AD-A083 647 NAVAL RESEARCH LAB WASHINGTON DC F/G 8/8

GREAT LAKES WAVE HEIGHT RADAR SYSTEM.(U)

NOV 79 D L HAMMOND MIPR-Z-70099-7-817597-A

UNCLASSIFIED USCG-D-6-80 NL

1 OF 2

AD A
083647

Report No. CG-D-6-80

(12)

AD A083647

GREAT LAKES WAVE HEIGHT RADAR SYSTEM

LEVEL II

SC

DTIC
ELECTE
APR 25 1980
S D
C

FINAL REPORT

January 1980

Document is available to the public through the
National Technical Information Service,
Springfield, Virginia 22151

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
United States Coast Guard
Office of Research and Development
Washington, D.C. 20590

80 4 25 010

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

The contents of this report do not necessarilv reflect the official view or policy of the Coast Guard; and they do not constitute a standard, specification, or regulation.

This report, or portions thereof may not be used for advertising or sales promotion purposes. Citation of trade names and manufacturers does not constitute endorsement or approval of such products.

(18) USCG (19) D-6-80

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
CG-D-6-80	AD-A083 647	

4. Title and Subtitle	5. Report Date
(6) Great Lakes Wave Height Radar System.	(11) 1 November 1979
	6. Performing Organization Code: USCG
7. Author(s): (10) Donald L. Hammond	8. Performing Organization Report No.: (12) 97
9. Performing Organization Name and Address: Advanced Space Sensing Application Branch, Naval Research Laboratory, Washington, D.C. 20375	10. Work Unit No. (TRAIS): Project #3306.02.02.3
	11. Contract or Grant No.: (15) MIPR-Z-70099-7-817597-A
12. Sponsoring Agency Name and Address: U.S. Coast Guard Headquarters, Office of Research and Development, G-DMT-1/TP54, Washington, D.C. 20593	13. Type of Report and Period Covered: (9) Final Report, Nov-Dec 79, 11/79 - 12/79
	14. Sponsoring Agency Code: G-DMT-1

15. Supplementary Notes

U. S. Coast Guard Project Officer: LT M. D. NOLL

16. Abstract

A study of the wave induced springing of the Great Lakes ore carrier M/V STEWART J. CORT is being done in two phases. Phase one is the installation, test, and evaluation of a shipboard wave measurement system. Phase two is the measurement and correlation of the waves encountered by the vessel and the vessel's response. This report describes the wave measurement system and presents some of the test results. The wave measurement system consists of two radars used to profile the surface waves and two sets of accelerometers to record the motion of the vessel.

Thirty-one data records, each about twenty to thirty minutes long, were recorded during the test period of phase one. Eight of these data sets were reduced to power spectral densities (PSD) in terms of the wave encounter frequencies. Each PSD value has about fifty degrees of freedom.

The results show the significant wave height (SWH) as measured by the two radars to agree within about ten percent. The visual estimates of the SWH show a larger variation of agreement relative to the radar derived SWH. One buoy measurement was available to compare with the radar results. The buoy derived SWH (0.5m) was about one-half the radar measurement. This is due to a light off shore wind that day that resulted in small SWH for both the buoy and the radars as well as a shorter fetch for the development of waves at the buoy site as compared with the ship location.

17. Key Words	18. Distribution Statement
Wave Encounter Spectra, Springing, Wave Heights	Document available through National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	93	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

251950 JOB

GREAT LAKES WAVE HEIGHT RADAR SYSTEM

DONALD L. HAMMOND
ADVANCED SPACE SENSING APPLICATIONS BRANCH
NAVAL RESEARCH LABORATORY
WASHINGTON, DC 20375

FOR

UNITED STATES COAST GUARD
OFFICE OF RESEARCH AND DEVELOPMENT
MARINE SAFETY TECHNOLOGY DIVISION
WASHINGTON, DC 20590

PROJECT NUMBER Z-70099-7-817597-A

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (cont'd)

LIST OF TABLES

LIST OF ABBREVIATIONS AND SYMBOLS

A	Normalization factor for radar antenna beam
B	Radar Antenna beam width factor
DD	Degrees of latitude or longitude
D(θ)	Radar antenna illumination intensity
db	Decibels
f_e	Encounter wave frequency of waves from ship
FFT	Fast Fourier Transform
FOV	Field of View of radar antenna
G	Radar antenna gain
g	Acceleration equal to earth's gravity at mean sea level
k	Water wave number equal to $2\pi/\lambda$
kc	Critical water wave number
ℓn	Natural logarithm
MHz	Megahertz

LIST OF ABBREVIATIONS AND SYMBOLS (cont'd)

MM	Minutes of latitude or longitude
MPH	Miles Per Hour
ms	Millisecond time interval
M/S	Meters per second
NRL	Naval Research Laboratory
PDP-11/03	Minicomputer by Digital Equipment Corporation
PSD	Power Spectral Density
R	Radar slant range to the surface
R_X	Radar receiver related
SWH	Significant Wave Height
T_x	Radar transmitter related
θ	Angle relative to vertical straight down
λ	Water wave length, crest-to-crest
ϕ	Relative angle between waves and vessel's heading
ψ	Phase angle of a water wave component

FORWARD

Introduction:

(References in the following text are listed at the end of FORWARD)

The U. S. Coast Guard (USCG) is interested in continuing research on the springing phenomena experienced by Great Lakes ore carriers and on the effect springing stresses have on the hull girder longitudinal strength. A vessel's structure is very complex when it comes to analyzing the structural response to static (cargo, fuel, ballast, etc.) and dynamic (slamming, wave-induced, springing) loads. Of primary interest is the combined effect of the springing and wave induced stresses (Figure I).

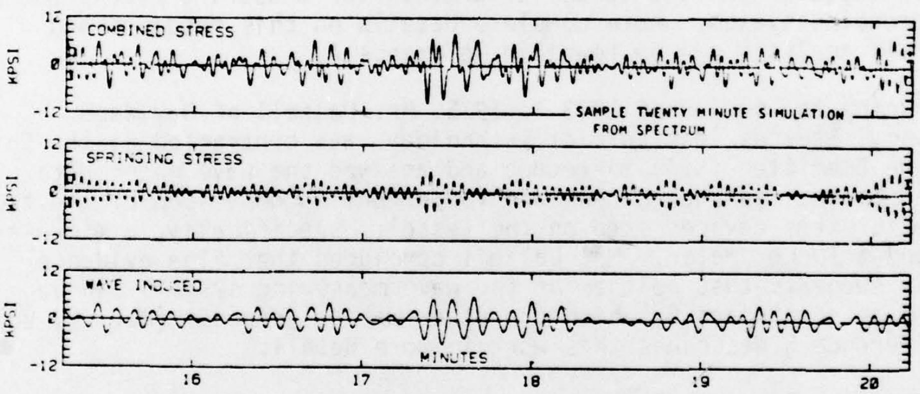


FIGURE I

Springing is induced by encountered waves matching the natural frequency of a vessel which creates a resonant, vertical 2-node oscillation of the hull girder. At times, springing may develop 1/3 to 1/2 of the total stress level within the hull girder. This is one area yet to be completely verified. The longest ships plying the Lakes have reached 1000 feet with an L/D ratio of 20/1 to 22/1. These vessels are very long and flexible and are susceptible to the effects of combined wave-induced and springing stresses. One such vessel is the M/V STEWART J. CORT.

Mr. Don Hammond of the Advanced Space Sensing Application Branch, Naval Research Laboratory (NRL), has submitted this Final Report, "Great Lakes Wave Height Radar System", as the preliminary evaluation of the wave measurement system installed on the M/V STEWART J. CORT. Of primary importance during the '78 and '79 operating seasons of the CORT has been to test and evaluate the wave measurement system. The discussion below will provide a description of how this research fits into the overall USCG Great Lakes springing program.

