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ABSTRACT

This paper describes a real-time VHF downlink communication system for transmitting side-looking airborne-radar (SLAR) data directly from an aircraft to a portable ground/shipboard receiving station. Use of this receiving station aboard the U.S. Coast Guard icebreaker Mackinaw for generating real-time photographic quality radar images will be discussed. The system was developed and demonstrated in conjunction with the U.S. Coast Guard and NOAA National Weather Service as part of the Project Icewarn all-weather ice information system for the Great Lakes Winter Navigation Program.

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1. INTRODUCTION

Prior to 1969 the Great Lakes-St. Lawrence Seaways system was traditionally closed to navigation during the winter ice season from mid-December until early April because of the adverse effects of weather and ice. Since 1970, Great Lakes shipping companies and twelve federal agencies led by the U.S. Army Corps of Engineers and the U.S. Coast Guard have participated in a federally sponsored program to demonstrate the practicality of extending the navigation system on the Great Lakes into the winter months. The collection, analysis, and timely dissemination of accurate information concerning the location, aerial extent, type and thickness of ice within the Great Lakes was recognized as an essential element in extending winter shipping operations. Storms, winds, and currents produce rapid changes in ice cover. Due to the dynamic nature of the Great Lakes ice cover, data more than 24 to 36 hours old is often of limited value for aiding vessel navigation.

2. PROJECT ICEWARN

Project Icewarn was instituted as a result of the need for all-weather near real-time ice information in the Great Lakes. The system developed to meet these needs collects and distributes sidelooking airborne radar (SLAR) imagery of Great Lakes ice cover to vessels as they move through the ice. The project is a cooperative one involving the NASA Lewis Research Center, the U. S. Coast Guard and the NOAA/National Weather Service. The system was designed by NASA and jointly demonstrated by NASA, USCG and NWS during the 1974-76 ice seasons. Since 1976 the system has been operated solely by the USCG and NWS with only technical assistance provided by NASA.

The various elements of the Project Icewarn system are depicted in figure 1. The radar data are recorded aboard a Coast Guard HC-130B aircraft. The side looking airborne radar system is the Motorola model AN/APS-94 (X-band). This system scans out to 50 km on both sides of the aircraft and results in an image 100 km wide centered on the aircraft ground track.

The radar data is digitized, recorded on magnetic tape and transmitted to vessels by two different modes. In the first mode the data is transmitted to the Coast Guard Ice Navigation Center in Cleveland, Ohio via a real time communications relay through the NOAA GOES satellite. The satellite data is received at the NOAA command and data acquisition station in Wallops Island, Virginia. It is then connected and sent out over dedicated telephone lines to Cleveland. At the Cleveland Ice Center, the radar data are used to generate photographic quality radar images on dry silver paper. From these images Coast Guard ice interpreters develop annotated charts depicting ice conditions containing geographical reference lines. The ice product, consisting of a radar image and an interpretative ice chart is transmitted by facsimile via the Great Lakes VHF-FM marine radio network to vessels operating in the lakes.

In the second mode the data is transmitted directly to U.S. Coast Guard icebreakers via a VHF downlink. This second mode which allows an icebreaker to receive real time data or a fast dump of tape recorded data will be discussed in detail in this paper. For more information pertaining to the other segments of the Project Icewarn System see reference 1.

