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RADIO-FREQUENCY RADIOMETRY AS A REMOTE SENSING TECHNIQUE IN MARITIME RECONNAISSANCE AND MARINE SCIENCES IN A NORTHERN ENVIRONMENT

by

A.W. Adey and G.N. Reed

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ABSTRACT

The note discusses the application of the RF radiometry technique to the general maritime reconnaissance and marine sciences role in the Canadian North. It includes results of tests carried out with a helicopter-borne, multichannel, UHF radiometer in August 1972 in the Hudson Strait and Labrador Coast areas. Radiation data were obtained during flights over ships, ocean and fresh water, pack ice, icebergs, glaciers and land features. These initial results were encouraging, in demonstrating the potential of the technique, not only in direct support of maritime operations through aiding in detection and identification of features of interest, but with possible application in areas such as hydrology and glaciology.

1. INTRODUCTION

It was emphasized, in the assessment of the results of the Canadian Maritime Forces' northern deployment in 1971 (NORPLOY 1971), that the ice environment is a source of difficulty, complication and danger to maritime operations in northern waters. The major problems are the detection of pack ice and icebergs, estimation of the concentration of the pack ice, and distinction between ships and icebergs during periods of darkness and limited visibility. Some of these problems are further accentuated in the presence of a high sea state, when sea clutter tends to mask the target of concern.

Staff at the Communications Research Centre (CRC) proposed that the RF-radiometry technique, currently under study at the CRC as a possible tool for the remote sensing of sea-ice thickness, should offer some potential in the direction of alleviating some of the problems noted in the previous paragraph. Operation would be possible during periods of darkness, and in the presence of fog and cloud cover. Specifically, it was proposed that trials with a helicopter-borne radiometer, using the CRC UHF instrument, operated by CRC staff, should be included in scientific experiments planned as part of NORPLOY 1972.

It was emphasized in the proposal that the CRC radiometer had not been designed specifically for the maritime reconnaissance role and was therefore not optimized in terms of frequency, spatial resolution, integration time, etc. Thus, in an operational situation, the optimum flight altitude and speed are related to the antenna beamwidth, radiometer integration time and sensitivity, and target size. However, it was estimated that the CRC instrument, with suitably adjusted flight parameters, would demonstrate the general potential of the technique.

The CRC proposal was accepted and a series of successful helicopter flights were carried out in August 1972, at the southern entrance to the Strait of Belle Isle, along the Labrador Coast and in Hudson Strait. The *SEA KING* helicopter used was based on *HMCS PROTECTEUR*. A very brief, qualitative report on the trials, including a discussion of the radiometry technique, the actual flight installation and the tests that were conducted, and concluding with a general assessment and recommendations for further experiments in northern waters, was prepared during the return trip to Halifax for inclusion in the Captain's report. The present note is somewhat more comprehensive, with illustrations, samples of data and a more extensive discussion of the results.

2. PRINCIPLE OF OPERATION AND PREDICTED RADIATION LEVELS

The principle on which the radiometry technique is based has been treated in detail in earlier reports and papers *(see list of references at the end of the text)*. The present note will therefore treat this aspect only briefly, and with special reference to the NORPLOY 1972 experiments.

The radiometer is a very sensitive receiver which takes advantage of the fact that all bodies radiate electromagnetic energy. The intensity or strength of the radiation depends on the frequency, on the absolute temperature, on the electrical properties of the materials of which the bodies are formed, and on the nature of the boundaries or surfaces. It is usual to refer to the level of the radiation in terms of a 'brightness temperature' in units of kelvins (symbol K), the number of kelvins in any instance being equal to the absolute temperature at which the body would need to exist, if it were a black body, and if it were to radiate at the given intensity and in the given bandwidth. The different types of surface or target being overflown can thus usually be identified and classified on the basis of the level or intensity of the received radiation. In other words, each class of radiator might be said to produce its own radiation signature.

We may note the following details of the relative radiation levels predicted for the surfaces and targets of interest in the present context, the numbers given in brackets being order-of-magnitude indications of the expected absolute levels:

(a) Salt water is a medium-strength radiator, the level of the radiation in the lower part of the UHF band varying, in general, with salinity, temperature and frequency (100 K).

(b) Metallic structures, such as ships, are weak radiators (20 K).

(c) On a ship, extensive areas of deck cargo of non-metallic materials, such as timber, can be strong sources of radiation (200 K).

(d) Thick sea ice and land features tend to be strong radiators (250 K).

(e) Icebergs would generally be expected to radiate at a level significantly greater than that of salt water, and possibly comparable to that of thick sea ice (250 K). However, this radiation level would depend on a number of factors, including shape, size, the amount of salt deposited on the surface which would alter the surface emission properties, and the inclusion in the ice of debris such as rock and soil.

(f) The level of the radiation from a continuous cover of sea ice will increase with the ice thickness, up to a certain limiting thickness which depends on the properties of the ice and the radiometer frequency (100 - 250 K). This prediction was confirmed in our previous Arctic trials.

(g) The level of the radiation from open pack ice will, in general, increase with the percentage of ice cover (100 - 250 K).

(h) For flights over land, the presence of water, either in the form of moisture in the soil or of surface water such as ponds, will be indicated by a decrease in the radiation level (100 - 150 K). The depths in the soil, for which the radiometer is sensitive to the presence of moisture, will be greatest for the lowest frequency of operation,

(i) For frequencies below approximately 2 GHz (i.e., for the band of frequencies which includes the lowest three CRC radiometer channels) the radiation level decreases as the salinity of the water increases. The sensitivity of the level of the radiation to water salinity increases with decreasing frequency and with increasing water temperature (60 - 100 K).

(j) Disturbance (roughening) of the water surface should result in an increase in the level of the radiation, the increase correlating positively, in general, with the degree of disturbance. Such disturbance could result from wind roughness or a ship's wake. No prior experimental data at the frequencies employed in the CRC radiometers were available, and the prediction or expectation of the effect represented only an extrapolation of the experience at much higher frequencies (150 - 200 K).

3. THE RADIOMETER INSTALLATION

This section will provide a general description of the installation, with the operating characteristics of the main components. Further details of the receiver itself can be found in the references cited.