Past Research:

The CORT has been the subject of past research with the full cooperation and support of her owner and operator, Bethlehem Steel Corporation. Teledyne Engineering Services (TES) (formerly: Teledyne Materials Research Corporation), under contract to the USCG, instrumented the CORT between 1971 and 1974 to study the bending stresses experienced by the vessel during normal operations. The vessel was instrumented with five sets of strain gauge transducers, a metritape liquid-level sensor to measure wave encounter periods, bow and stern vertical accelerometers, a pendulum located near the center of gravity for measuring pitch, and a data recording system. More complete details on this research and Teledyne's analysis can be found in Reference A.

During the period of 1973 to 1975, Mr. Dalzell of Davidson Laboratory, Stevens Institute of Technology, was contracted by the Ship Structure Committee (SSC) to reduce and analyze the wave meter data obtained on the Sea-Land McLean and to perform a comparison of the two wave measurement devices used on the vessel; specifically, a microwave radar and a Tucker Meter. Mr. Dalzell concluded that "The evidence strongly suggests that neither of the wave measuring systems can be regarded as a standard by which the other may be judged." (Ref. B, Vol. 10) Reference B describes this work in more detail.

USCG Springing Research Program:

In an effort to build upon this past research, the USCG has undertaken a four part program to obtain a more thorough understanding of springing.

Part 1. Wave Measurement Device Survey - (Reference C)
In September of 1976, NRL was contracted by the USCG to survey existing wave measurement devices capable of providing wave height and direction. NRL took into consideration the conclusions and recommendations reached by Mr. Dalzell (Ref. B). As a result, NRL recommended (1) to replace the marine radar on the CORT with a Raytheon Model 1020 marine radar which would provide the wave images necessary for determination of wave length and wave direction via a laser fourier transform using an optical processor and (2) to install a Collins Radio Co. radar altimeter for measuring wave height. The USCG considered these

recommendations and finally authorized a modified wave measurement system to be installed on board the CORT. This system is described in Part 3 below and within the text of this report by NRL.

Part 2. Damping Coefficient Determination - (Reference D)

During a three year period (1972-1975), stress measurements were collected from three Great Lakes ore carriers, namely the M/V CORT, the M/V ROGER BLOUGH, and the S/S RYERSON. (References F,G and H) In June 1977, TES was contracted by the USCG to transfer specified analog stress records from these 3 vessels to FM magnetic tape. These stress records contained intervals representing high, medium, and low stress levels during loaded and ballasted conditions. These magnetic tapes and the associated quick-looks were delivered to Structural Dynamic Research Corporation (SDRC), under separate USCG contract, to determine the system damping (combined hydrodynamic, structural and cargo damping) coefficient for each specified interval of the stress records. An evaluation of these coefficients was performed by the USCG to determine a relative accuracy of the damping coefficients determined by SDRC.

SDRC used an analytical technique known as MODAMS (MODal Analysis and Modeling System). The technique used to determine the modal parameters desired was the multi-degree-of-freedom (MDOF) curve fit to the frequency response data over a specified frequency range. The USCG evaluation compared SDRC's coefficients with coefficients derived from a mechanical analysis of independent stress records from these vessels. The damping coefficients, the damping frequency and the logarithmic decrement were used in the comparison. The evaluation concluded that SDRC's results were reasonable but not totally conclusive. Further damping definition may be provided via full scale hull exciters. Further detail on SDRC's analysis and the evaluation may be found in Reference D.

Part 3. Wave Measuring Device T&E - (This Report)

In December 1977, NRL was contracted by the USCG to install a wave measurement system and to perform a test and evaluation (T&E) of this system. The wave measurement system proposed by NRL (Part 1) was modified to measure wave height from two different radars and to immediately input the information via an analog/digital interface to an on-board data acquisition system. The decision was made to opt on the side of obtaining a point spectra (in lieu of a directional spectra) with a PDP-11/03 data acquisition system rather than go for a directional spectra with no acquisition system capable of on board data analysis. The wave measurement system consists of a NRL microwave radar and a Collins Radio Co. radar altimeter, two sets of accelerometers for reduction of ship motions, and a roll potentiometer.

Validation of the on-board measurements was attempted by comparing these with wave measurements of a NOAA wave buoy positioned 2 miles offshore of Copper Harbor, Michigan in Lake Superior. This effort proved to be unsuccessful due to (1) infrequency of rendezvous with the buoy, (2) distance of CPA with buoy (varied from 2 to 10 miles) and (3) the difference in water depth and wind fetch between the buoy and the CORT. NRL's report evaluates the data obtained by comparing spectral analyses of both radars with visual observations and with a few NOAA buoy measurements. Generally, the comparisons show some agreement but the evidence is not conclusive and stills raises many questions and many doubts.

Part 4(a) Full Seaway Instrumentation - (In progress during '79 and '80)

This project is an extension of Part 3 to measure hull girder stresses concurrently with measuring desired wave parameters on-board the M/V STEWART J. CORT during normal operations in fiscal year 1979. The results of this data collection project will provide stress and wave data measured in a simultaneous manner that can be used by later investigators to explain the phenomenon of springing and wave induced responses as well as the method for combining the two. With the on-board data acquisition and reduction system on the CORT, many of the questions related to these phenomena may be investigated during this full scale instrumentation project. This work will be performed by David Taylor Naval Ship Research and Development Center (DTNSRDC).

Part 4(b). Full Scale Pressure Distribution Measurements - (In progress during '79 and '80)

As an add-on to Part 4, the Ship Structure Committee (SSC) has contracted with DTNSRDC to collect full scale pressure distribution measurements concurrently with the wave and stress measurements on the M/V CORT. Fifteen 50 psig pressure transducers have been installed in the forward section of the vessel. These pressures are scheduled to be analyzed by the American Bureau of Shipping (ABS) in conjunction with a time-domain analysis of the wave heights.

Figure II shows the instrumentation on the CORT that will be used for full scale measurements during the '79 - '80 operating season.

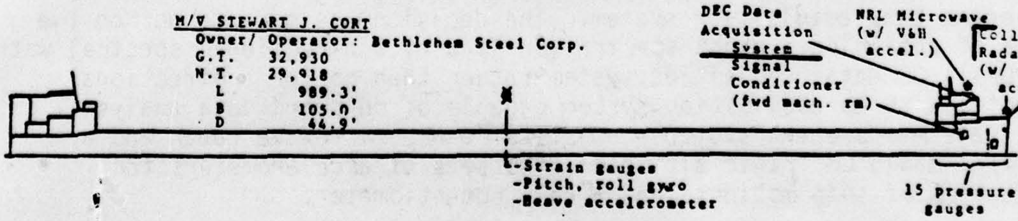


FIGURE II

The validation of the wave measurement system remains foremost in importance as the full scale measurements continue. During the 1979 fall season, DTNSRDC will continue the full scale measurements on the CORT. This time validation of the wave measurement system will be attempted by deploying a wave buoy approximately 2 miles ahead of the vessel via USCG helicopters. Helicopters were available from USCG Air Station Chicago (Illinois) and USCG Air Station Traverse City (Michigan). Two modified Eastech Model 226 wave buoys will be utilized for this project.

Bethlehem Steel Corporation, the Master of the CORT, the ships' crew, and the personnel at USCGAS Chicago and USCGAS Traverse City have provided their full cooperation and support for this research project.

Mark D. Noll, Project Officer
LT, U.S. Coast Guard

Forward References:

A. Teledyne Materials Research Corporation, "Instrumentation of M/V STEWART J. CORT, 1971-1974", Final Report, DEC 75, #CG-D-162-75, NTIS AD A022-164. (Change of name of authoring organization: Teledyne Engineering Services)

B. J. F. Dalzell, "Correlation and Verification of Wavemeter Data from the SL-7", Reports 1-10, Stevens Institute of Technology, SSC Report SR-1221, March 1977.

C. D. L. Hammond, "Wave Measurement Systems Applicable to Great Lakes Vessels and Spectra", Advanced Space Sensing Applications Branch, Naval Research Laboratory, Washington, D. C. 20375, #CG-D-4-78, NTIS AD A050-767.

