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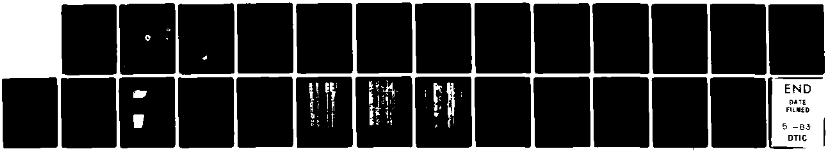

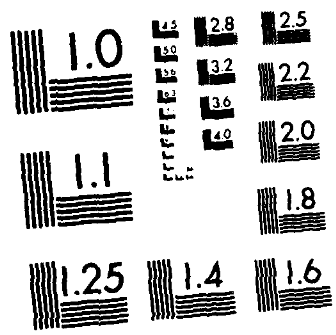
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UNDERWAY ICE THICKNESS PROFILING USING IMPULSE RADAR - CGC POLAR SEA EXPERIMENT, FEBRUARY 1981

P.A. TEBEAU

U.S. Coast Guard Research and Development Center
Avery Point Groton, Connecticut 06340

Final Report

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16. Abstract

A field experiment was conducted in February 1981 to determine the feasibility of impulse radar sea ice profiling from the bow of the icebreaker CGC POLAR SEA. This experiment was conducted in offshore areas to the north and west of Point Barrow Alaska. The objectives of the experiment were to determine the feasibility of taking underway impulse radar profiles from an icebreaker for use in ice surveys and icebreaker performance tests, and to investigate the utility of the impulse radar system as an operational ice reconnaissance tool.

The experiment was unsuccessful in that the system was unable to produce a recognizable profile of the ice/water interface over an extended portion of the ship's track. Intermittant subsurface reflections in the profiles could not be identified due to lack of ground truth data. The lack of success was attributed primarily to interference from the ship's hull and limited penetrating power of the radar system used in the tests.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures. Price $2.25. SD Catalog No. C13.10.286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

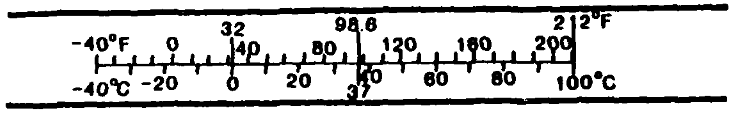

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Summary

The Coast Guard Research and Development Center conducted a field experiment in February 1981 to determine the feasibility of impulse radar sea ice profiling from the bow of the icebreaker CGA POLAR SEA. This experiment was conducted in offshore areas to the north and west of Point Barrow, Alaska during the 1981 Arctic Winter West deployment. The impulse radar system used was an off-the-shelf electromagnetic subsurface profiling system manufactured by Geophysical Survey Systems Inc. The two underlying objectives of the experiment were

1) To determine the feasibility of taking underway impulse radar sea ice thickness profiles from an icebreaker for use in ice surveys and icebreaker performance tests.

2) To investigate the utility of the impulse radar system as an operational ice reconnaissance tool.

Although previous field studies support the feasibility of underway impulse radar profiling for several types of sea ice, the experiment aboard CGC POLAR SEA was unsuccessful in clearly demonstrating the system's effectiveness in this application. Specifically, the system was unable to produce a recognizable profile of the ice/water interface over an extended portion of the ship's track. Intermittent subsurface reflections in the profiles could not be identified due to the lack of ground truth data, which was not collected due to operational difficulties encountered by the ship. Possible modifications to the system which might improve effectiveness include:

1) Reconfiguring the support boom to move the antenna closer to the ice to reduce hull interference and signal attenuation,

2) Designing an impulse radar antenna specifically for underway sea ice profiling,

3) Incorporating signal processing equipment in the system to remove background noise and enhance interface resolution in the graphic display.

As for future work, it appears that the impulse radar system could be modified for effective underway sea ice thickness profiling of first-year and multi-year level ice, and possibly multi-year pressure ridges. This data could be useful during icebreaker performance tests and ice properties surveys. In terms of further development as an ice reconnaissance tool, this will be far more difficult due to the system's inability to profile rubble ice and first-year pressure ridges, and the complexity and subjectivity of the data analysis.

Acknowledgement

I would like to thank the personnel aboard the CGC POLAR SEA and at the Icebreaker Support Facility, Seattle, for their assistance with the logistics of this experiment. I also thank the members of the ARCTEC Inc., field party for their assistance on the ice. Finally, special thanks goes to Dr. Paul Greisman for his assistance as the other member of the R&D Center field party.

1.0 INTRODUCTION

As development of resources in the Arctic gains momentum, there is a growing research effort to remotely measure the thickness of sea ice. From a navigational standpoint, outside of ice concentration and ice type, ice thickness is the primary consideration in choosing the optimum route for an icebreaker transitting Arctic waters. From a scientific standpoint, knowledge of the sea ice thickness is essential in order to understand the growth and deterioration of the ice, and various ice dynamics. In engineering applications, ice thickness data is essential in determining the bearing capacity of the ice, the survivability of structures surrounded by the ice, and the resistance that the ice will exert on the hull of an icebreaker.

In recent years, a particularly successful method for the remote sensing of sea ice thickness has been Electromagnetic Subsurface Profiling (ESP) using impulse radar. To date, impulse radar has been used in the experimental mode to profile fresh water ice, first-year and multi-year sea ice, multi-year pressure ridges, and icebergs. Profiling has been successfully accomplished both from the ice surface, and from aircraft (helicopter or fixed wing). Therefore, impulse radar appears to be a prime candidate for further development as an operational ice thickness remote sensing tool.

In recognition of this, a field experiment was conducted in February 1981 to determine the feasibility of impulse radar sea ice profiling from the bow of the icebreaker CGC POLAR SEA. This experiment was conducted in offshore areas to the north and west of Point Barrow, Alaska, during the 1981 Arctic Winter West deployment, in conjunction with a series of icebreaker performance and trafficability studies conducted by ARCTEC, Inc. The profiling equipment was an off-the-shelf ESP system manufactured by Geophysical Survey Systems Inc. (GSSI). The impulse radar antenna was suspended from the bow of the POLAR SEA using a fiberglass support structure. The experimental procedure called for taking a series of impulse radar scans using the bow antenna over the various types of ice encountered along the ship's trackline. These scans would then be compared with scans taken on the ice surface and ground truth measurements gathered during the ARCTEC, Inc. study to judge the performance of the underway profiling system. The two underlying objectives of this experiment were:

1) To determine the feasibility of making underway ice profiles from the icebreaker for use in ice surveys and icebreaker performance tests,

2) To investigate the utility of the impulse radar system as an operational ice reconnaissance tool. In the reconnaissance mode, the impulse radar would ideally be mounted aboard a helicopter or fixed-wing aircraft, and used to obtain real-time ice thickness measurement of a variety of ice types (first-year ice, multi-year ice, pressure ridges, rubble fields, etc.).

