NASA TECHNICAL MEMORANDUM

NASA TM X-71481

NASA TM X-71481

(NASA-TM-X-71481) AIRBORNE PROFILING OF ICE THICKNESS USING A SHORT PULSE RADAR (NASA) 7 p HC $3.00
CSCL 08L

N74-11204

Unclas
G3/13 21380

AIRBORNE PROFILING OF ICE THICKNESS USING A SHORT PULSE RADAR

by R.S Vickers
Dept of Electrical Engineering
Colorado State University

and

J. Heighway and R. Gedney
Lewis Research Center
Cleveland, Ohio 44135

TECHNICAL PAPER proposed for presentation at
Advanced Concepts and Techniques in the Study of
Snow and Ice Resources
Monterey, California, December 2-6, 1973

AIRBORNE PROFILING OF ICE THICKNESS USING A SHORT PULSE RADAR

R.S. Vickers
Dept. of Electrical Engineering
Colorado State University

J.E. Heighway
R.T. Gedney
NASA/Lewis Research Center

ABSTRACT

The acquisition and interpretation of ice thickness data from a mobile platform has for some time been a goal of the remote sensing community. Such data, once obtainable, is of value in monitoring the changes in ice thickness over large areas, and in mapping the potential hazards to traffic in shipping lanes.

This paper describes measurements made from a helicopter-borne ice thickness profiler of ice in Lake Superior, Lake St. Clair and the St. Clair river as part of NASA's program to develop an ice information system.

The profiler described is a high resolution, non-imaging, short pulse radar, operating at a carrier frequency of 2.7 GHz. The system can resolve reflective surfaces separated by as little as 10 cm. and permits measurement of the distance between resolvable surfaces with an accuracy of about 1 cm. Data samples are given for measurements both in a static (helicopter hovering), and a traverse mode. Ground truth measurements taken by an ice auger team traveling with the helicopter are compared with the remotely sensed data and the accuracy of the profiler is discussed based on these measurements.

INTRODUCTION

Techniques for the remote measurement of ice thickness have been studied for many years. In some cases, the thickness is inferred from the surface temperature as in the case of thermal infrared scanning, or from the microwave brightness temperature (Meier and Edgerton, 1971). A more direct method, that of profiling with an active radar system was used in 1966 by the U.S. Army (Rinker, 1966) to map the thickness of the Greenland Ice Cap. This technique proved successful in terms of penetration through a great thickness of ice, but the resolution was not suitable for other applications involving relatively thin ice due to the small (14 MHz) bandwidth employed.

In this paper, a radar system is described which has been used to profile lake ice down to a thickness of 10 cm. Data from the system both in a static and mobile mode are given. The platform used was a Sikorski H-52 helicopter furnished through the cooperation of the U.S. Coast Guard stations at Selfridge Field and Traverse City.

MICROWAVE PROPAGATION THROUGH ICE

A summary of the microwave properties of ice and snow is given by Holter and Lowe (1966) based on data published by Von Hippel (1954) and Cummins (1952). At 3 GHz the value given for the loss tangent of ice is 0.9×10^{-3}, corresponding to an attenuation of 0.44 db/meter for ice with a dielectric constant of 3.2. This figure assumes no losses from scattering processes.

The losses indicate that a plane parallel layer of ice could easily give rise to multiple returns when illuminated by a radar pulse, due to energy being multiply reflected within the layer with minimal absorption. This phenomenon was noted in some of the data obtained over smooth ice. One advantage of the low absorption is the attendant high penetration capability of the radar. Using a dielectric approximation for the calculation of the reflection coefficient, the values to be expected at 3 GHz are as follows:

Air/Ice interface	28%
Air/Snow interface	10%
Snow/Ice interface	19%
Ice/Water interface	67%

The presence of surface roughness would of course modify these figures, as would also the presence of surface films of water in the liquid phase. The calculations do indicate however that in an ideal case of horizontally stratified snow/ice/water, a substantial reflection would result from each boundary. Previous work (Vickers and Rose, 1972) on layered snow and ice supports this contention.