D. M. D. NOLL, "Evaluation of SDRC Damping Analysis", USCG, 1 January 1980, Report #CG-D-5-80

E. TES, "Instrumentation of the M/V STEWART J. CORT - 1971-1974", FR # CG-D-162-75, Aug 75, NTIS AD 022-164

F. TES, "Instrumentation of M/V ROGER BLOUGH, 1973-74 Season", 30 JUN 74, Tech. Report E-1739, TES TR-1738(c)

G. TES, "Instrumentation of M/V ROGER BLOUGH - Second Season (1974-75)", 6 JUN 75

H. TES, "Measurement of Seaway Stresses Aboard Great Lakes Ore Carrier EDWARD L. RYERSON - (1967 Operating Season Only)", SNAME Project E-1125(c)

INTRODUCTION

The ore vessel M/V STEWART J. CORT was the first of the Great Lakes vessels with a length as great as one thousand feet. For this reason, it has been a subject of particular interest for the study of hull vibration and springing.

One of the early studies (reference 1) used five vertical accelerometers, one on each side near the bow, one at the quarter point, one at the mid point and one at the stern, and a midship strain gage. Based on the analysis of records taken in Lake Superior when the vessel, in the loaded condition, encountered 4 to 6 foot seas, 60° off the bow, a determination was made of the maximum first mode deflection profile, the RMS deflection profiles for the first three modes of flexural vibration, and the maximum and RMS midship stress values. An evaluation of the first mode damping was unsuccessful because the Cort was undergoing springing in the stationary anchor drop position.

Another study (reference 2) analyzed the midship bending stress obtained from a deck mounted strain gage for two half-hour intervals of high stress for the M/V STEWART J. CORT and the SS CHARLES M. BEEGHLY. The stress records were analyzed for the RMS springing and wave bending, the maximum peak values, and the instantaneous values.

The present study is the first phase of a two-phase in-depth study of vessel springing induced by surface waves. This first phase involves the installation of a wave measurement system on the M/V STEWART J. CORT, the recording of wave data and the evaluation of the wave measurement system. The second phase will be done during the year 1979 and will include the simultaneous recording of the waves encountered by the CORT and the response of the vessel as recorded by hull-mounted strain gages.

ACKNOWLEDGEMENTS

Several other people made significant contributions to this project. LT Mark D. Noll was the technical representative for the U.S. Coast Guard. In addition to his keeping the project on course he, through Charles Walburn of the Marine Division of Bethlehem Steel, arranged the schedule of operations aboard the M/V STEWART J. CORT. LT Noll also rode the vessel to help record data on some of the field trips and provided many helpful suggestions. David Walden, U.S. Coast Guard, wrote the computer programs to obtain the power spectral densities of the data. Mr. Walden also assisted in most of the on board activities of shake down, calibration, and data collection. Al Uliana, U.S. Naval Research Laboratory, wrote the computer programs for recording data. Ray Wilkinson, U.S. Naval Research Laboratory, designed and installed the interface logic circuits between the NRL radar and the on board PDP-11/03 computer. John Dalzell, Davidson Laboratory, Stevens Institute of Technology, was a project advisor who was particularly helpful. CAPT Robert Brabander and his crew aboard the M/V STEWART J. CORT were extremely cooperative and lent their full support to the project.

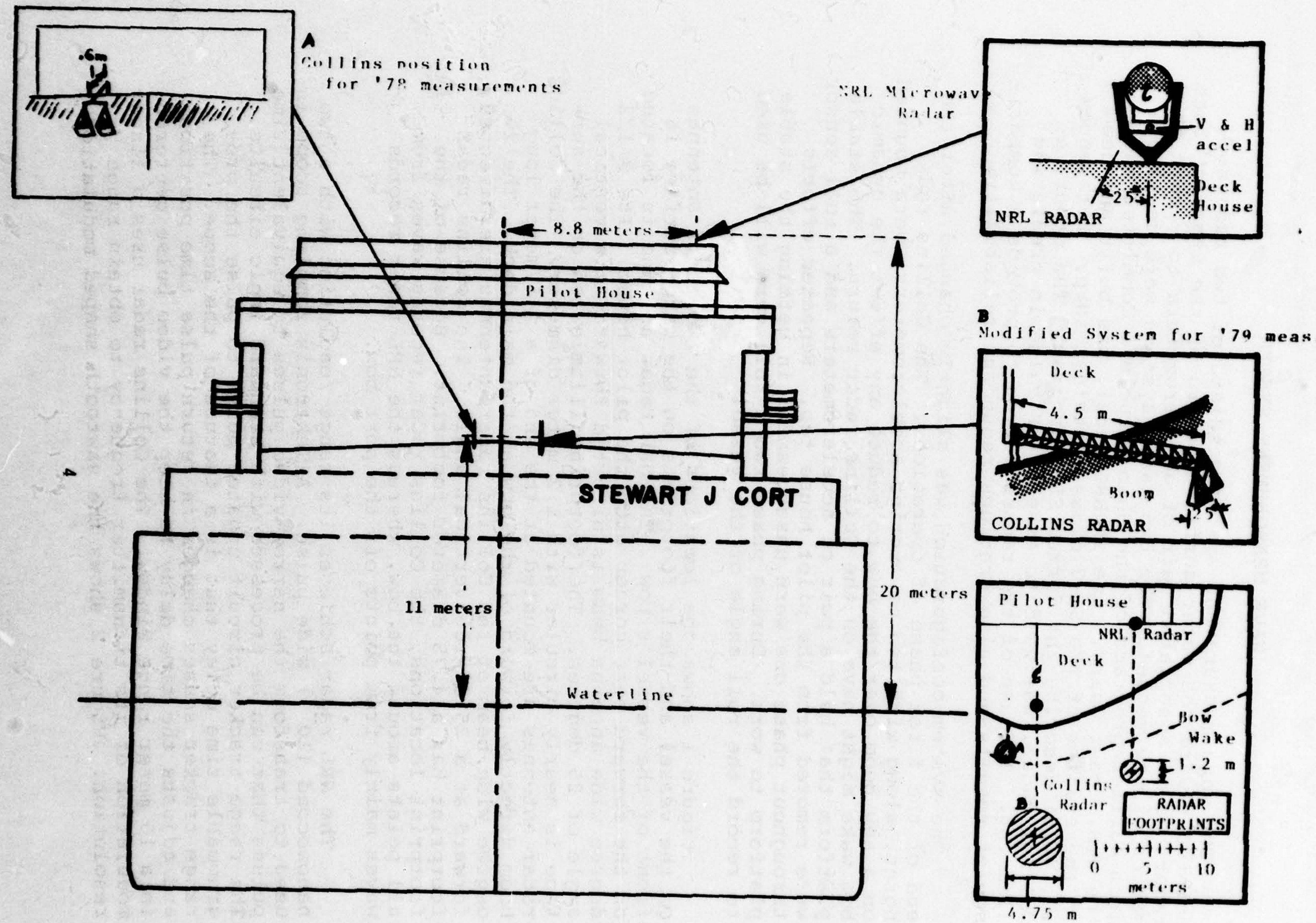
WAVE MEASUREMENT SYSTEM

The wave measurement system consists of two radars pointed toward the water surface forward of the vessel. Each radar has an associated pair of accelerometers to record the motion of the vessel. The two radar systems were available from earlier programs of the Ship Structure Committee and the U.S. Coast Guard. One an NRL radar, was built and used on the studies of the SL-7 class container ship. References (3, 4, 5) describe the former SL-7 program. The other, a Collins radar, was used to assess its value in predicting slamming. The use of two radars serves to provide a comparison of results and also provides redundant reliability.

The system configuration was slightly changed after the end of the first phase of operations. The Collins radar horns, along with two new motion accelerometers, were mounted on a new boom over the bow to reduce any effect the dynamic bow wake might have on the Collins radar return. The stable platform that held a pair of accelerometers and a roll sensor were removed from the pilot house top. Repeated efforts throughout phase one were unsuccessful in getting the stable platform to work. During phase two a roll gyro will be used to record the roll angle of the vessel.