2.0 BACKGROUND

2.1 Principals of Impulse Radar Profiling

The electromagnetic subsurface profiling of sea ice using impulse radar is a well-established technology and has been used for measuring sea ice thickness for over ten years (Bertram, Campbell, and Orange, 1972).

Conceptually it is the electromagnetic equivalent of the single-trace acoustic profiling methods used for marine sub-bottom profiling. A comprehensive review of the state-of-the-art for this technology is given by Rossiter and Bazeley (1980).

In impulse radar profiling, a short, broad band, VHF electromagnetic (EM) impulse is emitted from the radar antenna. For ice profiling, the impulse generally has a center frequency on the order of 100 MHZ. The impulse propagates into the underlying material until reaching an interface where the dielectric properties change abruptly (air/snow, snow/ice, ice/water). At this interface, a portion of the electromagnetic energy is reflected back through the material, and detected by the radar antenna which is now in the receiving mode. The impulse radar control unit measures the two-way travel time for the signal to reach the interface and be reflected back. If the effective propagation velocity of the EM signal for the material (or layers of material) is known, then the depth to the reflecting interface can be calculated according to:

$$D = V_e \frac{t_d}{2} \qquad (1)$$

where D = Depth of the interface

V_e = Effective velocity of EM signal

t_d = Travel time from transceiver antenna to and from the subsurface interface.

For homogeneous materials, such as fresh water and fresh water ice, the velocity of propagation can be calculated from:

$$V_e = \frac{C}{\sqrt{\varepsilon_r}} \qquad (2)$$

where C = Velocity of EM pulse in air

$= 3X10^8$ m/sec (0.9843 ft/ns $\doteq$ 1 ft/ns)

ε_r = Dielectric constant of the material.

The strength of the reflected signal is determined by the reflection coefficient at the interface (which increases with the difference in dielectric constants across the interface), and the attenuation in the material through which the EM signal is travelling (which quantifies the energy loss in the material). Both the dielectric constant and attenuation are somewhat dependent on the frequency of the impulse. Table 1 (from Morey, 1975) gives the dielectric constants and attenuation values for various materials at 100 MHZ.

TABLE 1. DIELECTRIC CONSTANT AND ATTENUATION AT 100 MHZ (Morey, 1975)

Material	Approximate Dielectric Constant ε_r	Approximate Attenuation (db/meter)
Air	1	0
Fresh Water	81	0.41
Sea Water	81	326
Fresh Water Ice (-12°c)	3.2	0.05
Sea Ice	3.5 to 10	1 to 10
Freshly Fallen Snow (-20°c)	1.2	0.03
Hard Packed Snow (-6°c)	1.5	0.04

In view of the above, it might appear that impulse radar profiling of sea ice in all its forms would be a relatively straightforward task. Knowing the dielectric constants in air, snow, and sea ice, and the two-way travel times to the air/snow, snow/ice, and ice/water interfaces, it should be easy to determine ice thickness using equations (1) and (2). However, two significant problems arise. First of all, first-year and multi-year sea ice are usually dielectrically non-homogeneous with depth due to vertical temperature and salinity gradients in the ice. In addition, the bulk dielectric constant (vertically averaged dielectric constant) may show wide variation depending on ice type, ice location, and time of the year. Hence (ε_r) is given as 3.5 to 10 in Table 1. This uncertainty in (ε_r) in turn causes uncertainty in the calculations of equations (1) and (2). Secondly, first-year sea ice contains liquid inclusions of brine entrapped in the ice matrix. Likewise, rubble fields and pressure ridges contain unconsolidated layers of ice and sea water. Both the brine inclusions and entrapped seawater greatly increase the attenuation in the ice such that the EM energy lost in the ice may prohibit a detectable reflection from the bottom ice/water interface from reaching the receiving antenna. This high attenuation can in turn lead to a tradeoff in antenna design. Antennas with lower center frequencies provide better depth penetration; however, higher frequencies provide better resolution of adjacent interfaces. This tradeoff can be particularly restrictive in profiling various types of sea ice (for example, deteriorating first-year ice) which may be highly attenuating, but relatively thin (1 to 2 meters).

It should be noted that the above discussion is intended as a concise summary of the principles involved in impulse radar sea ice profiling. A more definitive explanation of the theory and limitations of the technology is given by Bentram, Campbell, and Sandler (1972), Morey (1975), and Rossiter and Bazeley (1980).

2.2 Field Experiments

To date numerous field experiments have been conducted demonstrating the feasibility of ice thickness profiling using impulse radar. All of the original feasibility studies were conducted with the impulse radar antenna resting on the ice. Bertram, Campbell, and Orange (1972) demonstrated the ability of impulse radar to profile both sea ice and fresh water lake ice. Campbell and Orange (1974) further demonstrated the ability of the system to profile multi-year sea ice. Kovacs (1977) reported successfully profiling the thickness of a tabular Antarctic iceberg and an Arctic ice island. He also demonstrated the ability of impulse radar to profile multi-year pressure ridges (Kovacs, 1978). The only types of sea ice that have not been successfully profiled are unconsolidated rubble fields, first-year pressure ridges, and deteriorating first-year ice where the sea water and brine inclusions result in the rapid attenuation of the transmitted signal.

With regard to airborne deployment, Morey (1975) first demonstrated the feasibility of profiling first-year level sea ice with an impulse radar mounted on a helicopter. He found that it was possible to obtain clear profiles of the surface and bottom of the ice at antenna altitudes up to 40 meters, and helicopter speeds of 65 km/hr. Kovacs (1977) further demonstrated the feasibility of helicopter profiling of multi-year ice, and developed a dual antenna configuration which enabled him to estimate the dielectric constant of the ice being profiled from the impulse radar return signal. More recently, Rossiter and Butt (1979) have experimented with deployment of the impulse radar system aboard a fixed-wing aircraft.