The radiometer could be operated in four frequency bands in the range 400 - 2300 MHz. It was installed in a Canadian Forces' *SEA KING* twin-turbo helicopter *(Figure (1))*. Two downward-pointing antennas were used, as shown in Figure (2). The antennas were mounted on specially-fabricated brackets, fastened to lugs already available on the fuselage. The log-periodic antenna seen on the left of the loading door in Figure (2) could be operated simultaneously in three bands, each 100 MHz wide and centered on 407, 765 and 1415 MHz, respectively. The horn antenna, seen to the right of the door, covered a 100 MHz band centered on 2230 MHz. The beamwidths of the log-periodic and horn antennas were approximately 50 and 40 degrees, respectively. The general arrangement of the remainder of the radiometer components in the helicopter can be seen in Figure (3).

The signals from the receiver were recorded continuously on a paper chart and on magnetic tape for further analysis. A running commentary on the nature of the surface and targets being overflown, and on the flight and instrument parameters, was recorded on one of the tape tracks. Certain special surface and target features were photographed, to assist in post-flight study and interpretation of the data.

While observations could be made on all four channels, the design of the radiometer permitted observation on only two channels simultaneously - the 2230 MHz channel and one of the three lower-frequency channels (centered on 407, 765 and 1415 MHz, respectively). The 407 MHz channel was used on the first two flights, but was not satisfactory because of interference associated with the helicopter. Had more pre-trials time been available to us, it might have been possible to track down and suppress the source of the interference. The 765 MHz band was finally used for the second channel for all except the last flight, when a malfunction developed in the circuitry and the 1415 MHz band was used.

4. TEST OBJECTIVES

The main purposes of the NORPLOY series of tests were:

(a) to confirm experimentally the radiation properties predicted for the several classes of materials and targets noted in a previous section;

(b) to demonstrate to the Canadian Forces the type of radiometer signal for the various targets and types of terrain to be encountered during the trials;

(c) to overfly as many types of ship (both military and otherwise) and as many icebergs (of different size and shape) and sea-ice features as possible so as to determine the variations in radiation signature among objects of a particular class.

It was hoped that the tests could be performed for a range of helicopter altitudes and flight speeds, ships' speeds, sea states and types and concentration of ice.

Fig. 1. SEA-KING helicopter of Canadian Forces Maritime Command.

Fig. 2. Mounting arrangement of radiometer antennas on SEA-KING helicopter.

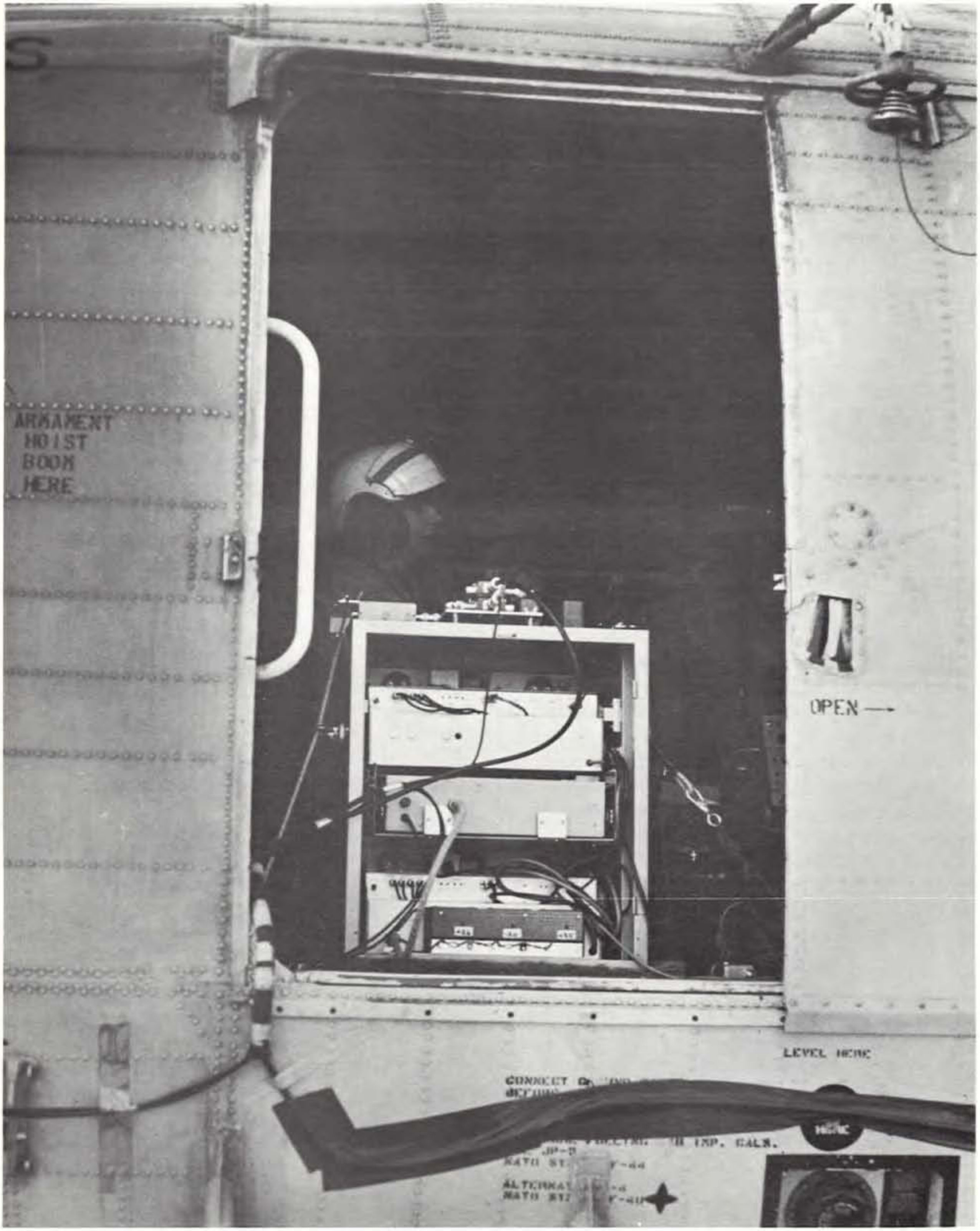

Fig. 3. Radiometer installation in SEA-KING helicopter.