Figure 1 shows the locations of the two radar antennas on the vessel and their footprints on the water surface in front of the vessel's bow. The NRL radar antenna is located on the forward port corner atop the pilot house. Its 3 1/2 degree wide antenna beam is directed forward at a vertical angle of 25 degrees. The footprint illuminated on the surface is nearly circular with 1.2 meter diameter. The Collins radar antennas are mounted at the end of a 4.5 meter long boom directly forward of the bow at the main deck. The 20 degree wide beam of the Collins radar antennas are directed forward at a 25 degree vertical angle. The Collins radar footprint has a 4.75 diameter footprint. Because of the footprint locations, the Collins radar records waves from all points around the bow, whereas the NRL radar records waves mainly from points off the port bow.

The NRL radar achieves its range resolution with a two nanosecond (10^{-9}) wide pulse. A Tektronix sampling scope is used to transform the narrow video pulses to equivalent time pulses that can be processed with standard logic circuits. The range tracker circuit updates pulse to pulse the programmable time delay that is a feature of the scope. The range tracker senses changes in return pulse time position and adjusts the time delay to keep the video pulse centered in a 15 meter range window. The Collins radar uses a linear modulation of its transmitter frequency to obtain range resolution. Figure 2 shows the sawtooth shaped modulation



RADAR ANTENNA LOCATIONS ON THE VESSEL

FIGURE 1

waveform. Figure 2 also shows that the return waveform is shifted in time, due to the round trip time of flight of the signal. The Collins radar uses the instantaneous frequency difference to measure distance in this fashion.

The NRL radar signal is in digital binary coded format for direct recording by the PDP-11/03 computer. The samples of NRL radar distance are sent to the computer ten times a second. The raw counts are converted to meters by multiplication by 0.01875. This factor is derived from the fact that each count represents exactly 1/8 of a nanosecond round trip delay. Each nanosecond in turn is equivalent to 0.15 meters distance. Therefore, each count is 1/8 times 0.15 meters or 0.01875 meters.

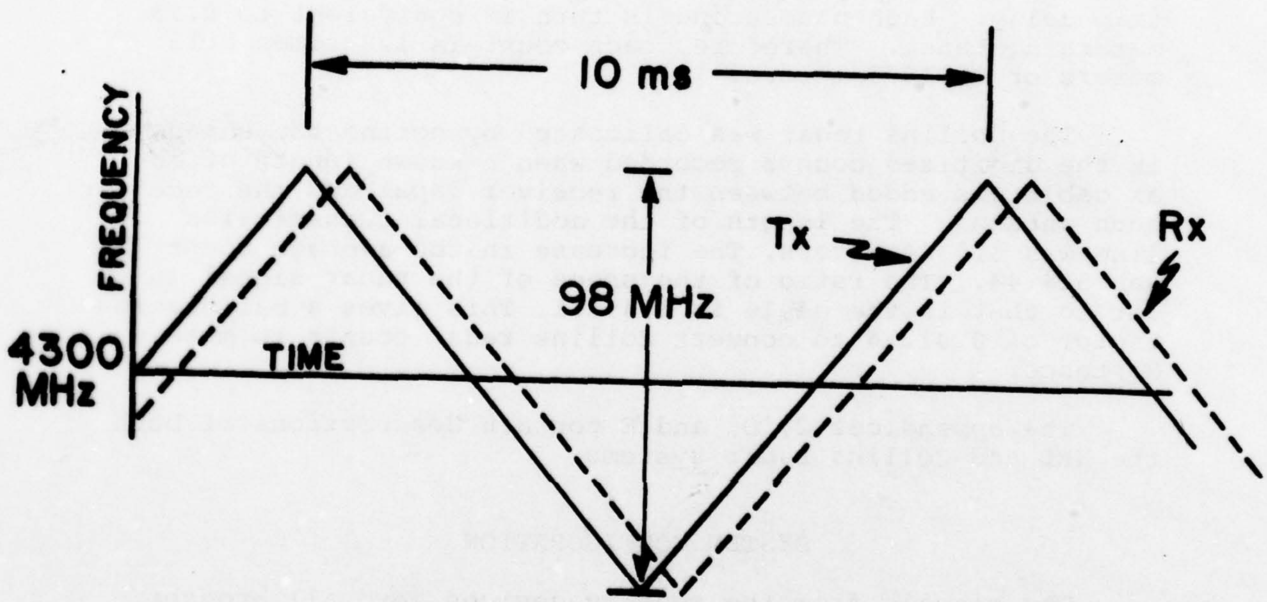
The Collins radar was calibrated by noting the change in the digitized counts recorded when a known length of coax cable was added between the receiver input and the receiver horn antenna. The length of the additional transmission line was 8.5344 meters. The increase in the average count was 524.44. The ratio of the speed of the radar signal in air to that in the cable is 1.492:1. This gives a calibration factor of 0.01214 to convert Collins radar counts to meters distance.

The appendices C, D, and E contain descriptions of both the NRL and Collins radar systems.

SYSTEM CONFIGURATION

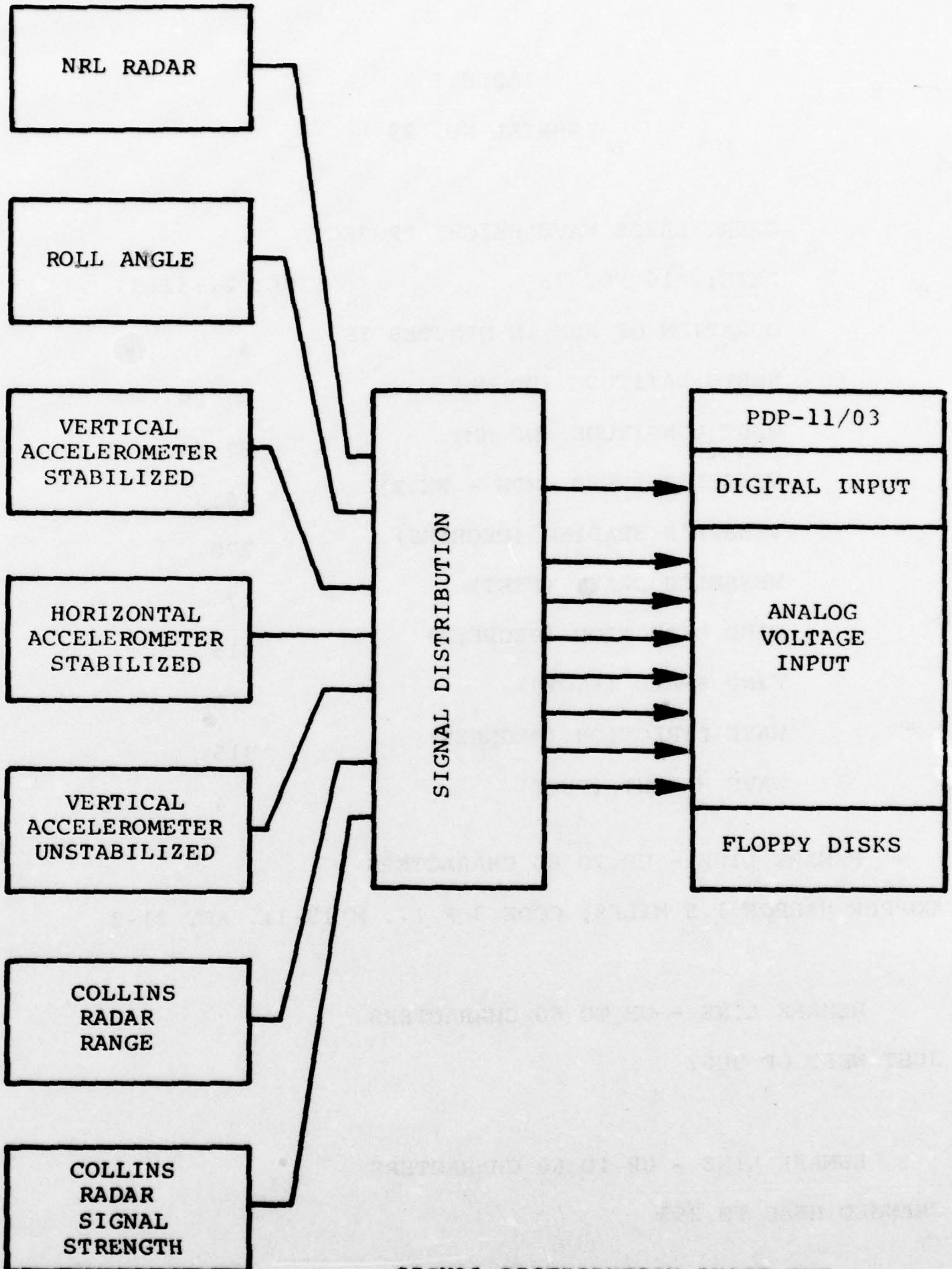
The signals from the sensing devices were all brought by cable to the signal distribution chassis and then to the PDP-11/03 computer during phase one as shown in figure 3. The NRL radar signal is in twelve bit digitial format. The NRL radar provides a data ready flag ten times a second to serve as an interrupt to the computer program. The computer program stores the NRL digital range signal and then it uses its analog-to-digital converter to sample the analog signals from the other devices. The program continues in this manner for the time duration entered by the operator in the header log. The Collins radar signal strength channel changes to a large value if the Collins return signal strength is below the valid signal threshold.