As for underway impulse radar ice thickness profiling from the bow of an icebreaker, two previous field experiments have been conducted to investigate this possibility. The first of these was conducted aboard the icebreaker CANMAR KIGORIAK in January 1980. Here an attempt was made to profile first-year sea ice in the Beaufort Sea using a 80 MHZ center frequency GSSI antenna suspended from a metal support boom. Unfortunately, no ice bottom echoes were distinguishable even after using electronic signal processing to remove background ringing from the metallic support boom and ships hull. Possible reasons for the lack of success were identified as noise generated by the support boom and hull, high conductivity (high signal attenuation) by the relatively thin first-year ice, and low radar system output power (C-CORE, 1981). The second field experiment was conducted aboard the icebreaker CGC BRISTOL BAY in March 1980 in the Great Lakes. In this experiment, an attempt was made by researchers from the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) to profile fresh water brash ice in conjunction with icebreaker performance tests conducted by the R&D Center (Martinson and Dean, 1981). Here a 300 MHZ center frequency GSSI antenna, specifically designed for airborne applications, was suspended from a non-metallic (fiberglass) support boom mounted on the bow of the icebreaker. The antenna was located 3 meters from the ship's hull and 4.0-4.6 meters above the ice. These measures effectively eliminated interference from the ship's hull and support boom. Although it was not possible to obtain a continuous profile of the brash ice/water bottom interface, it was possible after signal processing to locate the interface at various points along the ship's trackline. This limitation was not so much due to the particular impulse radar system design, but rather to the nature of the brash ice itself which often does not form a well-defined interface for impulse radar detection. It was this experiment in particular which suggested that further experimentation in deploying the impulse radar aboard an icebreaker to profile sea ice might prove profitable.

3.0 EQUIPMENT AND PROCEDURES

3.1 Description of The Impulse Radar System and Antenna Mount

The original experiment plan for the CGC POLAR SEA study called for a cooperative effort by the R&D Center and CRREL using the CRREL dual antenna system specifically tailored for airborne sea ice profiling (Kovacs, 1978). Unfortunately, this was not possible due to previous research commitments at CRREL. In view of this, the experiment was conducted using an off-the-shelf commercially available impulse radar system from GSSI.

This system is basically the SIR (Subsurface Interface Radar) System 7 (for scientific applications) marketed by GSSI. Technical specifications for the system are given in Appendix A. The radar system consists primarily of a control unit, an analog tape recorder, a graphic recorder, and a 300 MHz center frequency shielded antenna. The control unit manages the other units of the radar system through timing, data manipulation, and power conversion. It allows the operator to select sampling and recording rates, set time gain and data manipulation parameters, and monitor the signal received during data collection. The antenna, on signal from the control unit, functions both as impulse transmitter and reflected signal receiver. The tape recorder stores the analog data it receives from the control unit for future data processing and analysis while the graphic recorder provides a graphic printout for real time data interpretation. Figure 1 shows a schematic depicting the system in operation. The control unit transmits power to the electronics and a synchronizing signal to the pulse generator in the antenna. Whenever the antenna detects a reflected radar pulse, this electromagnetic signal is transmitted to the receiver. The receiver converts the electromagnetic signal, which is of the order of nanoseconds in duration, to an analog signal tens of milliseconds in duration and transmits this signal to the signal processor in the control unit. The processed analog signal is then sent to the graphic recorder and tape recorder. The graphic recorder accepts the analog signal from the receiver and produces a continuous, permanent chart on electro-sensitive paper. By recording a vertical scan for every few inches of antenna travel, a continuous profile is developed showing the reflecting interfaces encountered. The tape recorder also receives the analog signal from the control unit storing it on magnetic tape for future processing and analysis. The tape recorder can record data up to sixteen times faster than the graphic recorder, and is critical when a high sampling rate is required as in airborne profiling.

The impulse radar antenna was mounted on the bow of the CGC POLAR SEA using a non-metallic fiberglass support boom. Drawings of the boom are provided in Appendix B. Figure 2 shows photographs of the support boom and antenna mounted on the icebreaker's bow. The support boom was constructed of prefabricated FRP (Fiberglass Reinforced Plastic) structural members manufactured by Morrison Molded Fiber Glass Company. Sections were joined using wood couplings and fiberglass nuts and bolts. Boom rigging consisted of dacron or nylon line. Great care was taken to minimize the use of metal in the boom construction which might induce ringing in the radar return. The antenna itself was suspended below the boom on running rigging so that it could be lowered closer to the ice surface. From the structural standpoint, the support boom functioned well, suffering no damage throughout the experiment, and providing a stable support member for the antenna. Brittleness of the