5. EXPERIMENTAL RESULTS

It is not possible, within the scope of this note, to present and discuss the details of all the experimental results. A selection has been made as representing the major problem situations and as illustrating the success achieved in demonstrating the potential of the RF radiometry technique as an aid in maritime operations in the north.

In addition, although the radiometer output was calibrated in absolute brightness temperature or signal strength, it was considered that, in the present context, the relative level of the output record would be more significant than the absolute level, and the experimental data are presented accordingly.

To aid in interpreting and assessing the experimental results, it will be useful to recall that water is a medium-strength radiator, while metallic structures such as ships are weak radiators, and pack ice, icebergs, wakes and land are strong radiators. For this reason, and since features and targets of interest usually are seen against a water background, the level of the radiation or signal from water can be considered as a sort of reference level, with increases above, or decreases below, this level indicating the presence of an appropriate contrasting object (ship, iceberg, etc.).

The following examples illustrate the nature of the data obtained:

(a) *Ship's Wakes*

A series of recordings were made during a refuelling period, when the helicopter was maintaining rescue station astern of three of the ships. This station-keeping operation involved both hovering and traversing slowly from one side to the other over the wakes. Figure (4) illustrates the types of radiometer signature obtained. It was recorded during the initial flight, which was our first chance to check out the complete airborne system. A problem with the 'commentary' channel of the tape recording during this flight prevented our being able to extract all the necessary data on the radiometer operating parameters. While this initial record is thus qualitative, it illustrates the application of the technique and confirms the general predictions of the positive signature from the wakes.

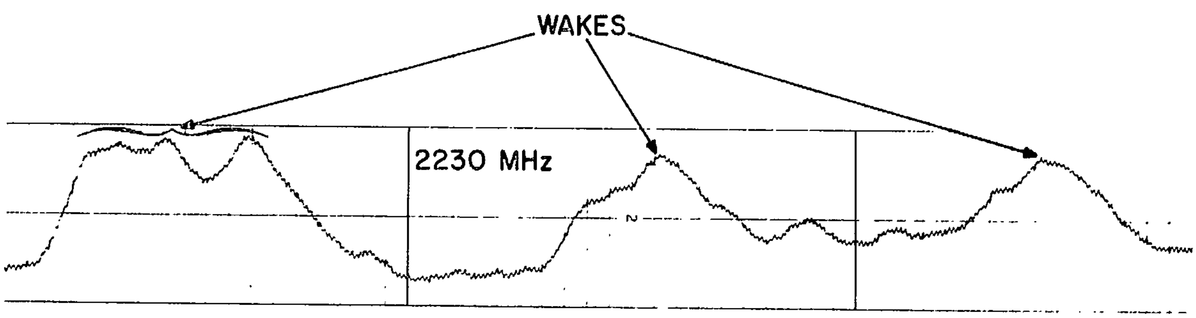

Fig. 4. Radiometer signature of ships' wakes during refuelling operation.

(b) *Ships*

The record of Figure (5) resulted from a flight over a medium-sized merchant ship. The helicopter flight track was in the same direction as that of the ship. The sea was fairly smooth. There were both a prominent bow wave and a very heavy wake. In the opinion of the flight crew there was heavy deck cargo extending from approximately amidships to some distance forward. The recording shows the sharp negative signature representative of metallic structures, but also two positive signatures - the one earlier than the negative signature and the other later. One of the positive peaks is interpreted as being due to the wake, and the other to a combination of the deck cargo and the bow wave (if the deck cargo was mainly timber or otherwise wood-like) or to the bow wave alone (if the deck cargo was predominantly metallic in character).

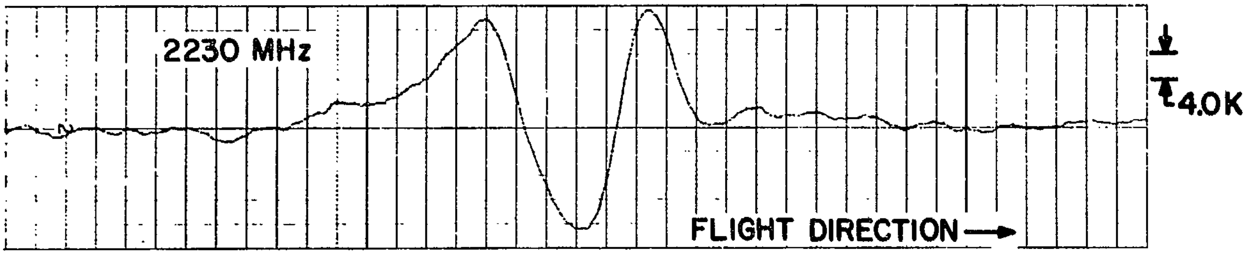

Fig. 5. Radiometer signature of a merchant ship.

A number of flights, at heights of 200, 400 and 700 feet, were made over one of the ships involved in the deployment, on each of several days. We wished to determine both the level and the nature of the radiation signature from the ship and to check on possible day-to-day changes. Figure (6) shows the record from one set of flights, with the helicopter passing from stern to stem of the ship at two different heights. The negative signature typical of a metallic target, with no apparent wake effect, can be seen in each case, even at a flight altitude of 700 feet. Figure (7) illustrates the record from another set of flights on a different day. On this occasion the signature on the lower frequency was characterized by an additional positive signal component, with fine structure, during the passage over the forward section of the ship. We have tentatively attributed this signal to emissions (either direct transmission, or leakage) from some component of the communications or the radar equipment on the ship, with the fine structure reflecting the combined effect of the side-lobe structure of the emitting antenna or structure and the radiometer antenna. This was the only set of flights for which we observed this particular shape of radiation signature.

