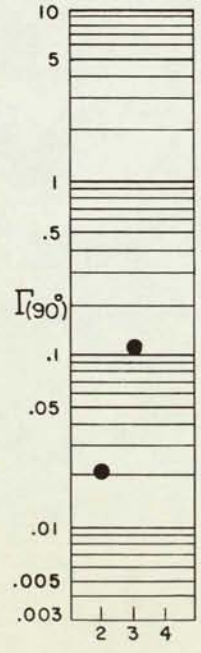
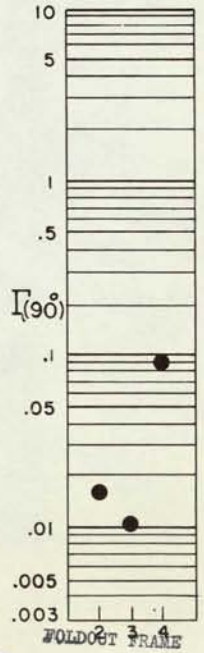
23-A







FOLDOUT FRAME

23-B

Fig. 10

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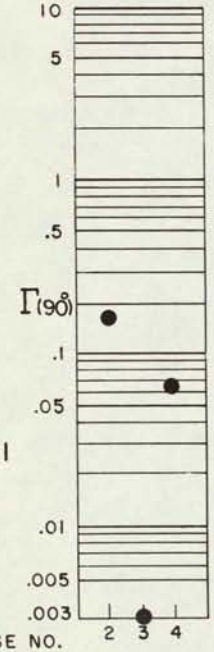
FRAME NO. 214 302 303 304 305

LOCATION: STOCKTON, CAL. ROLLING FARMLAND NEAR MERCED, CAL.



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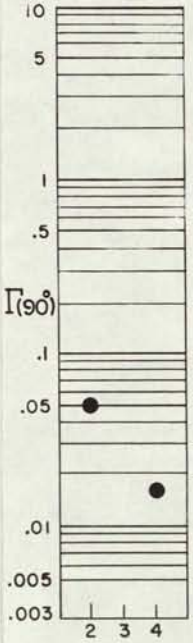
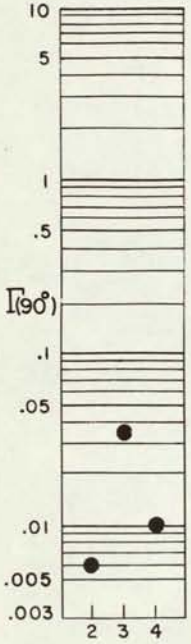


26-A



26-B

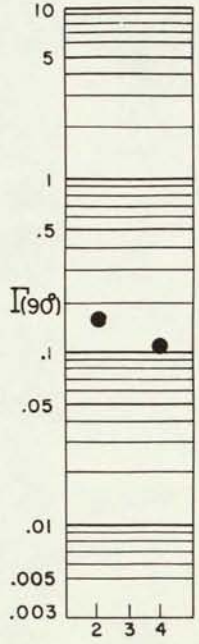


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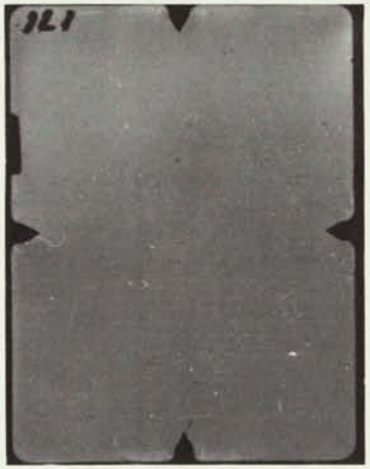
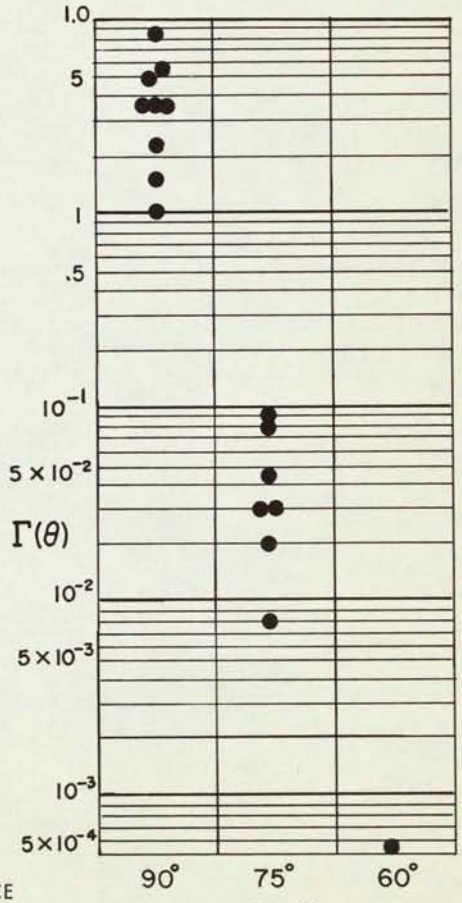
Fig. 11



TYPICAL OF GREAT
SALT LAKE, UTAH

GREAT SALT LAKE
SMOOTH SURFACE



ANGLE of INCIDENCE

Fig. 12a

MOUNTAINS, MALAD, IDAHO
ROUGH SURFACE

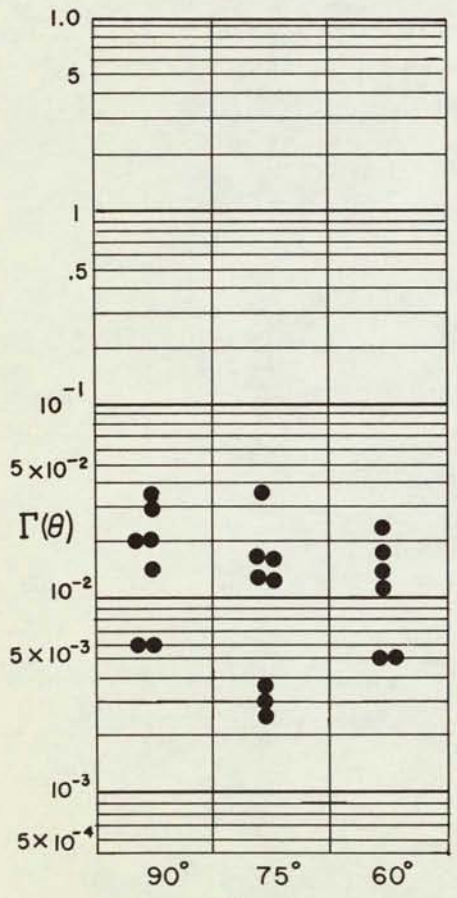


Fig. 12b

TYPICAL OF MOUNTAINS
NEAR MALAD, IDAHO

Fig. 12

Scattering Coefficient versus Angle of Incidence

27-A

FOLDOUT FRAME

27-B

FOLDOUT FRAME

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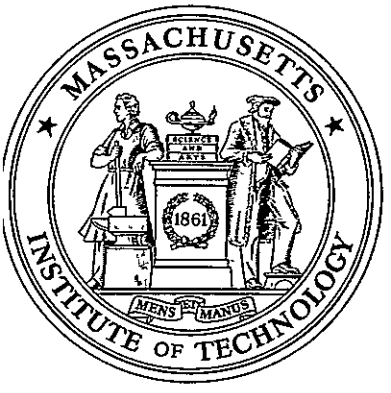
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