SYSTEM DESIGN

A diagram of the system is given in Figure 1. The generator is a solid state source capable of tuning from 2.5 to 2.9 GHz. The frequency was adjusted to 2.7 GHz to minimize leakage from the minimize leakage from the mixer. The C.W. signal from the oscillator was then switched with a double balanced mixer driven by a 1 ns pulse to give a short burst of 2.7 GHz carrier. This signal was amplified to a peak power of 1W with a Travelling Wave Tube amplifier (TWT) and then transmitted through a double ridged horn antenna. The TWT also had an amplitude modulation capability, thereby allowing range dependant gain to be employed if necessary.

The receiver chain consisted of two solid state amplifiers with a total gain of 70 db feeding an envelope detector. The output from this detector was then displayed on a sampling oscilloscope and recorded on either polaroid film (static mode) or on continuous strip film (traverse mode).

Options available to the operator included triggering the display on the first return, which removed helicopter altitude variations from the data, and an intensity modulation display mode.

The system was designed to operate at altitudes around 40m above the ice, although the gain was sufficient for greater altitudes if necessary. The detected return pulse, shown in Figure 2, had a half width of 1.3 ns. A photograph of the completed system appears in Figure 3.

A protype of the equipment, with some minor differences, had already operated for one field season in the measurement of snow depth in the Colorado Rockies (Vickers and Rose, 1972). The present system was therefore given brief preliminary testing by using it to view a vertical ice wall, of adjustable thickness built from commercial ice blocks. This experiment was used to determine the minimum measurable thickness of ice, under relatively controlled conditions. This minimum was less than 10 cm. Also evaluated were the effects of having the first surface (air/ice interface) covered with water to simulate melting ice conditions. The thin film of water retained on the vertical face of the ice wall had no appreciable effect. An effect was observed during these tests which later gave some experimental difficulty, namely the beamwidth of the antennas (45°) was large enough to allow returns from a number of paths to interfere with that from the line-of-sight path from the target. This interference effect between the returns caused significant amplitude modulation of the total signal as the range was varied, and made data interpretation difficult. The same effect was later noted in the helicopter installation where the return coming from the ice interfered with a reflection from the vehicle landing gear. It was eventually removed by lowering the antennas. An example of the test data from a 19 cm. thick wall of ice is given in Figure 4.

EXPERIMENTAL PROCEDURE AND RESULTS

After a number of trial flights over Lake St. Clair, the system was taken over Whitefish Bay in Lake Superior for demonstration. The procedure employed was to fly the system to a suitably thick region of ice and land the helicopter. An ice auger team then took a sounding of the ice thickness, and the radar system was subsequently flown over the area at an altitude of 20 to 30 m. A typical return from these tests is shown in Figure 5 where the two pulses correspond to the upper and lower surfaces of ice 30 cm. in thickness. The sites were photographed from the ground and from the helicopter for later correlation with the data. The radar data itself was recorded on polaroid film. In addition some traverse data was recorded on strip film.

An example of data taken in the traverse mode is given in Figure 6, where each excursion of the trace to the left indicates a target. An alternative and more powerful presentation in terms of visual impact is to detect the minima in each trace, and show these bright points in an intensity modulated display as shown in Figure 7. Visual separation of the ice stratigraphy from random returns due to roughness is then more easily achieved.

It was found that the ice thickness could be accurately measured in the case of a single unbroken layer thicker than 10 cm. and smooth on both its upper and lower surfaces. The accuracy of measurement was about 2 cm. for such sheets of ice. Quite often, however, one encounters ice that exhibits roughness on one or both of its surfaces, or possesses a layered structure. Surface roughness can be caused by 1) the freezing of slush formed from the melting of snow, or 2) the freezing of spray and droplets generated in the leads between storm-tossed floes, or 3)the upthrusting of edges in pressure ridges.