(c) *Icebergs*

Flights were made over a number of icebergs, of different size and shape and situated both in open water and in areas of open pack ice. Figure (8) and (9) illustrate typical iceberg radiation signatures, characterized by an increase in the radiation level with respect to that from the water. The iceberg of Figure (8) was in open water, and thus gave the sharp signature against a relatively-constant trace from the water. The iceberg of Figure (9) was surrounded by open pack ice that, in the vicinity of the iceberg, constituted six to seven tenths cover. Again one obtains the significant positive signature from the iceberg. The background radiation level in this latter case varied with position, and tended to correlate with the percentage of ice cover.

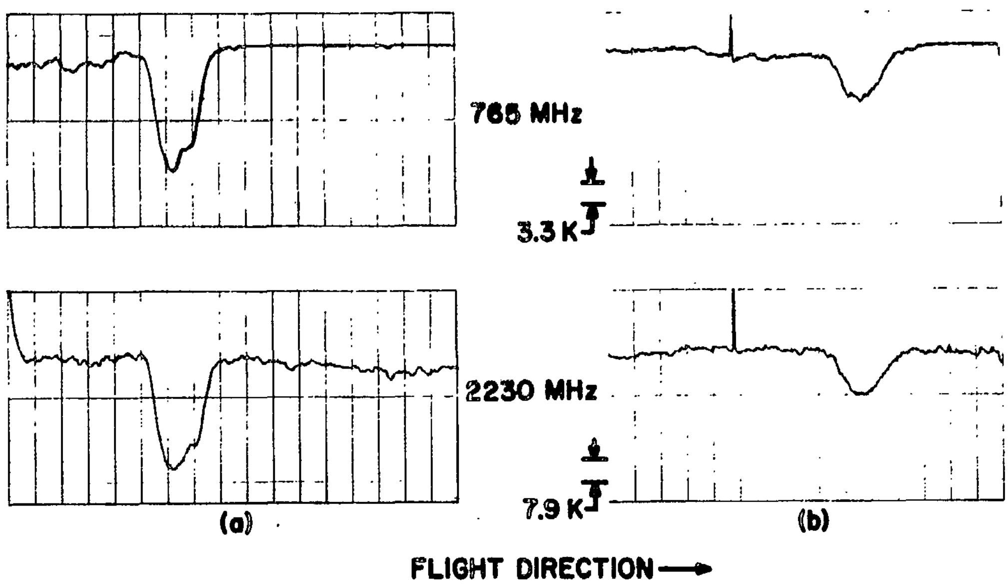

Fig. 6. Radiometer signatures of a NORPLOY ship.

Flight in the same direction as the ship track
Flight parameters: a) 200 ft., 30 knots
b) 400 ft., 37 knots

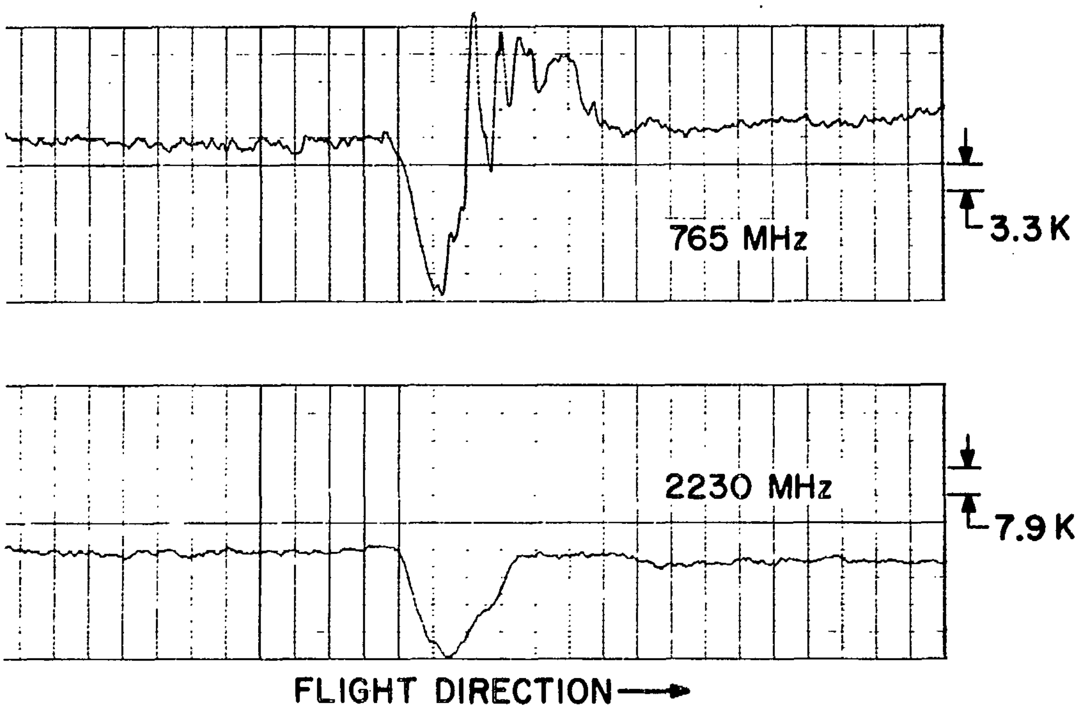

Fig. 7. Radiometer signatures of the NORPLOY ship of Figure 6.

Flight in same direction as the ship track
Flight parameters: 200 ft., 25 knots
Ship speed: 10 knots