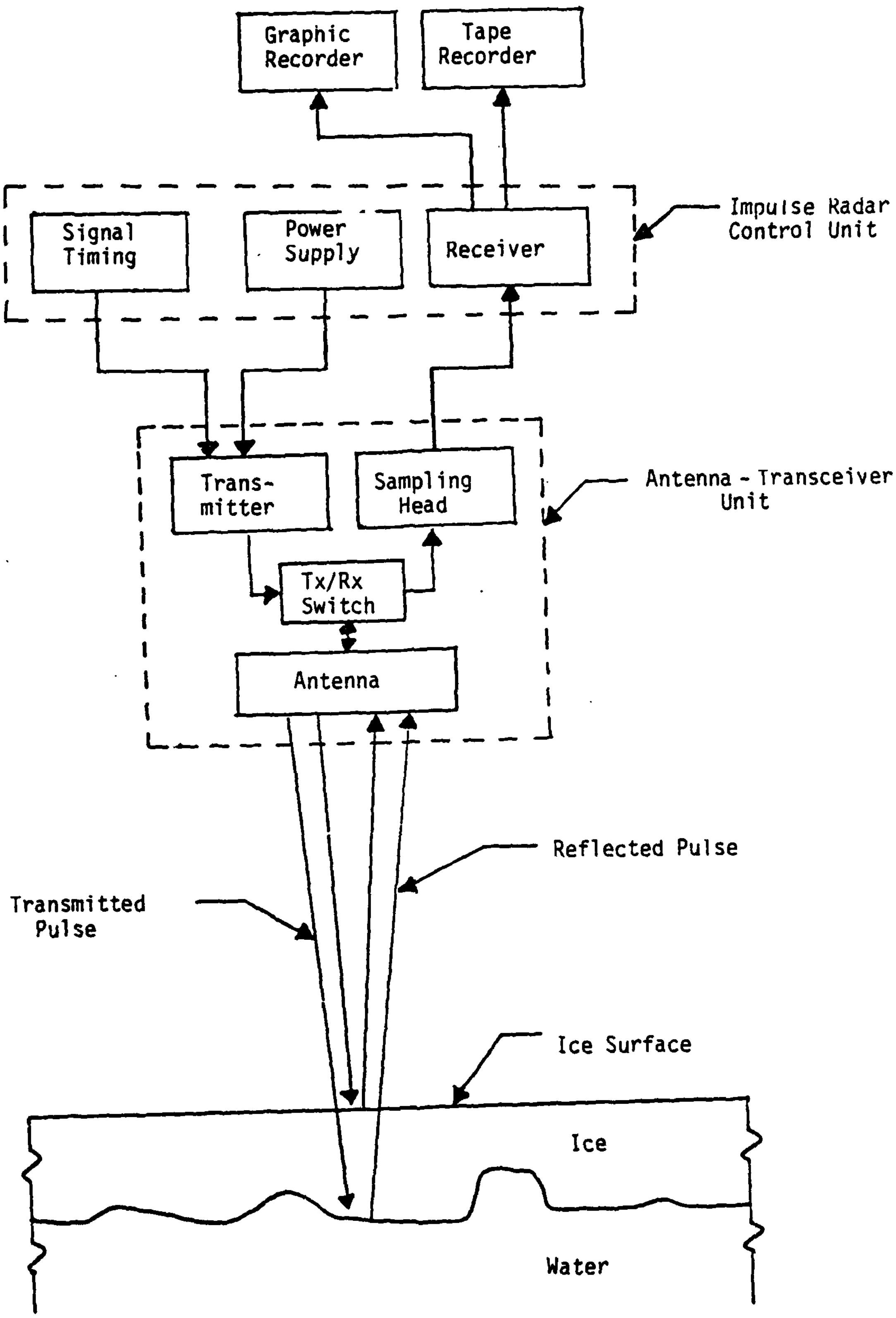

Figure 1. Schematic Diagram Showing Operation of Impulse Radar System in Ice Thickness Profiling.

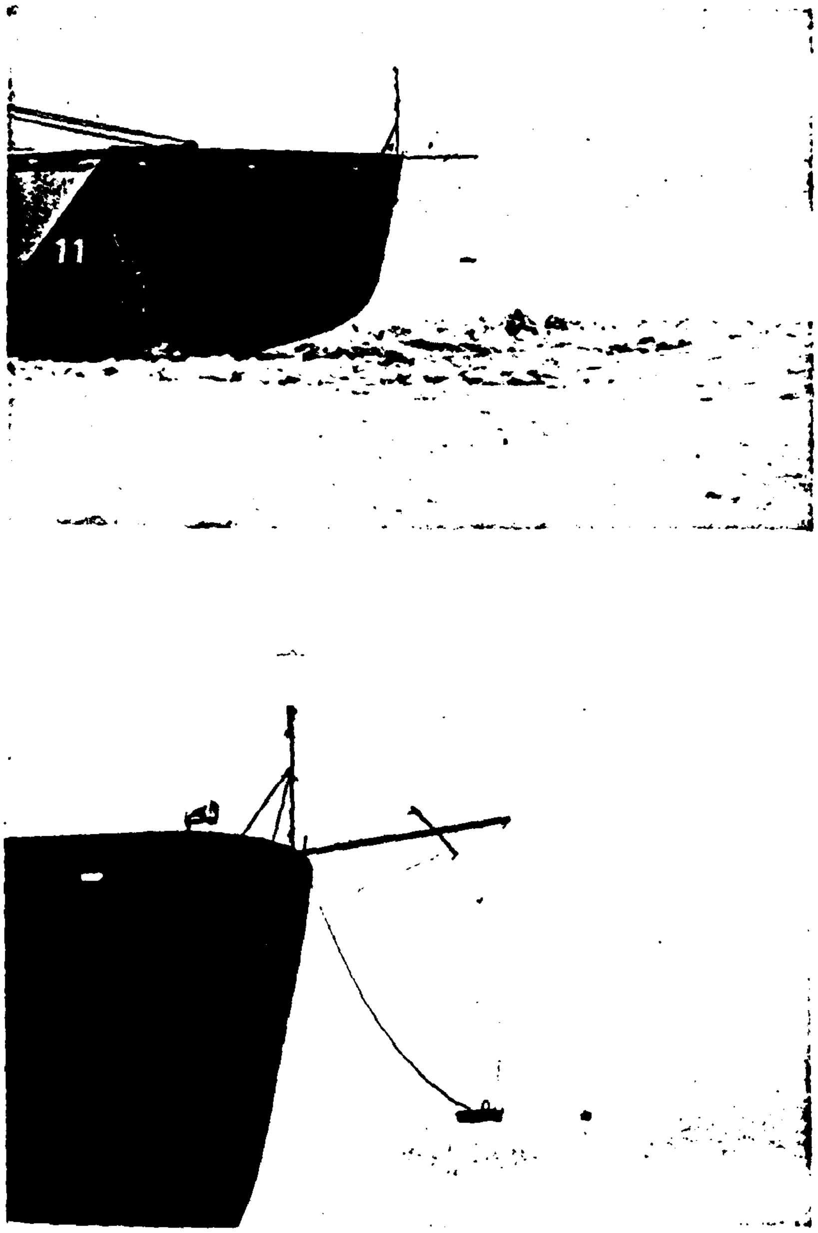

Figure 2. Photographs Showing Impulse Radar Antenna and Support Boom on the Bow of CGC POLAR SEA.

fiberglass due to cold temperatures was not encountered, and the flexible nature of the fiberglass appeared to dampen ship vibrations, with little or no vibrations transmitted to the antenna.

The system electronics were located below decks just aft of the bow in the winch room. Although this protected the equipment from the elements, it would have been better to locate the system on the bridge so that the system operator could observe the ice being profiled. Another way of accomplishing this would have been to install a TV monitor below decks.