3. VHF DOWNLINK COMMUNICATIONS SYSTEM

3.1 INTRODUCTION

The U.S. Coast Guard in carrying out its mission of support for Great Lakes shipping during the extended winter season maintains a number of vessels which assist in icebreaking. During the 1978-79 extended winter season, this fleet consisted of the Great Lakes icebreaker Mackinaw (88.4 m long, 22.7 m beam, 5.8 m draft and 10,000 SHP), the Arctic icebreaker Westwind (82 m long, 19.5 m beam, 8.2 m draft and 10,000 SHP) along with a new 42.7 m multi-purpose ice breaking tug, five 55 m long buoy tenders and five 33.5 m long harbor tugs. During the first few years of Project Icewarn, a number of these vessels were supplied with the standard SLAR image/ice chart facsimile products available from the Coast Guard Cleveland Ice Center via the Great Lake VHF-FM communications network. The scale of the facsimile image as received aboard the vessels was 1:762,000. This facsimile product proved to be adequate for many icebreaking applications. However, from operational experience gained during the first years of Project Icewarn with the icebreaker Mackinaw, it was determined that for icebreaking operations normally undertaken by the larger icebreakers it would be desirable to have a photographic quality radar image on a scale of at least 1:250,000. In addition the requirement was established that the data should be transmitted to the icebreaker in as near to real time as possible. The portable, real-time, VHF downlink communications system meets these requirements.

3.2 AIRCRAFT TO SHIP DATA TRANSMISSION SYSTEM

The SLAR aircraft to icebreaker data link employs two radio frequency communications systems. The first system is used to relay actual radar data in a digital format while the second is used strictly for voice communications.

Figure 2 is a schematic of the radar image receiving system employed aboard the icebreaker Mackinaw. This system uses frequency modulation (FM) and operates at a center frequency of 217.55 MHz (VHF). The transmitter, located aboard the SLAR aircraft, has a power output of 5 watts (+37 dbm). The carrier is deviated about 125 KHz for a TTL "1" level. The digital data is transmitted as BiPhase L information at either 50,000 or 6250 bits per second.

The VHF receiver is setup for a predetection bandwidth of 500 KHz and has a signal to noise ratio of -113 dbm. A bit syncronizer is used to recover the digital data from the demodulated output of the receiver. This bit syncronizer drives a data decoder. The decoder generates the proper syncronization and video signals to drive a Harris Laserfax image recorder. This recorder uses heat sensitive dry-silver paper to generate a photographic quality (109 lines/inch, 9-12 gray scale levels) image at a scale of 1:250,000. A magnetic tape recorder is included as part of the receiver station and is used for recording the initial data transmissions.

The communication equipment used in the data link system is commercial off-the-shelf equipment which is available at a very reasonable price. The details pertaining to the equipment including manufacturers is given in figure 3. From the performance specifications for this equipment a link margin is readily computed as follows:

Table I. Link Margin Calculations for VHF Downlink System

Receiver Sensitivity:

$$T_E = 290^o \; (10^{Nf/10} - 1) = (10^{5/10} - 1) = 627^oK$$

$$R_n = 10 \log_{10} \frac{KT_E \; B.W.}{10^{-3}} = \frac{(1.38 \times 10^{-23})(627)(500 \times 10^3)}{10^{-3}}$$

$$R_n = -113 \text{ dbm}$$

Free Space Loss:

$$\lambda = c/f = 3 \times 10^8 / 217.55 \times 10^6 = 1.38 \text{ meters}$$

$$FS_L = 20 \log_{10} \frac{4\Pi D}{\lambda} = \frac{(4\Pi)(322 \times 10^3)}{1.38} = -129 \text{ db}$$

Link Margin:

$$L_M = P_O + L_1 + A_T + FS_L + A_R + L_2 + R_n$$

$$L_M = 37 - 1 - 1 - 129 + 2 - 1 + 113 = 20 \text{ db}$$

Where:

P_O = Power output of transmitter (dbm)
L_1 - Coax line loss - transmitter (db)
A_T = Transmit antenna gain (dbi)
FS_L = Free space loss (db)
A_R = Receive antenna gain (dbi)
L_2 = Coax line loss - receiver (db)
R_n = Receiver sensitivity (dbm)
L_m = Link margin (db)
N_f = Receiver noise figure (db)
T_E = Effective noise temperature (^oK)
K = Boltzmanns constant = 1.38×10^{-23}
B.W. = Bandwidth (Hz)
D = Maximum range of communications for aircraft at 1500 ft altitude, meters
C = Speed of light = 3×10^8 (meters/sec)
f = Frequency (Hz)
λ = Wave length (meters)