The header log is produced by the computer operator responding via the Decwriter to each parameter listed by the computer. the computer program will cause the heading, date and time to be typed followed by a standard list. Table 1 shows a typical phase one header log. There is a provision at the bottom for the operator to type in three comment statements, each limited to sixty characters.



COLLINS RADAR MODULATION WAVEFORM

FIGURE 2



SIGNAL DISTRIBUTION PHASE ONE

FIGURE 3

TABLE I

SERIAL NO. 29

GREAT LAKES WAVE HEIGHT PROJECT	
DATE: 16 NOV 78	TIME: 22:52:33
DURATION OF RUN IN MINUTES IS	4
NORTH LATITUDE (DD MM)	47 29
WEST LONGITUDE (DD MM)	87 54
VESSEL'S SPEED (MPH - XX.X)	16.3
VESSEL'S HEADING (DEGREES)	270
VESSEL'S DRAFT (FEET)	17
WIND DIRECTION (DEGREES)	315
WIND SPEED (KNOTS)	20
WAVE DIRECTION (DEGREES)	315
WAVE HEIGHT (FEET)	4

REMARK LINE - UP TO 60 CHARACTERS

COPPER HARBOR 1.5 MILES, CODE 3 F 17, M 18-11, AFT 21-3

REMARK LINE - UP TO 60 CHARACTERS

JUST WEST OF BUOY

REMARK LINE - UP TO 60 CHARACTERS

CHANGED HEAD TO 265

Figure 4 is a flow diagram of the computer program to record data. The header is followed by the recording of the NRL radar sample taken at the data ready flag time. This is followed by a sequential scan by the computer analog-to-digital converter of the eight analog signal channels. The eighth analog channel is not connected for this phase of the project and is regarded as a spare.

ACCELEROMETER CALIBRATION

The accelerometers are mounted in pairs to sense the vertical movement of the vessel. The accelerometers were calibrated by the usual method of recording the static output voltage as the angular position of the accelerometer is varied relative to the gravity vector. Figure 5 is the plot of the calibration data for the unstabilized vertical accelerometer mounted on the NRL radar mount on top the pilot house. A least squares fit to the calibration data gives a factor of 9122 counts per "g". Figure 6 is the plot of the unstabilized horizontal accelerometer calibration data.

The Setra System, Inc., Model 100 accelerometers used on the CORT have a high natural frequency of 350 hertz. This is so far above any frequency at which the vessel can spring that the static calibrations are valid for all frequencies observed.

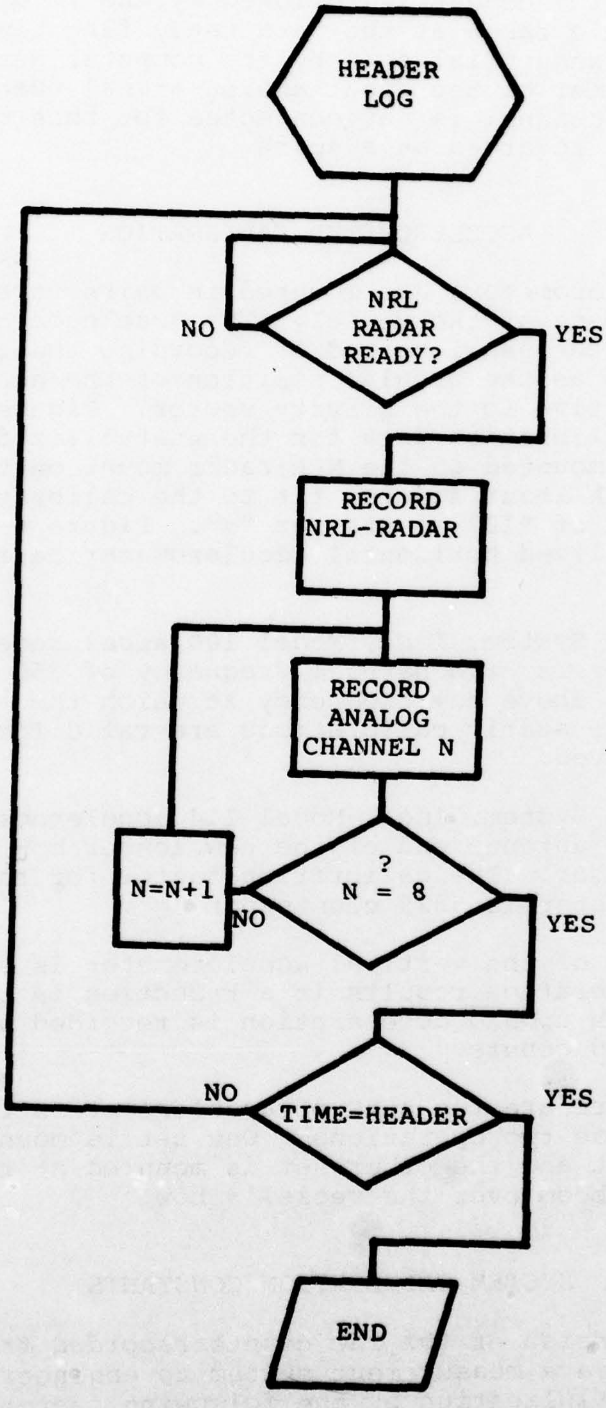
Two Setra System, Inc., Model 114 accelerometers were mounted on the antenna end of the new longer bow boom for the Collins Radar. The calibration factor for the vertical boom accelerometer is 5325 counts per "g".

The sense of the vertical accelerometer is such that a downward acceleration results in a reduction in the counts recorded and an upward acceleration is recorded as an increase in the recorded counts.

Thus, there are two sets of accelerometers for use during the phase two operations. One set is mounted at the NRL radar mount and the other set is mounted at the Collins radar antenna boom over the vessel's bow.