Lower surface roughness is observed in pressure ridges, of course. Besides this, one frequently encounters a "stepped" lower surface in re-frozen brash in which relatively thick floes are held together by a matrix of thinner ice.

Upper surface roughness causes difficulty because signals reflected from bumps located off the axis can interfere with the signal of primary interest, namely, that reflected from the ice-water interface. An example of such a case is given in figure 8.

The "stepped" lower surface encountered in refrozen brash seems to produce a complex return as off-axis signals are efficiently returned from surfaces forming corner reflectors, as it were. These reflections make interpretation of the return difficult. If the most straightforward interpretation is used, (identifying the largest peak after the first peak as that reflected from the ice-water interface) significant errors are made.

The problem of interference by off-axis reflections is judged to be the most serious impediment to the development of an operational radar ice thickness system.

Because of the large attenuation one would expect that if ice sheets are separated by more than a few millimeters of liquid water, lower sheets would be undetectable. No data bearing upon this issue was taken.

In the case of smooth sheets of ice, it was found that multiple reflections were often observable. While these multiple reflections caused no difficulty in inferring ice thickness for ideal ice sheets, they obviously increase the difficulty of interpreting the returns from more complex ice structures. This problem is considered to be minor as compared with that of off-axis reflections.

Figure 9 presents data from 14 sites comprising a variety of ice types. The R.M.S. error of these measurements is about 15%. Previous measurements on ice and snow show that with perfectly smooth surfaces an accuracy of better than 10% is easily achievable (Vickers and Rose, 1972).

CONCLUDING REMARKS

In summary, it has been demonstrated that a short pulse radar system can make accurate measurement of the thickness of simple, smooth ice sheets, and at least give an indication of the structure of rough-surfaced or broken ice. Furthermore, the data indicate that a system capable of making thickness measurements of nearly all types of ice is feasible, provided that interference from off-axis reflections can be overcome. The most natural attack on this problem is to reduce the beamwidth of the system. For the 1973-74 season, an array of four receiving antennae will be used, reducing the beamwidth from 45 degrees to somewhat less than 20 degrees. In addition, the use of a higher carrier frequency (up to 5 GHz) will be studied to determine whether the higher attenuation will reduce the amplitude of multiple reflections.

ACKNOWLEDGEMENT

The authors wish to acknowledge the generous cooperation of the United States Coast Guard Stations at Selfridge Field and at Traverse City.

REFERENCES

Cummins, W.A., 1952. The Dielectric Properties of Snow and Ice at 3.2 cms. J. Appl. Physics, vol. 23, No. 7 p.768.

Holter, M.R. and Lowe, D.S. ed, 1966. Peaceful Uses of Earth Observation Spacecraft. vol. III, Report No. 7219-1-F (III). Willow Run Labs., University of Michigan.

Meier, M.F. and Edgerton, A.T., 1971. Microwave Emiss n from Snow, a Progress Report. Proc. 7th Int. Symp. on Remote Sensing of Environment, University of Michigan. pp. 1155-1163.

Rinker, J.N., 1966. Radio Ice Sounding Techniques, Proc. 4th Int. Symp. on Remote Sensing of Environment. University of Michigan.

Vickers, R.S. and Rose, G.G., 1972. High Resolution Measurements of Snowpack Stratigraphy using a Short Pulse Radar. Proc. 8th Int. Symp. on Remote Sensing of Environment. vol. 1, University of Michigan.

Von Hippel, A.R., 1954. Dielectrics and Waves, John Wiley & Sons, Inc.