The second communication system used for voice communications operates at 219 MHz. Converted 1¼ meter FM ameteur radios are used for this purpose. These units are capable of an output up to 10 watts. Both the voice and digital data communications systems employ belly mounted ¼ wave monopole antennas on the aircraft and vertically polarized dipoles at the receiver end. In both cases the antennas are enclosed in weather proof fiberglass envelopes. The effective range of both systems is limited to line of sight. Typically the SLAR aircraft operates at an altitude of 3350 m (11,000 feet) and reliable data transmissions are received out to a range of about 220 km (120 nautical miles).

Figure 4 is a photograph of the portable package comprising the shipboard data acquisition system. The equipment is rack mounted and is approximately 120 cm high, 61 cm wide and 64 cm deep. It weighs approximately 90 kg.

4. USE OF DOWNLINK SYSTEM ABOARD THE ICEBREAKER MACKINAW

At the present time icebreaking services for the Great Lakes are provided primarily by the two large icebreakers, Mackinaw, specially built for Great Lakes use and the polar class Westwind. Icebreaking activities for the Mackinaw are centered mainly in Whitefish Bay at the eastern end of Lake Superior and the St. Mary's River which connects Whitfish Bay and Lake Huron. Icebreaking activities for the Westwind are centered in the Straits of Mackinac. The task of both icebreakers is to keep the shipping lanes open primarily for ore boats carrying taconite from the parts in upper Minnesota (Two Harbors, Silver Bay and Taconite Harbor) to steel mills.

The portable downlink communications system was used aboard the icebreaker Mackinaw during the last three extended winter navigation seasons (1976-77, 1977-78, 1978-79). Figure 5 is a photograph of the icebreaker Mackinaw. The antennas were located on the main mast while the equipment was located in a room behind the bridge.

During the winter the Mackinaw is stationed at Sault Sainte Marie, Michigan operating normally in the Saint Mary's River or in Whitefish Bay of Lake Superior. The downlink communication system has a range of 220 km limited primarily to a "line of sight" distance between the SLAR aircraft and the icebreaker. Therefore the Mackinaw can receive a real-time downlink transmission from the aircraft as it images Whitfish Bay while the icebreaker is operating in the St. Mary's River, Whitefish Bay or at anchor in Sault St. Marie. The icebreaker image recorder is capable of generating an image of the 50 km swath track on one side of the aircraft ground track or the other. For Whitefish Bay one 50 km swath is adequate to map the navigational areas. However, the tape recorder stores the complete 100 km swath (50 km on both sides of the aircraft) of data. The other 50 km swath can therefore be played back and an image generated at the completion of the downlink transmissions. The data rate for real time transmission is 6250 bits per second (BPS). A high speed data rate transmission of 50,000 bits per second (eight times faster than the time to collect the original data) is also available. This allows radar images of ice covered areas outside the 220 km range of the data link, previously imaged by the SLAR aircraft, to be relayed to the icebreaker where it is recorded on magnetic tape only. An image cannot be generated during the high speed data transmission but only during low speed (6250 BPS) playback at a later time.

During a typical SLAR mission, once the aircraft has established communications with the icebreaker it will begin the real-time downlink transmission. The icebreaker will select either the 50 km right or left swaths of the radar coverage depending on its primary area of interest for generating a real-time radar image. Radar data for the full 100 km swath is recorded on magnetic tape. Once the aircraft has completed its coverage of Whitfish Bay the real-time data transmission is terminated. At this time a fast playback downlink transmission is initiated for data previously tape recorded in Lake Superior outside the 220 km range of the icebreaker.