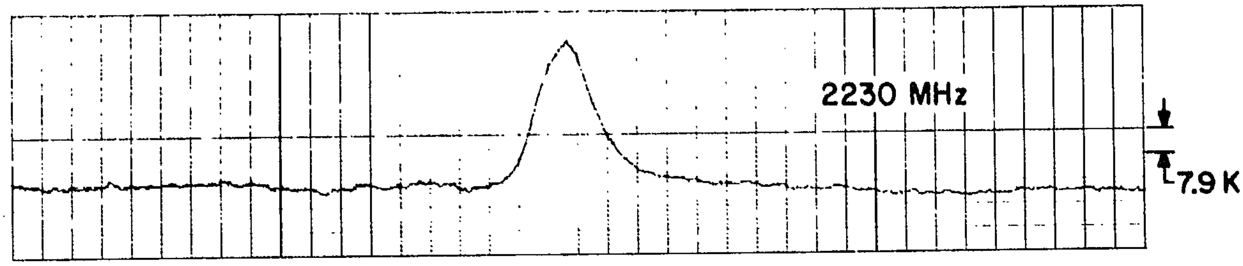

Fig. 8. Radiometer signature of an iceberg.
Flight parameters: 100 ft., 50 knots

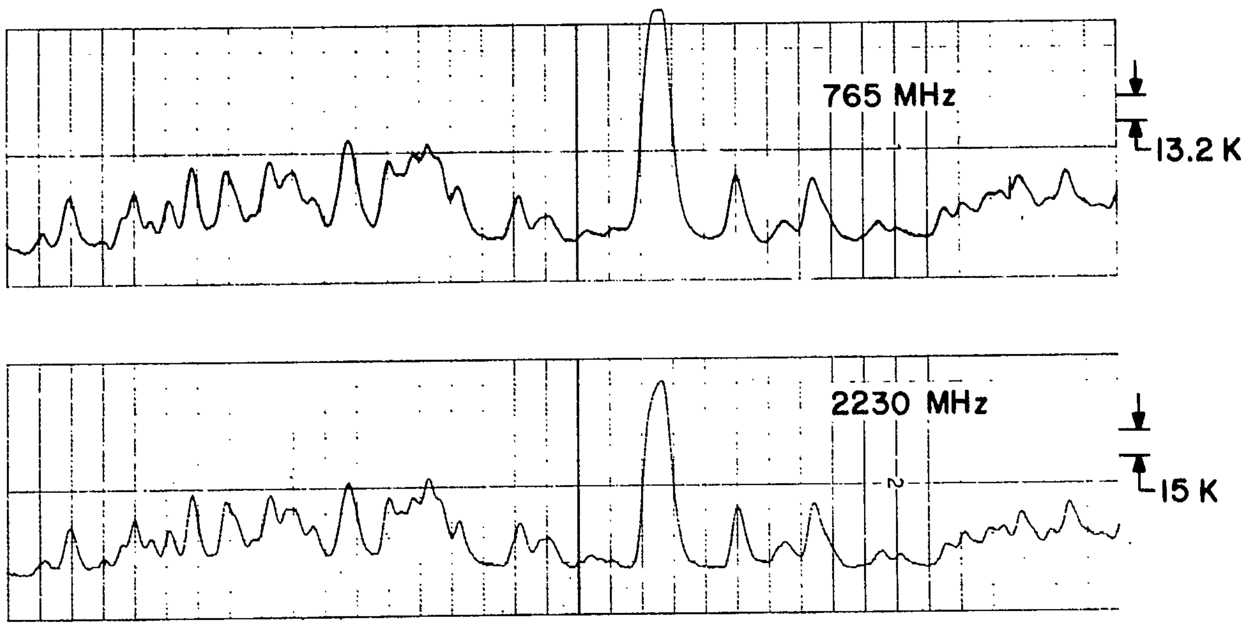

Fig. 9. Radiometer signature of an iceberg in $\frac{6-7}{10}$ pack ice.
Flight parameters: 120 ft., 120 knots

An interesting feature of the iceberg signatures was the variety of shapes, in terms of the degree of symmetry. The two presented in Figures (8) and (9) showed examples of highly-symmetrical traces. Figures (10) to (12) illustrate signatures with varying degrees of symmetry. One is prompted to attempt to interpret the shape of the signatures in terms of certain properties of the icebergs (e.g., the height profile along the flight track, etc.). However, the shape of the signature depends on several factors, other than the properties of the iceberg. These are the flight altitude and speed, and the antenna beamwidth, the frequency, and the integration time constant of the radiometer. The traces of Figures (10) and (11) correlated well with observed height profiles of the icebergs along the flight path. The records of Figure (12) resulted from two flights, made at different altitudes and speeds, over an iceberg with steep sides and fairly uniform height along the flight track. There is only a slight departure from symmetry apparent in Figure (12a), and that only on the higher-frequency record (due, probably, to the narrower antenna beamwidth, and therefore the better spatial resolution, of the higher-frequency channel). By contrast, the highly-asymmetrical appearance of the traces of Figure (12b), on both channels, shows the effect of decreasing the flight speed by a factor of two, the effect of the decrease in speed more than compensating for the effect of the increase in flight altitude.

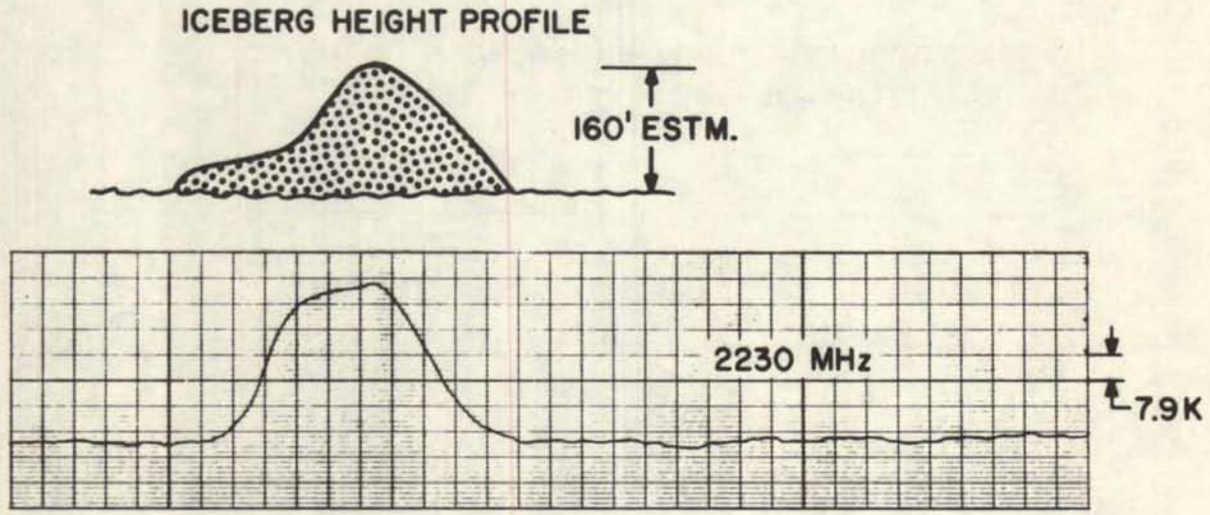

Fig. 10. Radiometer signature of an iceberg.
Flight parameters: 200 ft., 70 knots

Operation at much higher frequencies, with the corresponding narrower antenna beamwidths and thus better spatial resolution, should enhance the diagnostic capability of the radiometer in this respect, as long as the skin-depth or optical depth is sufficiently great to permit monitoring the radiation from the major portion of the iceberg volume.