SYSTEM CALIBRATION CONSTANTS

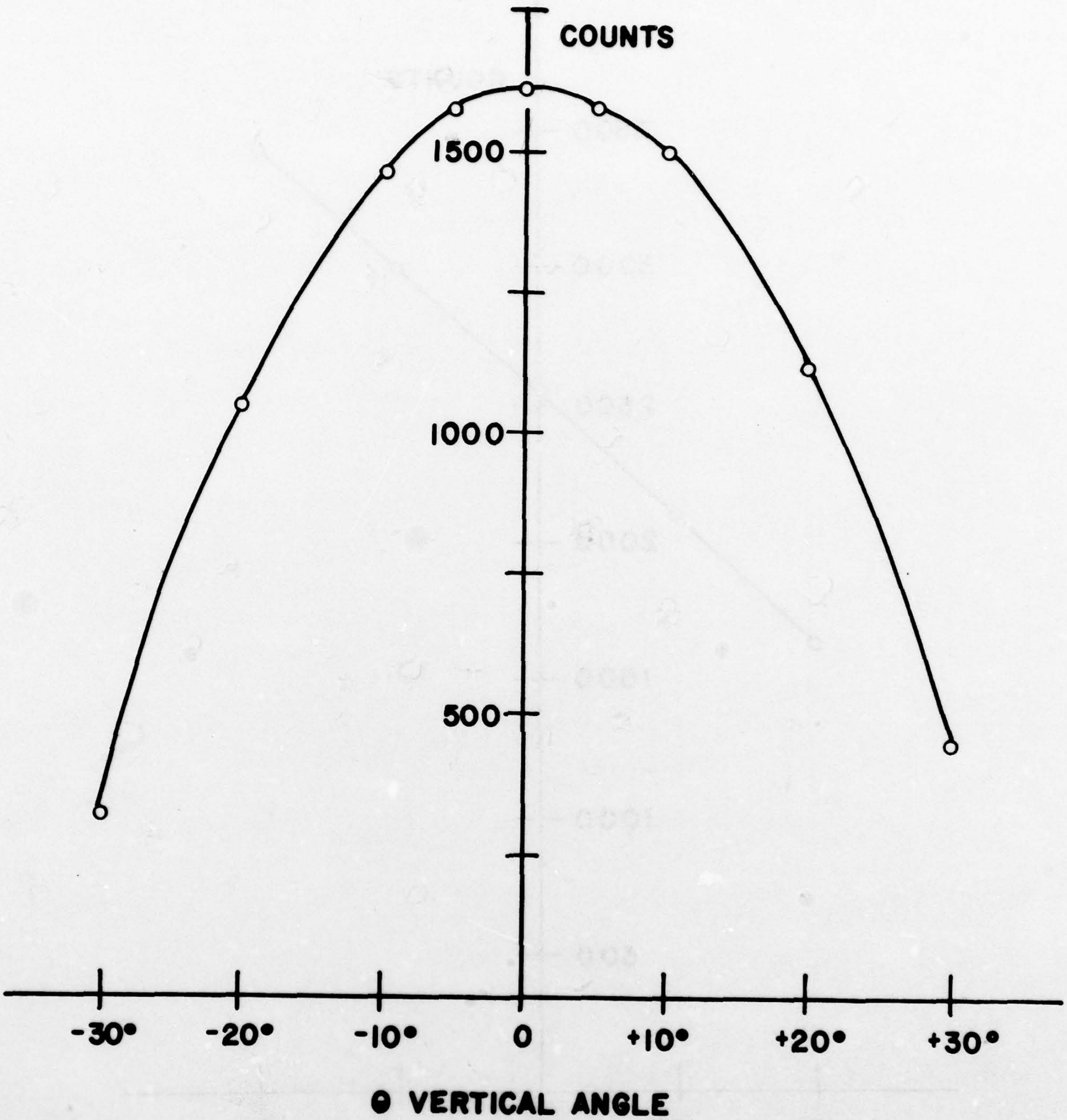
The conversion of the raw counts recorded from each device in the wave measurement system to engineering units is done by multiplication by the following factors:



COMPUTER FLOW CHART

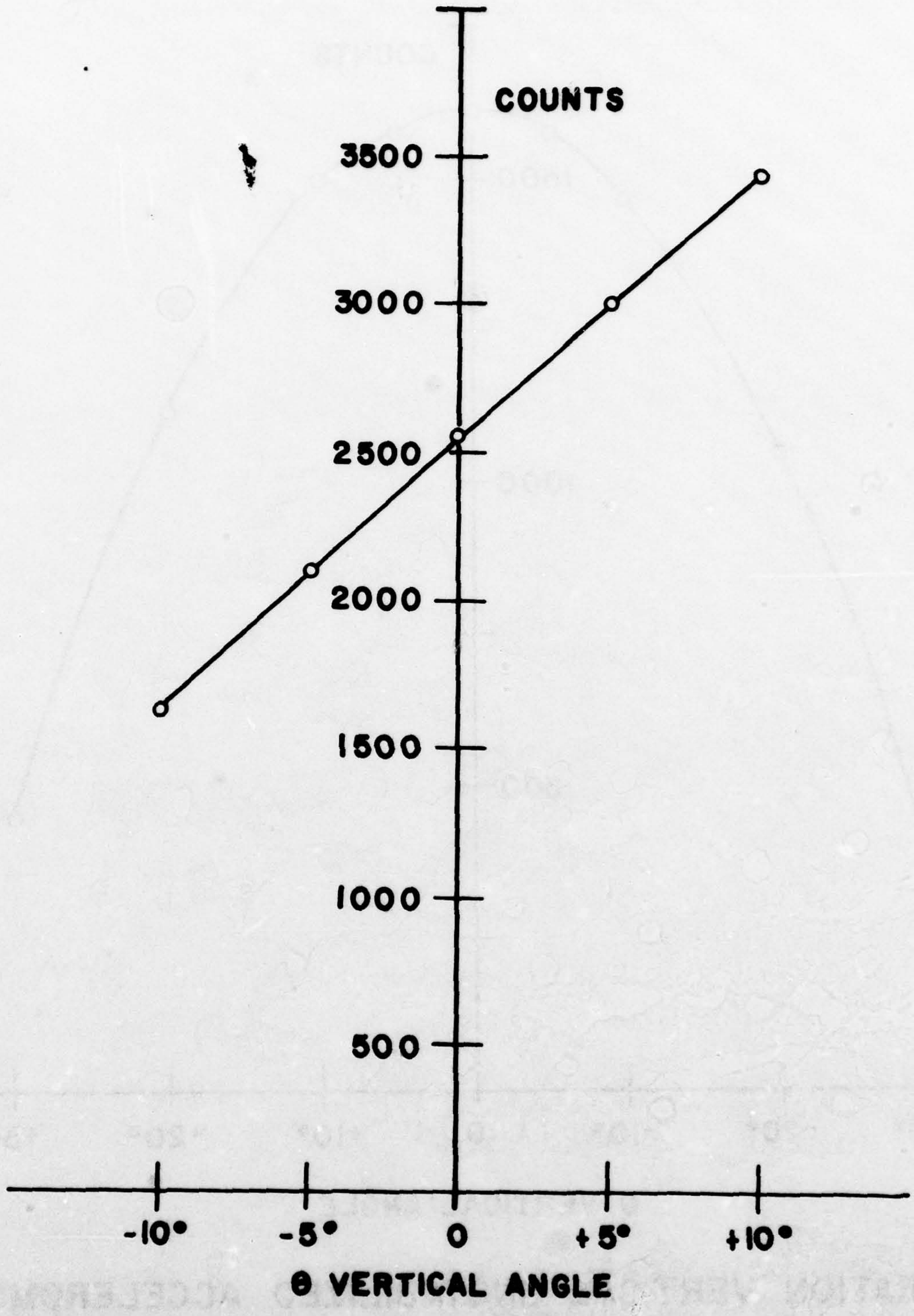
DATA RECORDING PROGRAM

FIGURE 4



CALIBRATION VERTICAL UNSTABILIZED ACCELEROMETER
17 NOV 1978

FIGURE 5



CALIBRATION HORIZONTAL UNSTABILIZED ACCELEROMETER
17 NOV 1978

FIGURE 6

DEVICE	FACTOR	ENGINEERING UNIT
PILOT HOUSE TOP		
NRL Radar Range	0.01875	Meters
Vertical Accelerometer	1.096×10^{-4}	g's
Horizontal Accelerometer	1.938×10^{-4}	g's
END OF BOW BOOM		
Collins Radar Range	0.01214	Meters
Vertical Accelerometer *	1.783×10^{-4}	g's
Horizontal Accelerometer *	2.520×10^{-4}	g's

* For Phase two measurements only

SPATIAL FILTER EFFECT OF THE RADAR FOOTPRINT

Since the two radars measure the distance to an area on the water surface it is necessary to analyze how the diameter of the radar footprint affects the results. It is reasonable to assume that the amplitude of a water wave with a crest-to-crest distance that is short compared with the diameter of the radar footprint will be "averaged out". That is, the radar distance will be the result of a spatial average over the footprint. One dimensional analysis of this effect is adequate because the radar illumination function is symetrical about its center axis.

The illumination function for each radar due to the directivity of its antenna is a gaussian function of angle relative to its center axis.

$$D(\theta) = A \exp - \frac{\theta^2}{B^2} \qquad (1)$$

"A" is a factor such that the definite integral of D is one. Where θ is the angular direction relative to the beam center axis and B is a measure of the width or fall off of intensity with angle. For small angles, θ is approximately

$$\theta \simeq \frac{S}{H} \qquad (2)$$

Where θ is measured in radians, S is the distance on the surface from the point of intersection of the surface with the antenna beam's center axis and H is slant range of the antenna to the surface.