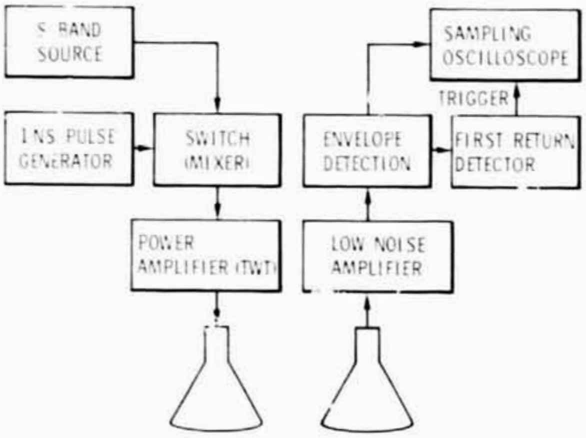


Figure 1. - Block diagram of ice profiler.

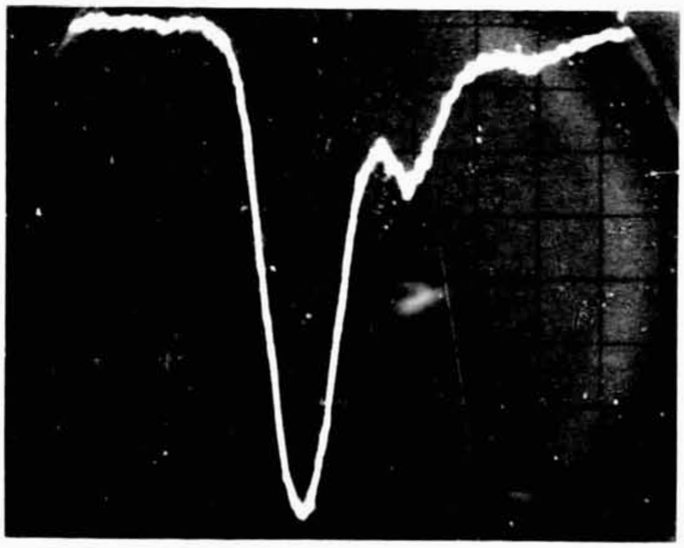


Figure 2. - Waveform (1 ns per division) as passed through complete system, with receiving horn facing the transmitting horn.