(d) *Open Pack Ice*

Our previous experience had confirmed the prediction that the level of radiation received over sea ice is higher than that from open sea water. This circumstance indicates that the radiometer could be used to detect ice-water boundaries and, thus, to estimate the percentage ice cover. Both of these are key problems in ice reconnaissance. The record shown in Figure (13) illustrates the potential of the radiometer for this application: the pronounced change in the level of the radiation in traversing the boundary between water and close pack ice, and the general correlation between the level of the radiation and the percentage ice cover are clearly indicated.

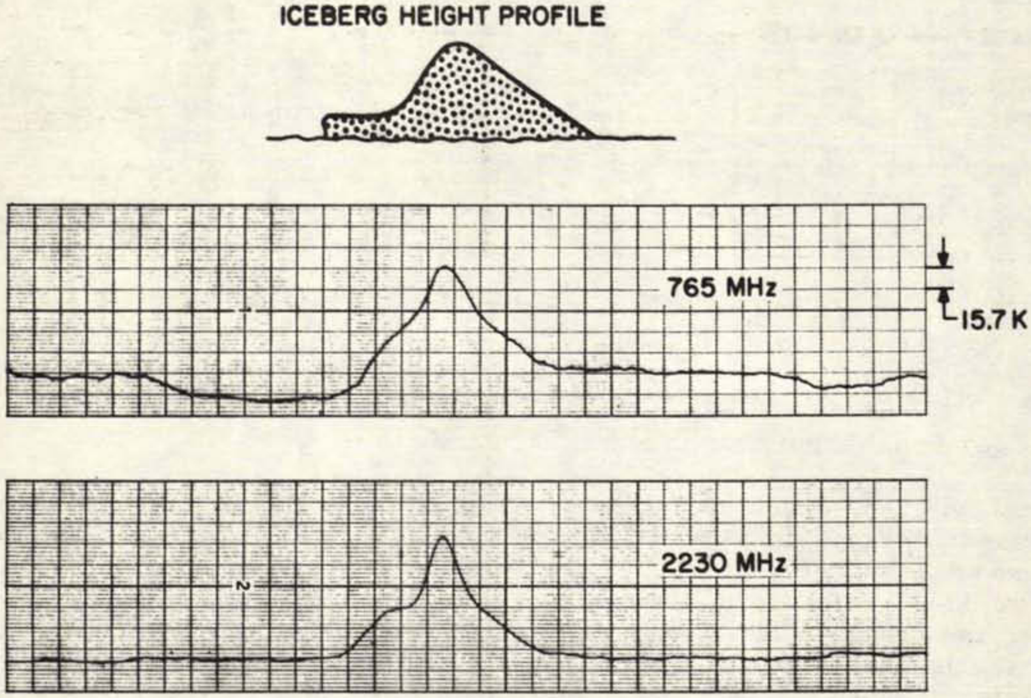

Fig. 11. Radiometer signature of an iceberg.

Flight parameters: 150 ft., 68 knots

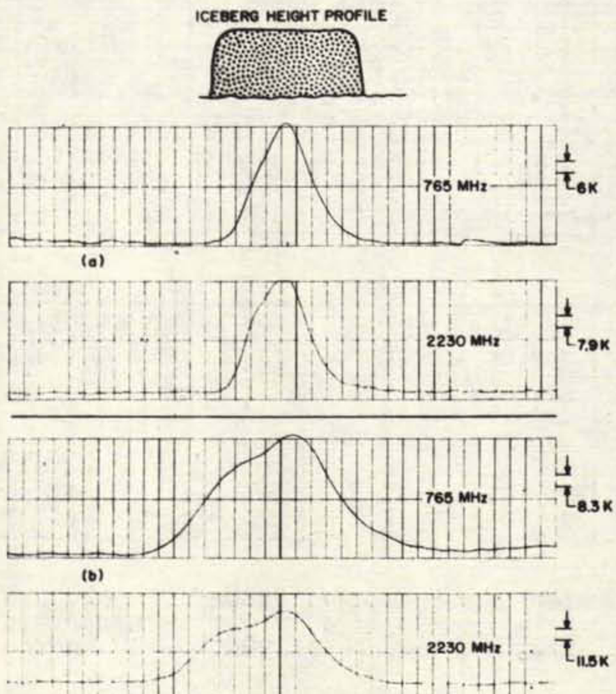

Fig. 12. Radiometer signatures of an iceberg.

Flight parameters: a) 200 ft., 83 knots
b) 300 ft., 40 knots

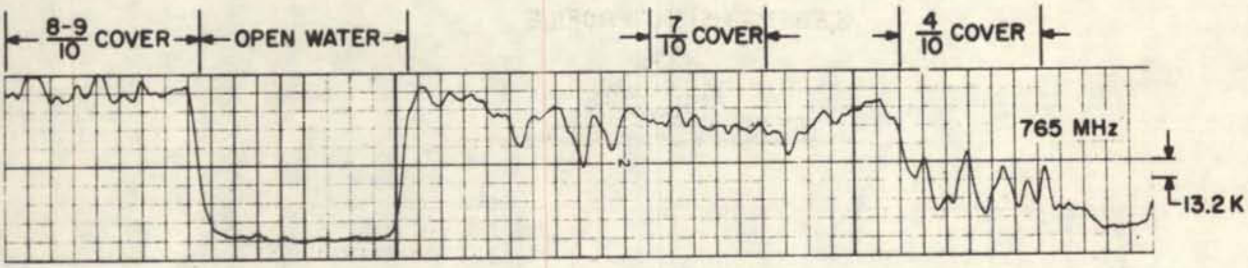

Fig. 13. Radiometer signature of open pack ice.