This substitution for θ in equation (1) gives

$$D(S) = \frac{1}{\sqrt{\pi} HB} \exp - \frac{S^2}{H^2 B^2} \tag{3}$$

A water wave component with wave number k will have its apparent amplitude reduced as a result of being averaged with equation (3) as

$$F(k) = \int_{-\infty}^{+\infty} D(S) \cos(kS+\Psi) dS \tag{4}$$

Where k is 2π divided by the wavelength of the water wave λ and Ψ is the phase of the wave component relative to the radar beam center axis.

The result of scanning the cosine shaped water wave of wave number k is to reduce its amplitude by the following factor.

$$F(k) = \exp-\left(\frac{k^2 H^2 B^2}{4}\right) \tag{5}$$

The relation used to find the critical wave number (k_c), that is where the variance is reduced by one half due to spatial filtering, is found by setting the exponent function equal to the natural logarithm of the square root of two and solving for k_c. This can then be related to the encounter frequency for different encounter angles.

$$\frac{k_c^{\,2} H^2 B^2}{4} = \frac{1}{2} \ln 2 \tag{6}$$

$$k_c = \frac{(2 \ln 2)^{1/2}}{HB} \tag{7}$$

$$fe_c = \sqrt{\frac{gk_c}{2\pi}} + \frac{Uk_c}{2\pi} \cos\phi \tag{8}$$

Where fe is the frequency of encounter in Hertz, g is the acceleration of gravity, U is the speed of the vessel, and ϕ is the angle between the vessel's heading and the water waves. The speed of the vessel is very close to 6.7 meters/second (15 miles per hour) for all data sets. Next this relation is applied to both radars as follows.

The illumination function for the Collins radar is derived by the relation between the half power angular width or field of view (FOV) and the antenna gain factor. The Collins radar antenna horns have a gain of 100. Since

$$FOV = \text{arc cos } (1-\frac{2}{G}), \tag{9}$$

the angular FOV is 0.2 radian for the one way antenna beam. The two way beam width is narrower by the factor of the square root of one half.

From (1):

$$D(.1414) = \frac{A}{2} = A \exp-\left(\frac{.1414}{B}\right)^2 \tag{10}$$

$$\ell n2 = \left(\frac{.1414}{B}\right)^2 \tag{11}$$

$$B = \frac{\sqrt{2}}{10(\ell n2)^{1/2}} \tag{12}$$

$$B = 0.16986 \text{ radians}$$

The slant range (H) of the Collins radar antenna from the surface is 12 meters.

The NRL radar has a 60 centimeter diameter parabolic antenna. The NRL radar wavelength is 3 centimeters. This combination gives a one way antenna angle of 0.0611 radians. The two way antenna half power beam width is $0.0611/\sqrt{2}$. Therefore, the beam factor B for the NRL radar is

$$B = \frac{(.0611)}{\sqrt{2 \ \ell n \ 2}}$$

$$B = .05189 \text{ radians}$$

The slant range of the NRL radar antenna (H) from the surface is 23 meters.

Table 2 is a list of the encounter frequencies (fe) for which the PSD is reduced to one half its true value due to the spatial averaging of the radar's illumination function. The angle ϕ is zero for seas head on the bow. The angle increases as the seas are off either the starboard or port bow. For seas close on the bow the Collins spatial filter begins to reduce the variance of the encounter frequency for components above one Hertz. The NRL radar spatial filtering becomes a significant factor for encounter frequencies above 1.5 Hertz. The data shows the peak in the PSD to fall

TABLE 2

ϕ Degrees OFF THE BOW	Encounter Frequency for 1/2 Variance Response COLLINS HERTZ	NRL HERTZ
0	0.994	1.547
10	0.985	1.531
20	0.957	1.483
30	0.912	1.406
40	0.851	1.300
50	0.775	1.171
60	0.687	1.020
70	0.589	0.855
80	0.486	0.678
90	0.379	0.495

between 0.3 and 0.4 Hertz. Therefore, spatial filtering by either radar's antenna pattern should not affect the results. This applies to head to beam seas only. Following seas are more complicated and are not addressed because the main interest of this study is head seas.

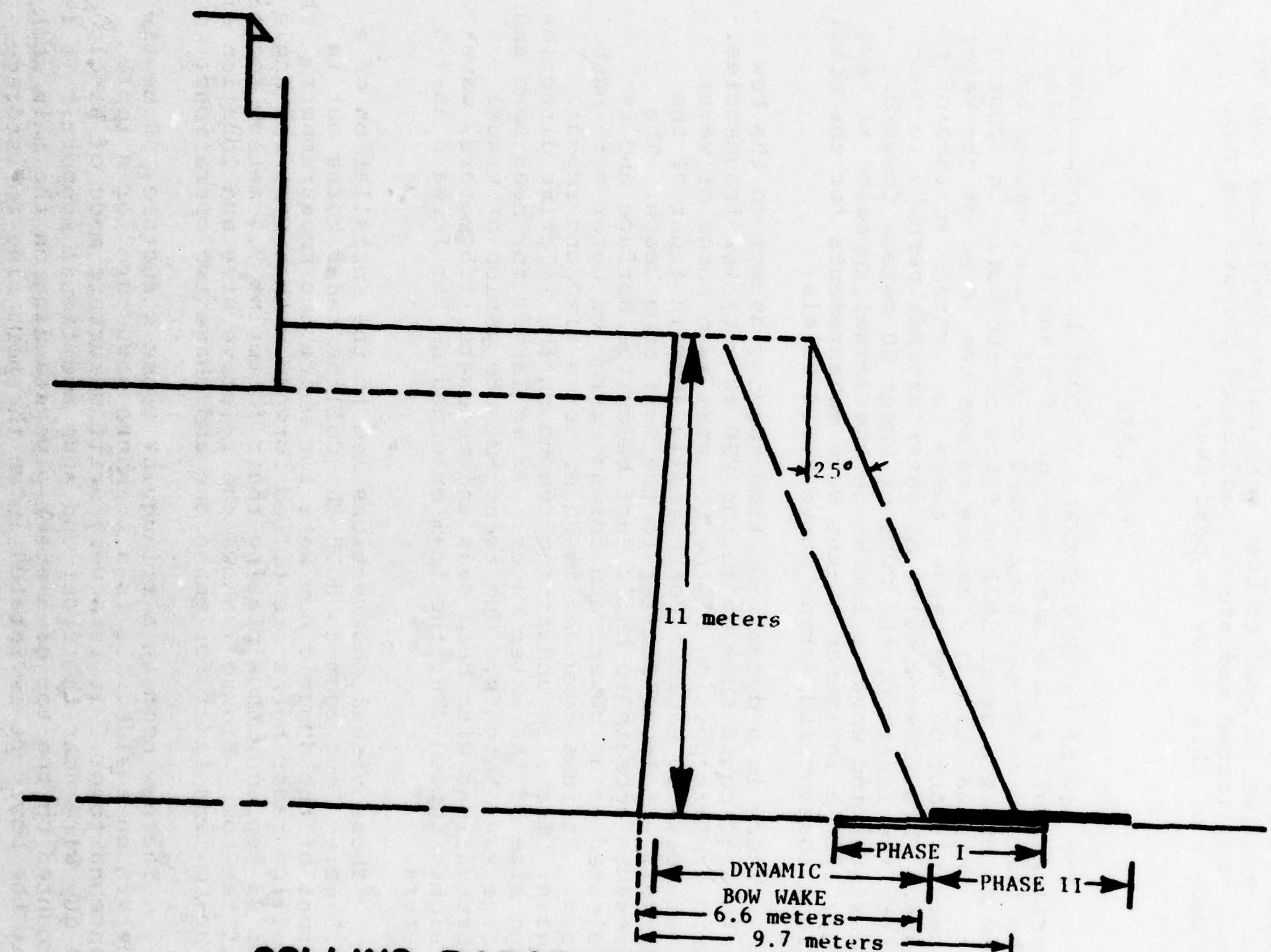
BOW WAKE

The bow of the M/V STEWART J. CORT is a blunt, almost vertical wall with a small amount of slant to either side. The fifteen miles-per-hour speed of the vessel causes the bow to exert a great deal of force on the water in front of it. This additional pressure raises the level of the water just in front of the vessel above the average surface of the lake. This forward bulge of water extends perhaps to one-fifth the length of the CORT or about 60 meters forward. This standing wave, relative to the vessel,appeared to have very little influence on the wave measurements for the conditions encountered during these field trials.