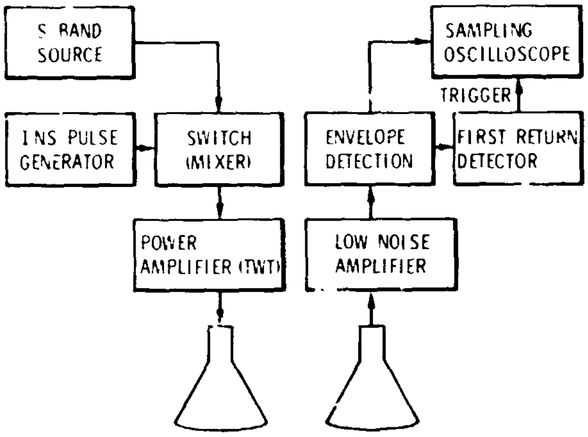
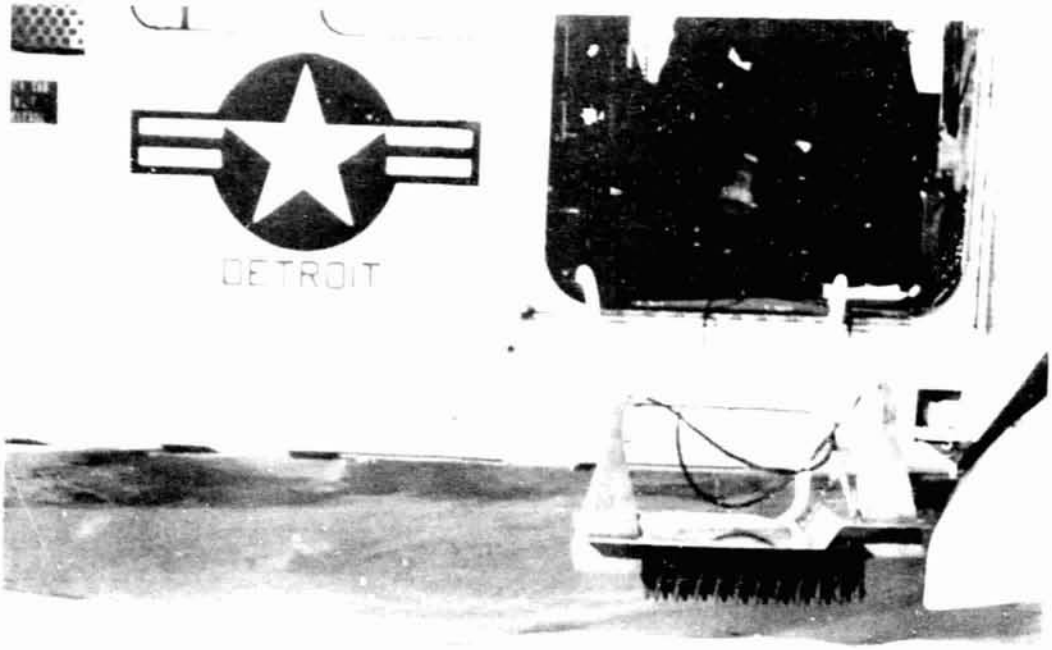
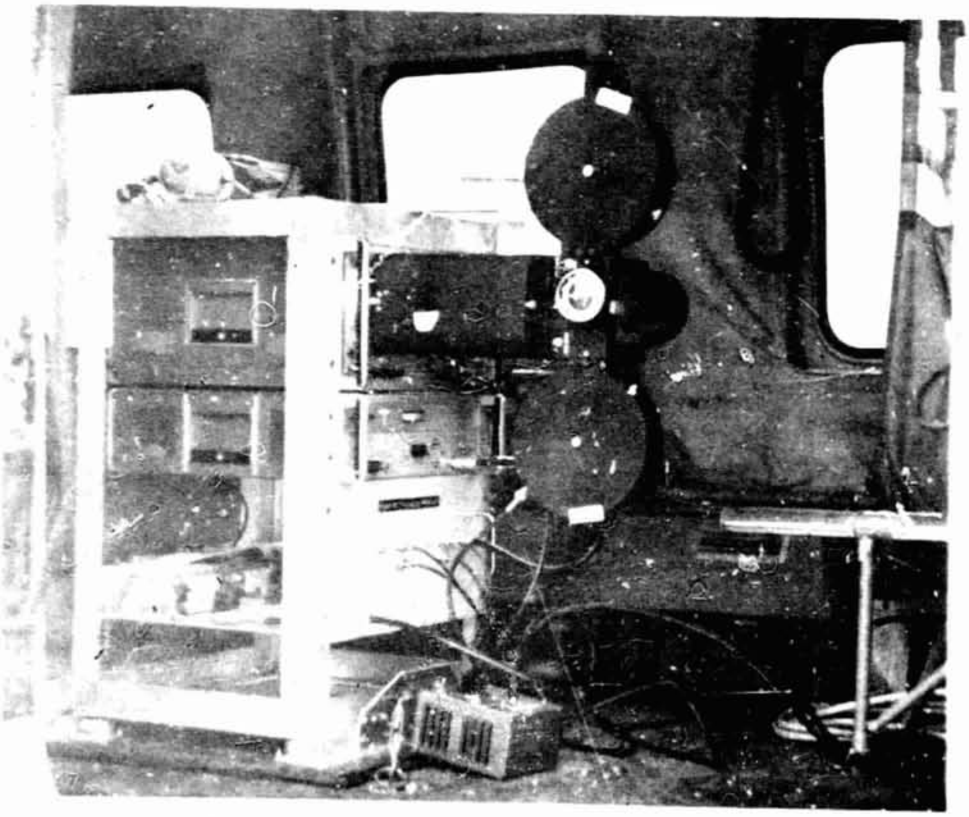


Figure 1. - Block diagram of ice profiler.