The portable radar downlink communications system described in this paper had an additional application. For instance in 1976, the downlink equipment was located at Point Barrow, Alaska as part of an Arctic ice information demonstration (Reference 2) in support of the North Slope resupply sealift. Vessel movements along the North Slope were controlled by Crowley Maritime Corporation from their field operations center in Barrow. The SLAR aircraft routinely surveyed the ice conditions along the north coast of Alaska from Wainwright to Barter Island. Radar data were transmitted to Barrow via the downlink communications system in both real-time and fast data playback modes.

5. CONCLUDING REMARKS

In conclusion, Project Icewarn has had as its objective the collection and dissemination of ice information to Great Lakes vessels. Because time plays such an important part in the usefulness of this information, communications systems have been vital to its success. The VHF downlink communications system described herein has successfully met the need to provide icebreakers with optimum ice information to support tactical operations. Using todays technology, the system was readily implemented at a reasonable cost and has proved to be easy to operate with a very high degree of reliability.

REFERENCES

1. Schertler, R. J., et al: Grat Lakes All Weather Ice Information System, Proceedings of the Symposium on Remote Sensing of Environment, University of Michigan, Ann Arbor, 1976 (NASA TM X-71815).

2. Gedney, R. T., et al: All-Weather Ice Information System for Alaskan Arctic Coastal Shipping, Proceedings of Ninth Annual Offshore Technology Conference, Houston, Texas, May 1977 (NASA TM X-73619)