Flight parameters: Start - 100 ft., 40 knots
End - 170 ft., 60 knots

(e) *Land-Water Boundaries*

Since land areas are strong radiators, much of the discussion in the previous section applies in the present case. Thus, land-water boundaries should show up sharply, as should small islands. The application is illustrated in Figure (14), which is a record of a flight over a series of small, low islands. The presence of small ponds on two of the islands resulted in the series of ripples in the trace in the right-hand portion of the figure. The correlation, for the two frequencies, of the signature of the water on the islands is characteristic of the radiation from *surface* water.

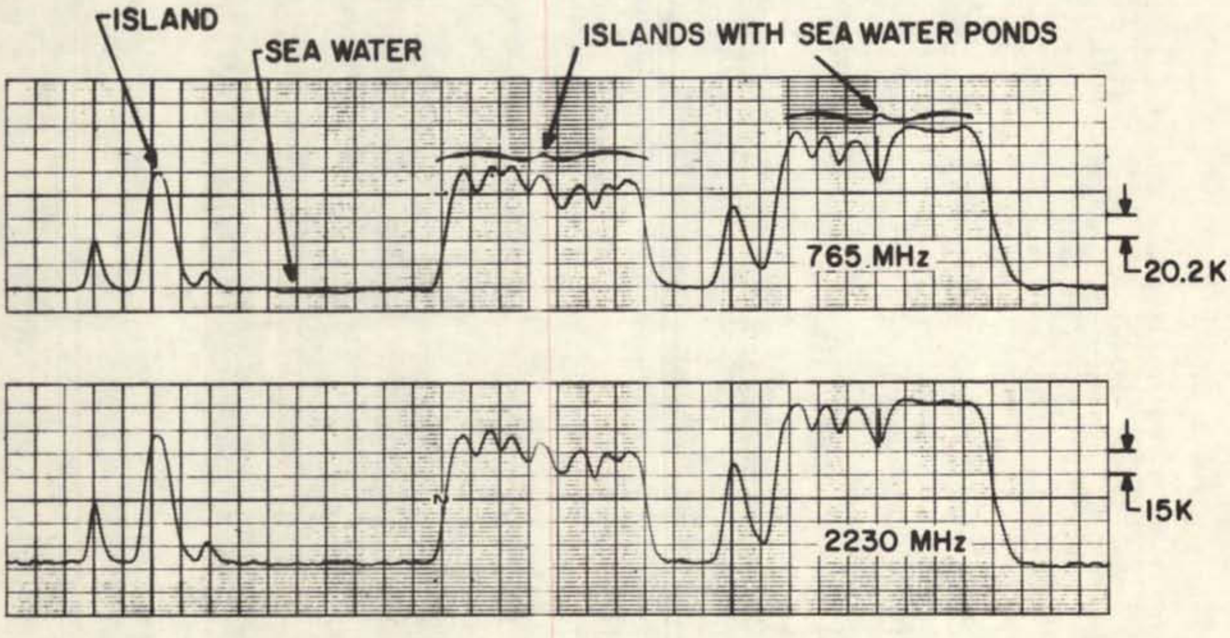

Fig. 14. Radiometer signatures of islands, showing effect of ponds.

Flight parameters: 90 ft., 30 knots

By contrast, Figure (15) shows a record of a flight over a neck of land consisting of dry rock, except for a central, low-lying area that appeared to be covered with lichen or moss. No water was visible on this latter area. However, we tentatively interpret the record as suggesting the presence of moisture below the surface, and at such a depth that the radiation signature from the water at the higher frequency could not penetrate to the surface. This interpretation is consistent with information from local residents as to the general nature of many such low-lying areas, although we ourselves had no direct ground truth for the particular area. This phenomenon suggests an application of the UHF radiometer for sub-surface-water studies.

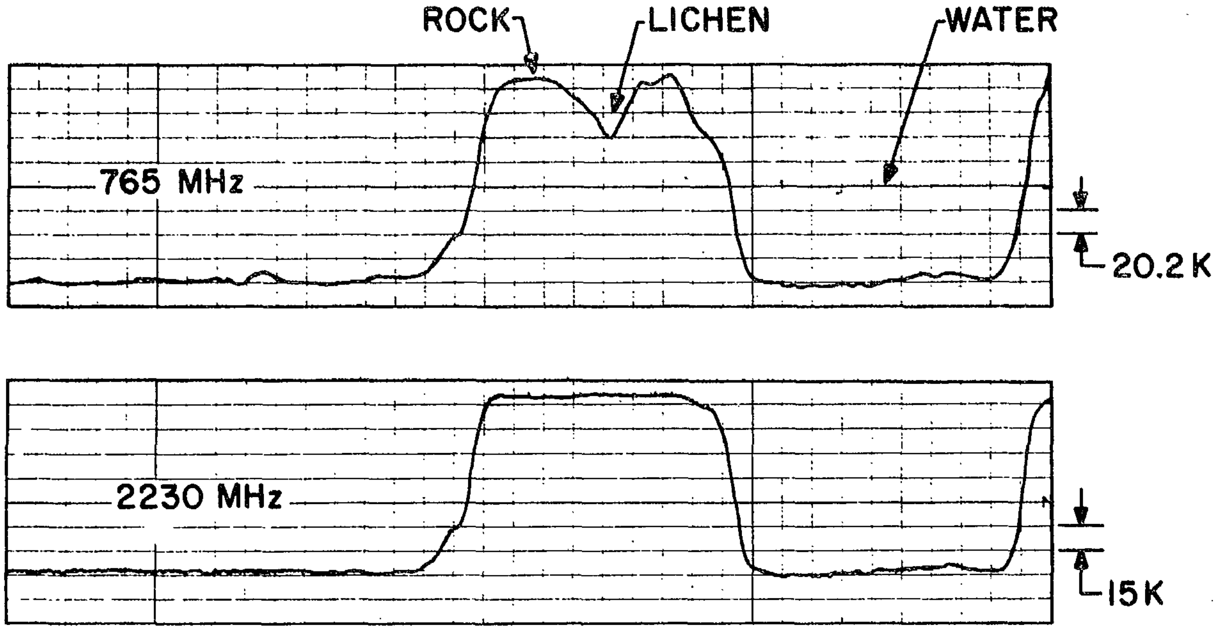

Fig. 15. Effect of frequency on radiometer signatures from rocky and lichen-covered areas.