Figure 2. - Waveform (1 ns per division) as passed through complete system, with receiving horn facing the transmitting horn.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.





[illegible]

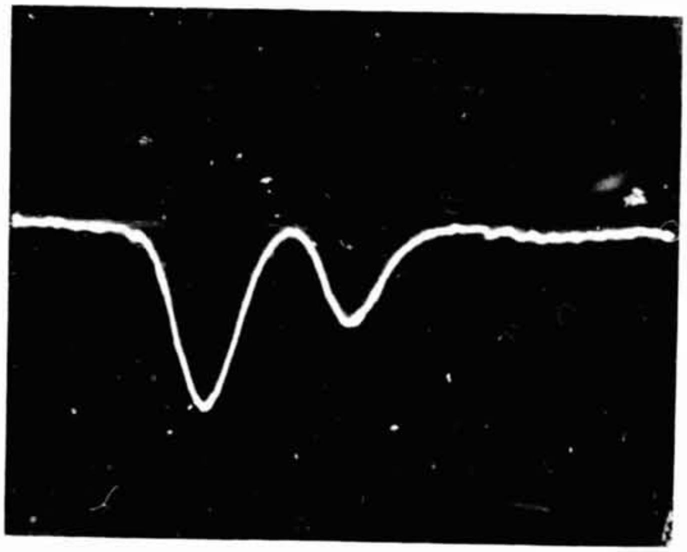


Figure 4. - Radar return from 7 1/2'' of block ice (1 ns per division).

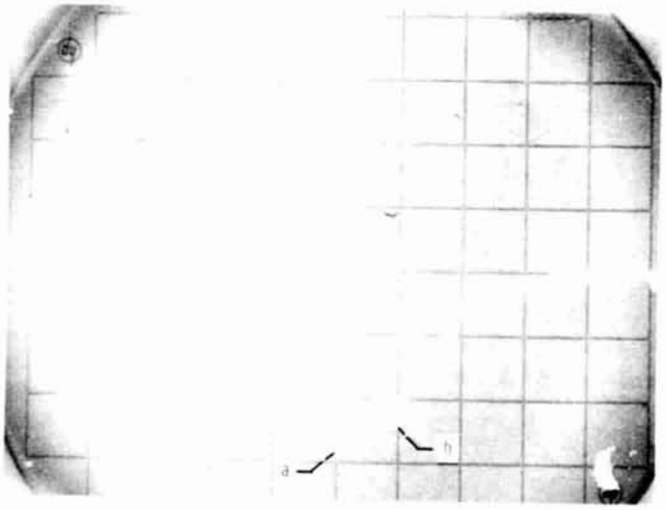


Figure 5. - Radar return from old ice cemented by newer thin ice (5 ns per division). a: Return from air-ice interface; b: return from ice-water interface.

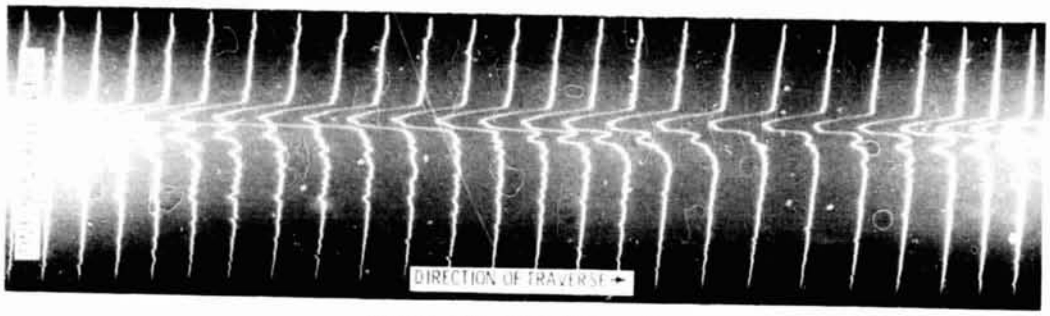


Figure 6. - An example of traverse data.