3.2 Experimental Procedures

The impulse radar experiment was conducted in conjunction with icebreaker performance tests by ARCTEC, Inc., which included detailed on-the-ice measurements of ice thickness and ice properties at various points along the ship's trackline. These measurements were to be used as ground truth data for the R&D Center impulse radar experiments. The R&D Center effort called for taking a series of impulse radar scans, each an hour in duration, using the bow antenna while the ship was in transit from one ARCTEC survey site to the next. The volume of data collected would depend on the initial success of the underway profiling in that data collection would be continued only if the initial traces indicated that the location of the ice/water interface, and the difference between various ice types were clearly discernable. If the scans were not more or less readable, then adjustments would be made to the electronics, or the antenna repositioned until a clear trace was obtained.

During the time when the POLAR SEA was stopped for the ARCTEC on-the-ice surveys, the R&D Center team planned to collect ground truth data using an impulse radar ice antenna towed behind an all-terrain vehicle. This 100 MHZ center frequency antenna was specifically designed by GSSI for profiling from the ice surface. This antenna was to be used during the ARCTEC level ice resistance tests to obtain a high resolution on-the-ice profile to be compared with the bow antenna profile taken along the same track. This would aid in determining the degree of resolution that could be obtained using the bow antenna, and identify ship noise in the bow antenna trace. In addition to level ice, the ARCTEC, Inc., survey called for profiling both first-year and multi-year pressure ridges using both drill hole measurements and a profiling sonar. The R&D Center experiment plan called for profiling these same ridges with the bow antenna to check the system's ability to measure pressure ridge depth.

4.0 RESULTS

The desired outcome of the experiment was for the impulse radar bow antenna system to provide a clear picture of ice thickness for a variety of ice conditions (i.e. first-year ice, multi-year ice, rubble fields, pressure ridges, etc.) backed up by a set of ice thickness data for ground truth. If the system had worked as hoped, it was planned to document its effectiveness by obtaining numerous scans of ice conditions along the POLAR SEA's entire track. Given these expectations, the level of success can be described as limited at best. However, some data was collected, and some worthwhile experience gained.

Several extended ice profiles were obtained which clearly show a reflection from the ice surface, and occasional reflections from what appear to be interfaces underneath. However, it was not possible to conclusively identify the ice/water interface in these profiles over an extended portion of the ship's track. One problem appears to be signal "noise" generated by the ship as shown in Figure 3, which may have obscured the ice/water interface. A portion of this noise appears to be interference from the hull described as "ringing". This noise shows up in Figure 3 as multiple sets of parallel, horizontal bands running the length of the profile. It also appears that there may be a secondary reflection from the ice surface possibly bouncing off the hull of the ship prior to being received by the antenna. Initially, this second reflection just below the initial surface reflection was thought to be the ice/water interface (ice thickness of 1-2 feet). However, it quickly became apparent that this reflection never changed position (i.e. thickness never varied) even though the ship was transitting different ice types with different thicknesses. Another source of signal interference was electrical noise from the ship (presumably radio transmissions) as indicated in Figure 4.

The impulse radar traces also showed some intermittent subsurface interface reflections as indicated in Figures 4 and 5. The shallower reflections appear 20 to 80 nanoseconds behind the surface reflection which, assuming a dielectric constant for the ice of five ($\varepsilon_r = 5$), would put the interfaces roughly 4 to 18 feet below the surface. This is within the general thickness range of the ice types encountered along the ship's track (i.e., first-year, multiyear, pressure ridges, etc.). However, without ground truth data it is impossible to verify that this was the ice bottom, and not anomalies within the ice, or ice surface features picked up by the antenna off to the side of the ship's track.

With regard to the ground truthing efforts on the ice, these were curtailed due to the operational difficulties experienced by the ship. The most useful ground truth measurements would have been those taken during the ARCTEC, Inc., level ice resistance tests. Unfortunately, these tests could not be conducted. The only available ground truth data were a few spot thickness measurements from holes drilled in the ice. However, in light of the ambiguity of the radar profiles, these measurements were of little value in assessing the system's effectiveness.

In terms of modifying the system to improve its performance, several possible solutions come to mind. The first of these would be to move the antenna closer to the ice and farther forward of the bow. Some experimentation with lowering the antenna during the final stages of the cruise indicated that this would shift a large portion of the noise farther down the trace, away from the area where the ice/water interfaces might be located. In addition, this would improve the penetration power of the signal by reducing the area of the antenna radiation pattern on the ice surface, which in turn reduces signal attenuation at the surface. This surface attenuation is particularly strong when the ice is rough or deformed resulting in a high degree of signal scattering. This lowering of the antenna would be limited by swinging of the antenna on the support cables, and the possibility of antenna damage due to striking pressure ridges.