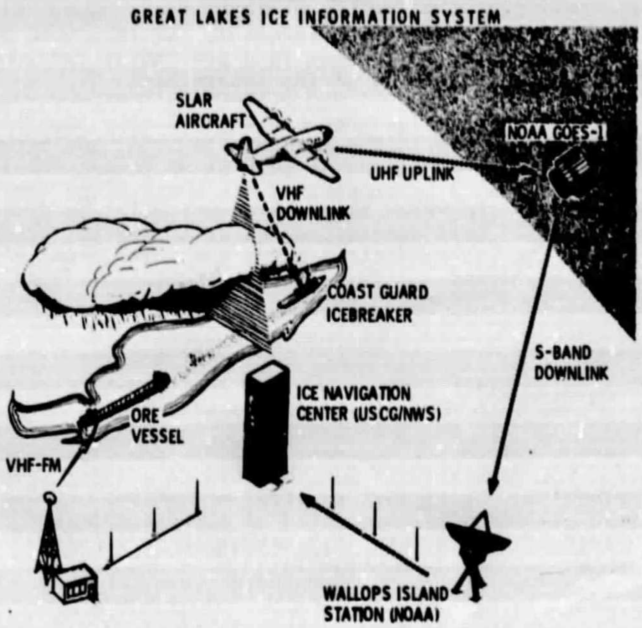

FIGURE 1 SCHEMATIC OF PROJECT ICEWARN, GREAT LAKES ICE INFORMATION SYSTEM

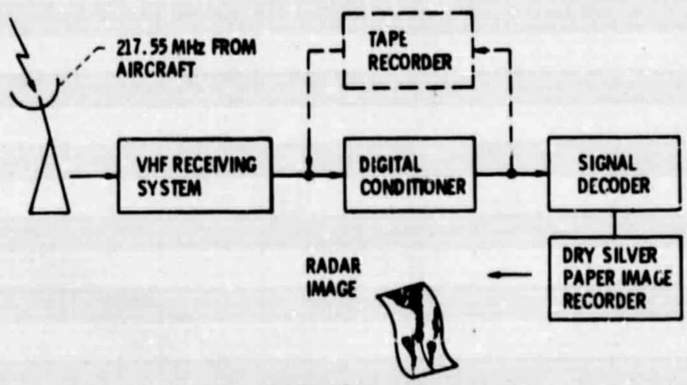

FIGURE 2 SCHEMATIC OF THE VHF RADAR DOWNLINK COMMUNICATIONS SYSTEM

VHF TELEMETRY LINK

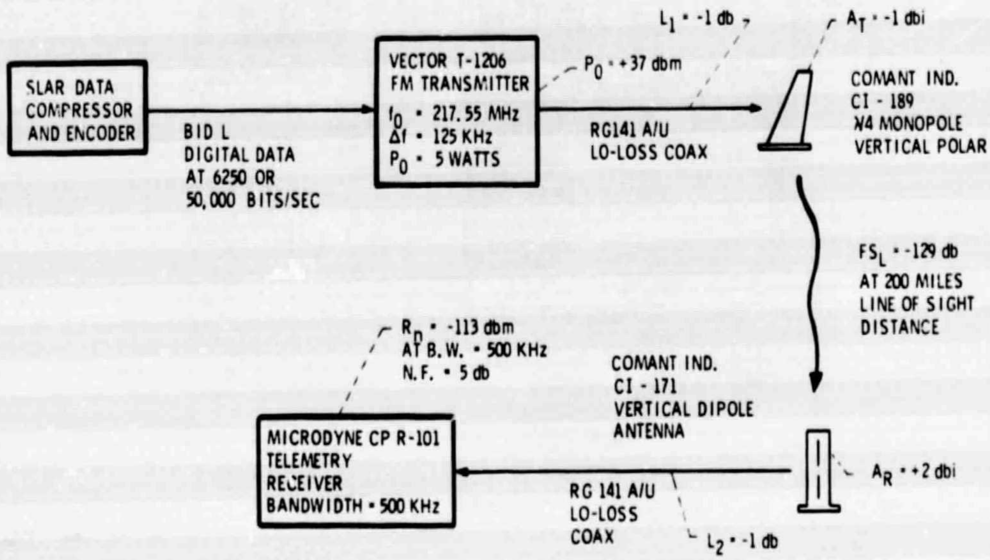

FIGURE 3 VHF TELEMETRY LINK

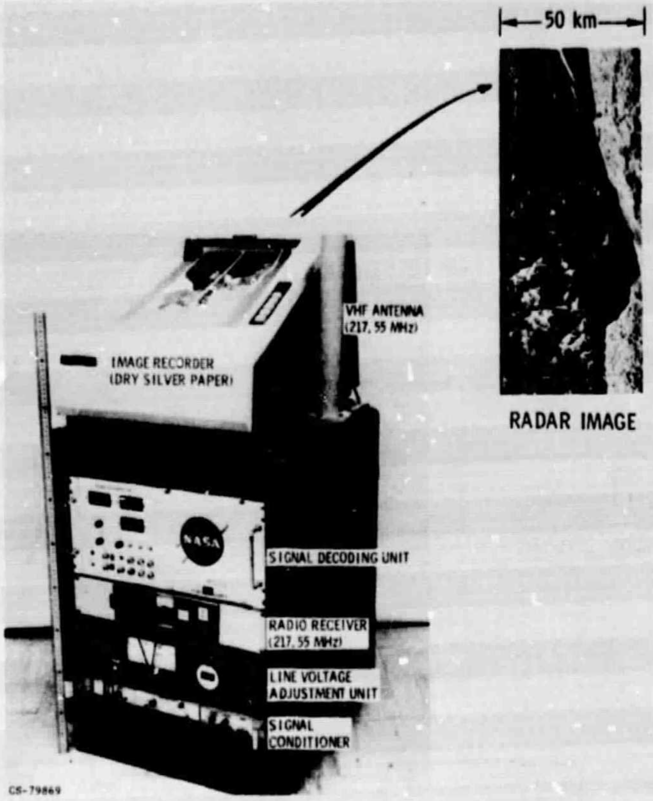

FIGURE 4 PHOTOGRAPHY OF THE PORTABLE VHF RADAR DOWNLINK COMMUNICATIONS EQUIPMENT

FIGURE 5 PHOTOGRAPH OF THE U.S. COAST GUARD ICEBREAKER MACKINAW