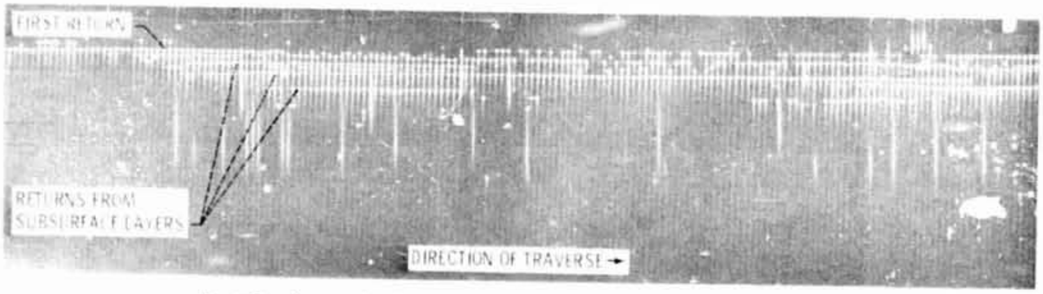


Figure 7. - An example of intensity modulated traverse data showing stratification.

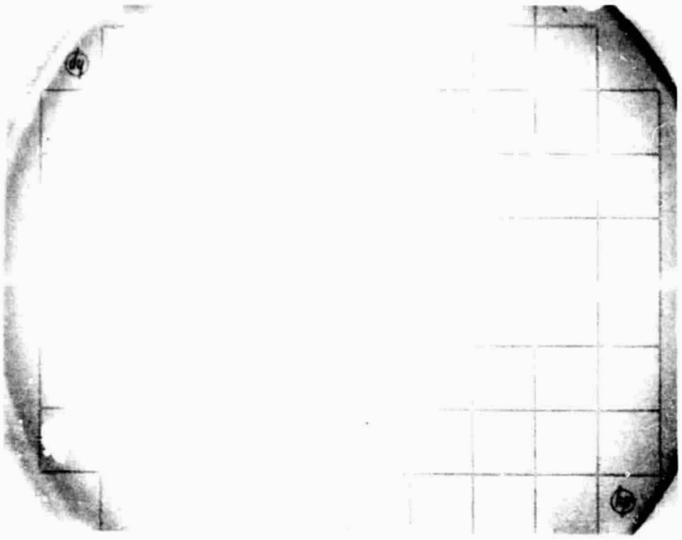


Figure 8. - Radar return from 1 meter ice with 30 cm of debris, 5 ns per division.

E-7804

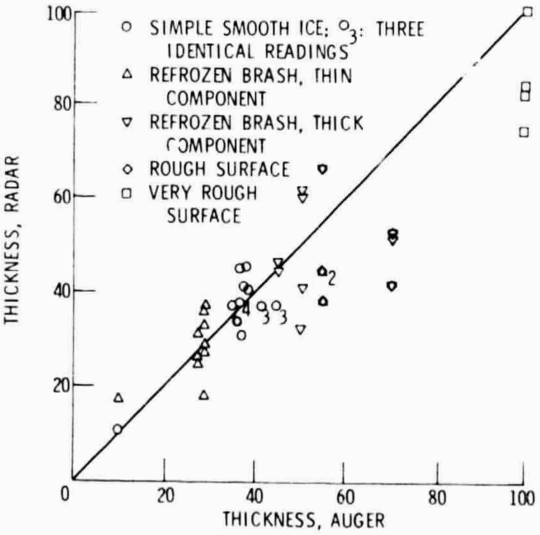


Figure 9. - Comparison of radar derived thickness (cm) with ice auger readings.

NASA-Lewis