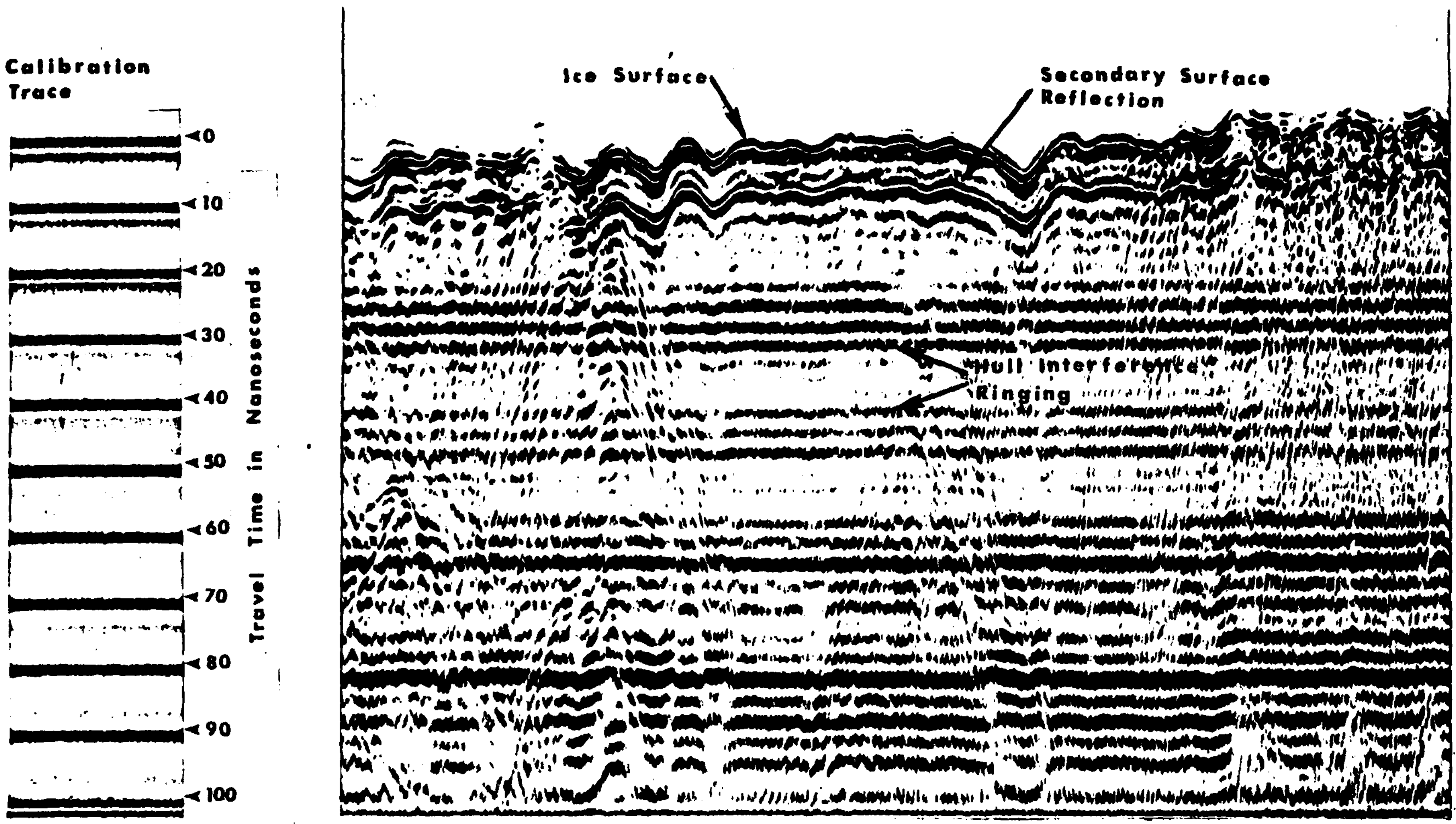

Figure 3. Impulse Radar Trace Showing Ringing Induced by Ship's Hull and Secondary Surface Reflection from Ship's Hull.

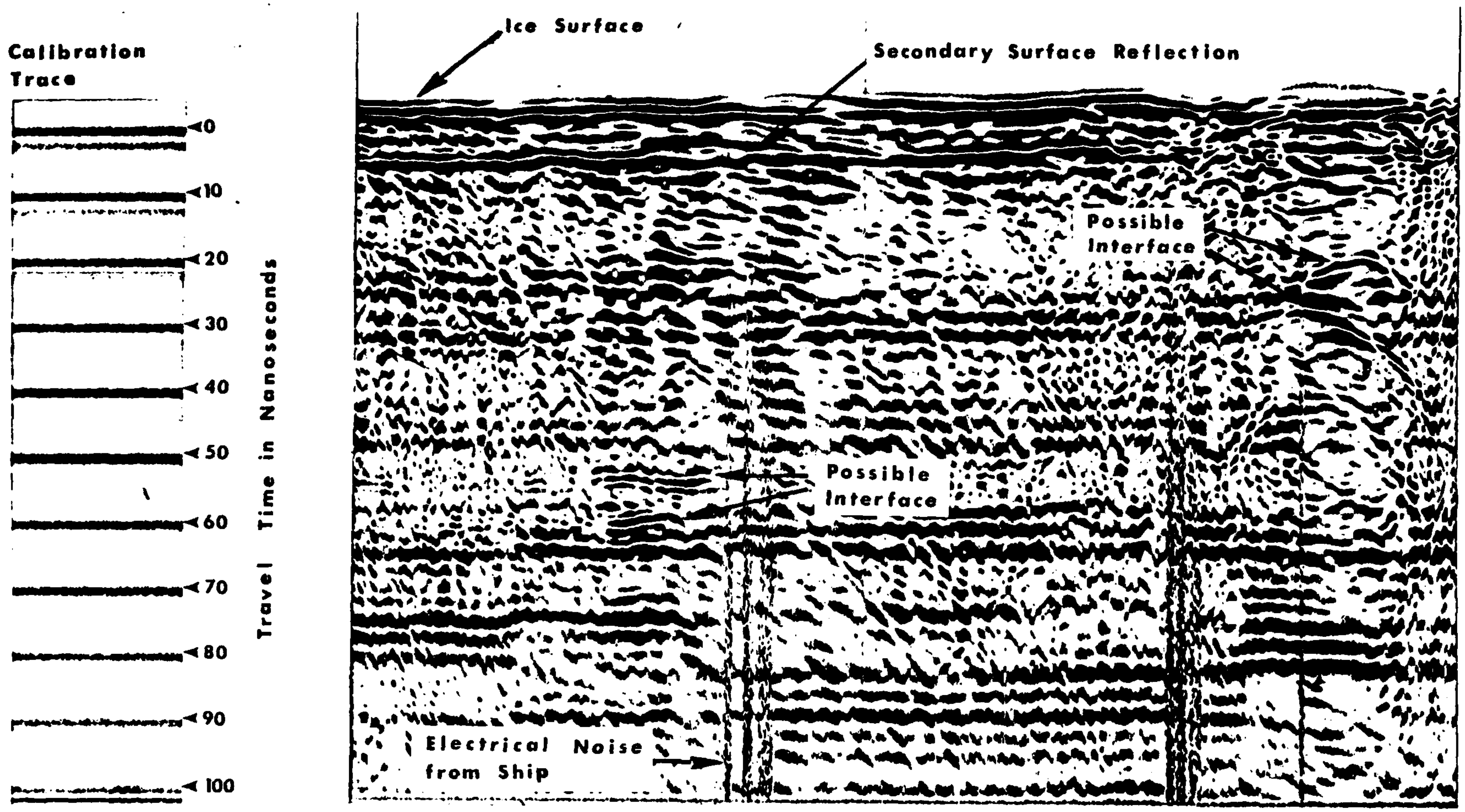

Figure 4. Impulse Radar Trace Showing Possible Subsurface Interface Reflections.