Flight parameters: 300 ft., 74 knots

(f) *Effect of Water Salinity*

An application of RF radiometry that could be exploited in maritime reconnaissance but which is probably more useful in hydrology and pollution studies, is based on the circumstance that, for frequencies in the lower part of the UHF band, the level of the radiation from water is sensitive to the degree of salinity. Recordings from two flights, each over both ocean and fresh water, are shown in Figure (16). In each case, and consistent with the prediction, the level of the radiometer signal at the lower frequency is greater for fresh water than for ocean water, while there is no significant salinity effect at the higher frequency.

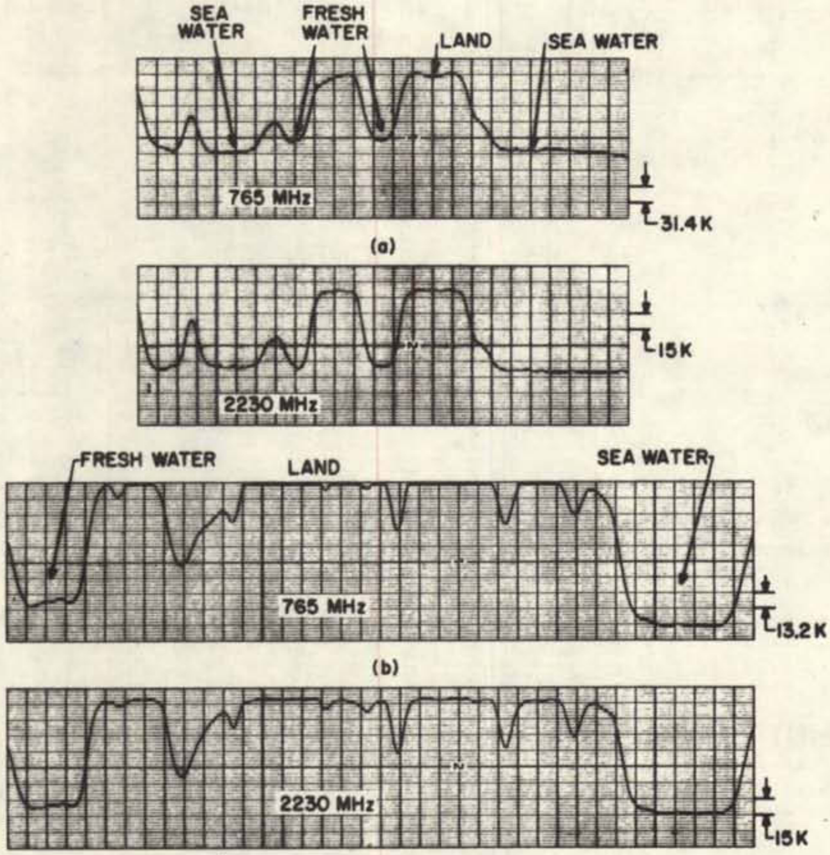

Fig. 16. Radiometer signatures of fresh and sea water.

a) Fresh-Water Lake
Flight Parameters: 200 ft., 65 knots

b) Pool in River
Flight Parameters: 200 ft., 52 knots

6. ASSESSMENT OF RESULTS

We conclude, from these preliminary tests, that the predictions as to the nature of the radiometric signatures to be expected from the classes of surface or target overflown are qualitatively correct. In particular:

(a) There is a clear distinction between the signature of an iceberg and that of a ship. This distinction is expected to be enhanced if a higher-frequency radiometer were employed.

(b) Icebergs can be clearly detected against the water background. Improvement of the iceberg-water radiometric contrast with increasing frequency is expected, as in (a).

(c) The height profile across an iceberg generally correlates fairly well with the variations in level of the radiometer signal, though some exceptions were noted.

(d) The radiometer signal from open pack ice, in a given area, correlates with the fractional ice cover.

We acknowledge that, while these conclusions are based on the data from a limited number of flights, the results are in qualitative agreement with the theoretical expectations, and surface or terrain identification based on this radiometry technique would likely improve with experience based on a more extensive data set.

Three tests could not be carried out, because of scheduling and other considerations. They were (a) flights over a submarine, (b) flights over a ship in an ice field, and (c) flights during high sea states.

7. RECOMMENDATIONS

The results of the 1972 tests appear sufficiently encouraging to justify a further, more-comprehensive series of tests. The following proposals are made to assist in the planning of such tests:

(a) The helicopter-borne radiometer should be capable of operation in at least two frequency bands - the low UHF band and a band near 35 GHz. Operation in the former band (e.g., with one or more of the channels of the present CRC system) should provide information on the thickness of the ice in areas of extensive ice cover, while operation at the higher frequencies should provide enhanced spatial resolution and offer the possibility of incorporating antenna-beam scanning. The latter feature would make possible the real-time production of a radiometric map of the scanned area, just as in the case of a radar or an IR scanner.

(b) A shipboard installation, operating at the higher frequencies mentioned above, should be considered, and preferably with some scanning capability.

(c) A land-based operation with a helicopter installation should be considered as an extension of sea trials. With the appropriate choice of site and timing it should be possible to take advantage of the presence of sea-ice cover, icebergs and shipping.

(d) The requirement to obtain data from as wide a variety as possible of each of the relevant classes of target, and for a range of environmental factors, has already been stressed.

8. ACKNOWLEDGEMENTS

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8. ABSTRACT:

The note discusses the application of the RF radiometry technique to the general maritime reconnaissance and marine sciences role in the Canadian North. It includes results of tests carried out with a helicopter-borne, multichannel, UHF radiometer in August 1972 in the Hudson Strait and Labrador Coast areas. Radiation data were obtained during flights over ships, ocean and fresh water, pack ice, icebergs, glaciers and land features. These initial results were encouraging, in demonstrating the potential of the technique, not only in direct support of maritime operations through aiding in detection and identification of features of interest, but with possible application in areas such as hydrology and glaciology.

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