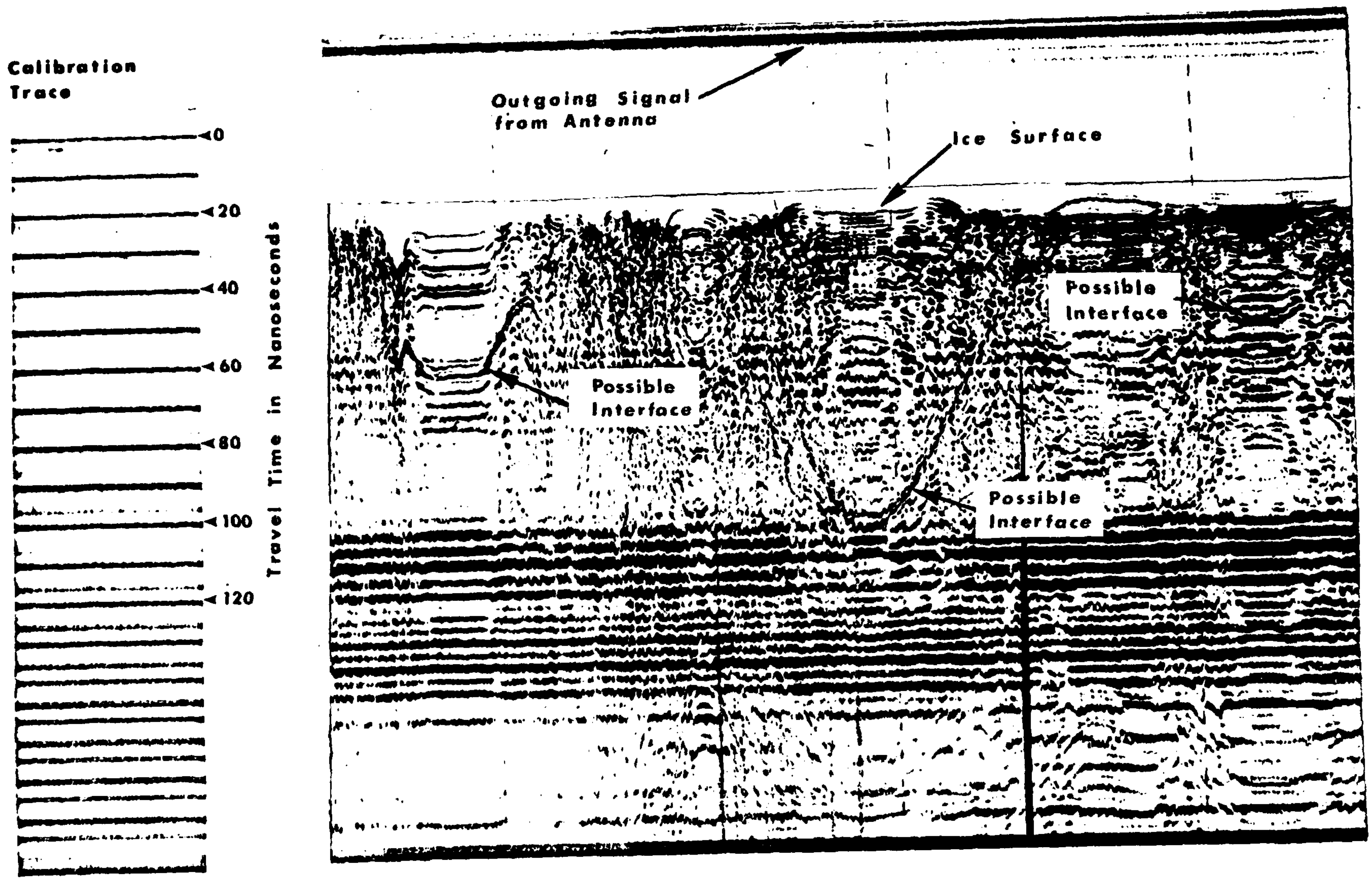

Figure 5. Impulse Radar Trace Showing Possible Subsurface Interface Reflections.

A second possible solution is to redesign the antenna specifically for underway sea ice thickness profiling. For most types of ice this would require a lower center frequency antenna (80-100 MHZ) as used in most of the previous sea ice profiling field experiments, to improve ice penetration. In addition, the antenna should be specifically designed for airborne applications which generally includes antenna shielding and a concentrated radiation pattern. This would improve the penetrating power of the antenna, and also eliminate impedance mismatch problems associated with antennas designed to rest on the surface of the ice. It would also be advantageous to be able to vary the center frequency of the antenna to optimize ice penetration and interface resolution for various types of ice. Unfortunately, this is difficult in a single antenna as antenna dimensions govern the center frequency, and hence it might be necessary to use two or more antennas mounted together with a provision for rapid antenna switching.

A third possible solution would be the incorporation of electronic signal processing to remove background noise and enhance interface resolution. This technique is being used routinely in other systems with some success, and in fact GSSI manufactures a system which contains a built-in microprocessor programmed for real-time or off-line signal enhancement. However, the signal processing does not increase the performance factor (penetrating power) of the system.

5.0 CONCLUSIONS

Although previous field studies support the feasibility of underway impulse radar profiling for several types of sea ice, the experiment aboard CGC POLAR SEA was unsuccessful in demonstrating the system's effectiveness in this application. Specifically, the system was unable to produce a recognizable profile of the ice/water interface over an extended portion of the ship's track. Intermittent subsurface reflections in the profiles could not be identified due to the lack of ground truth data. Possible modifications to the system which might improve effectiveness include:

1) Reconfiguring the support boom to move the antenna closer to the ice. This would reduce interference from the hull (both ringing and hull reflections) and signal attenuation at the ice surface.

2) Designing an antenna specifically for underway profiling including a lower center frequency (80-100 MHZ) and concentrated radiation pattern to improve signal penetration; and shielding to prevent electronic interference from the hull.

3) Incorporate signal processing equipment to remove background noise and enhance interface resolution in the graphic display. This would help reduce the subjectivity in data interpretation and allow more accurate thickness measurements.

6.0 SUGGESTIONS FOR FURTHER RESEARCH

With regard to future work, the immediate question is whether to continue to develop the impulse radar bow antenna system for underway ice thickness profiling. The results of this year's experiment and previous work by other researchers indicate that the system could probably be modified to give reliable ice thickness profiles for level ice, and possibly multi-year pressure ridges. It appears unlikely that the system would provide profiles of saltwater brash ice, rubble ice, and first-year pressure ridges. Thus, the bow antenna system could be developed as a research tool to provide underway level ice thickness profiles for level ice resistance tests, ice growth surveys, and similar studies requiring level ice thickness data along an extended trackline.

In terms of developing the impulse radar as an ice reconnaissance tool (particularly mounted on a helicopter), this seems questionable. First of all, the system will not profile first-year pressure ridges or rubble fields which are often the primary impediment to navigation, thereby limiting the system's operational usefulness. Secondly, the analysis of the data is involved and somewhat subjective (involving considerable ground truth data and pattern recognition by a trained researcher), thus limiting real-time application of the data. Ongoing research programs are being conducted by several groups (CRREL and the Office of Naval Research in the U.S., C-CORE and Barringer Ltd. of Toronto in Canada) to develop a real-time ice thickness remote sensing system. However, at present no commercially available system exists. Whether the Coast Guard should undertake the development of such a system also seems questionable due to the funding and electronics expertise that would be required. It may be wiser to monitor the success of other researchers until such time as a prototype system is developed and tested, and then modify the system for Coast Guard use.

7.0 REFERENCES

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APPENDIX A

Specifications for Impulse Radar System
Used in CGC POLAR SEA Experiment

SIR System 7

Geophysical Survey Systems, Inc.
17 Flagstone Drive
Hudson, New Hampshire 03051

Components

Control Unit: GSSI Model 4700

Dimensions: 44 x 38.8 x 17.7 cm
Weight: 11 kg.
Power Requirements: 11-15 VDC

Tape Recorder: Hewlett Packard Instrumentation Recorder, Model HP 3964A

Dimensions: 48.3 x 24.1 x 40.7 cm
Weight: 28 kg.
Power Requirements: 100-240 VAC, 48-1000 HZ, 85 WATTS

Graphic Recorder: EPC Model 2201 grey scale graphic recorder

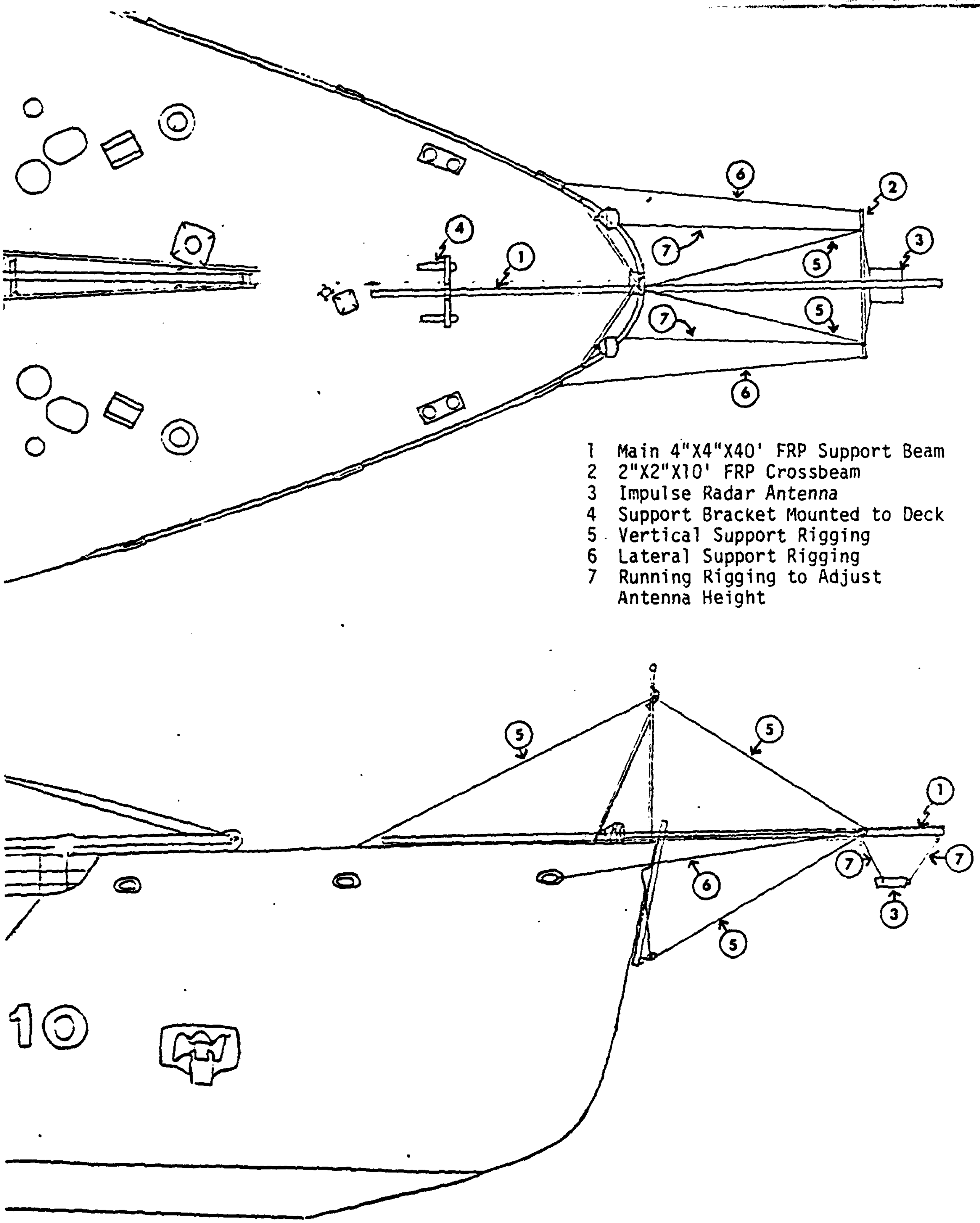
Dimensions: 82.6 x 52.7 x 12.1 cm
Weight: 27 kg.
Power Requirements: 100-120 VAC, 50-60 HZ, 120 WATTS

Antenna: GSSI Model 3105AP high resolution, shielded, bistatic

Dimensions: 76.2 x 63.5 x 19 cm
Weight: 16 kg.

System Performance Specifications

Pulse Repetition Frequency: 51.2 KHZ
Scan Rate: 3.2 to 51.2 scans/second, adjustable in steps of X2
Range Window: 20-2000 nanoseconds, fully adjustable
Antenna Center Frequency: 300 MHZ
Pulse Width: 3 nanoseconds



Appendix B - Sketch Showing Construction of Fiberglass Boom for Mounting Impulse Radar Antenna on CGC POLAR SEA.

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