There is a dynamic or time varying aspect to the bow wake that could show up in the PSD at very low frequencies. This dynamic portion of the bow wake is a surge of water that seems to explode periodically just in front of the vessel. It looks similar to the surf on a beach. The pressure appears to build just below the surface and is released as an upward and forward surge of water with much foam. It runs down and is quiet for a time and repeats again. The size and timing depend on the relative direction and size of the water waves. It is larger for head seas and large wave heights. One twenty-minute period of visual observations with head seas and moderate, 1.5 meters, wave heights showed that the foam extended as far forward as 7.5 meters.

These visual observations led to the installation of a 4.5 meter long boom to hold the Collins radar horns out in front of the dynamic bow wake for phase two measurements. The Collins radar horns are tilted forward with a vertical angle of 25 degrees, thus placing their footprint 9.7 meters forward of the bow. Figure 7 shows the relative size and location of the Collins radar for phase one and phase two operations.

The new boom is a triangular truss structure, 30 centimeters on a side. It is a standard structure for a radio antenna tower. It is a very stiff structure made of steel. A guy wire near the front end adds additional support. It is mounted on the top of a steel pipe standing on the main deck at the bow. It is rotated in on the port side for storage



COLLINS RADAR FIELD OF VIEW

FIGURE 7

between runs or while going through the Soo locks. The motion sensing accelerometers are mounted in a weather proof can right at the forward end of the boom. They, therefore, measure the motion of the Collins horns directly.

DATA RECORDED

There were 31 floppy disks of data recorded during the October November 1978 period. Table 3 is a serial list of the data by date with a notation of the significant wave heights. The data that has its Power Spectral Density plotted in this report is noted by an asterisk. The header log sheets for these sets are included in Appendix B. The selection of the data was based on (1) close approach to Copper Harbor NOAA wave buoy, (2) Head seas, (3) vessel springing, and (4) large wave heights.

Serial numbered runs 6, 7, 23, 27 and 29 were near Copper Harbor. Serial numered runs 10 and 14 were nearly head seas. Serial numbered runs 6, 7, 10, 14, and 30 show springing of the vessel as evident by the vertical accelerometer PSD coefficient near the vessel's resonant frequency of 0.32 Hertz. Runs 14 and 30 have large wave heights.

It is important to note that the accelerometer PSD of vertical displacement is multiplied by 100 so that it can be plotted on the same scale as the radar PSD of range. In general, the accelerometer shows a narrow band of energy near the vessel's springing frequency of 0.32 Hertz. A comparison of the maximum estimated peak-to-peak deflections near 0.32 Hertz of run serial number 30 of 7.6 centimeters with Critchfield's (reference 1) maximum of 11.1 centimeters shows reasonable agreement.

DATA ANALYSIS

The data counts are reduced and analyzed in terms of power spectra components by a Fast Fourier Transform (FFT) computer program written by Dave Walden of the U.S. Coast Guard. The program allows the operator to select the duration of the data used for analysis. The numerical printouts are in terms of total sample variance at a particular frequency within the resolution bandwidth.

These FFT values were converted to engineering units of centimeters squared via the calibration constants and, to make all the data comparable, each component was divided by the resolution bandwidth expressed in Hertz. The results are plotted versus encounter frequency in Hertz (one Hertz

TABLE 3

DATA RECORDS

Serial Number		Date 1978	Significant Wave Height-Meters COLLINS RADAR	NRL RADAR	VISUAL	BUOY
1		10-9				
2		10-9				
3		10-9				
4		10-9				
5		10-9				
6	*(1)(3)	10-11	1.5		1.53	
7	*(1)(3)	10-11	1.36		1.53	
8		10-11				
9		10-12				
10	*(2)(3)	10-12	2.5		1.83	
11		10-21				
12		10-21				
13		10-22				
14	*(2)(3)	10-22	2.7		2.44	
15		10-22				
16		10-22				
17		10-22				
18		10-24				
19		10-24				
20		10-25				
21		10-30				
22		11-8				
23	*(1)	11-9	1.7		0.9	
24		11-10				
25		11-10				
26		11-10				
27	*(1)	11-12	1.1		0.9	0.52
28		11-13				
29	*(1)	11-16	0.91	0.8	1.22	
30	*(3)	11-23	2.67	2.98	1.83	
31		11-25	1.96	1.73	1.53	

*** DATA REDUCED**

(1) Near Copper Harbor
(2) Head Seas
(3) Vessel Springing

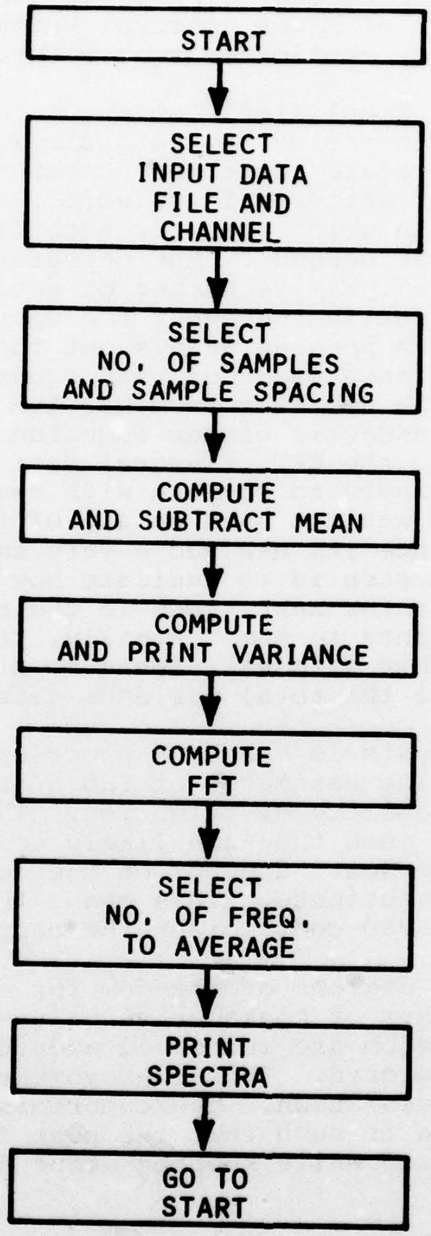
equals one cycle per second). Therefore, the results are plotted in the form of Power Spectral Density (PSD) with engineering units of centimeter squared-seconds.

Figure 8 is a simplified flow chart for the FFT program. The operator selects one of the data files (numbered 0 up to 9) on the data floppy disk. Next the number of data samples to be used for the FFT analysis is selected. The next option is to use every data point (ten per second) or every other data point (five per second). The operator then selects the data channel for analysis. A number of data samples are selected for printout in the event the operator desires to check the data. The program prints out the data mean value in counts, the variance and root mean square (rms) values in units of counts. The operator then has the option of using a three term Blackman-Harris window function on the time sampled data before the FFT. Several data passes were made that include the window to compare with results without the window. The window was not used on any of the data plotted for this report since its use had a very small effect on the results. The next step is to indicate how many FFT values to print. The operator next types in the number of consecutive frequency coefficients to sum. Finally, the operator types in the desired number of coefficients to print after summing. These printouts are the total variance versus frequency.

The data analysis is based on procedures for the analysis of random noise. The estimates of PSD of random noise have a Chi-squared probability distribution. The stability of the estimates, how much they are likely to change, from one data segment to the next, depends on the number of degrees of freedom in each estimate. This means the more data used to obtain a single PSD coefficient the better the estimate.

There are two degrees of freedom for each estimate of the PSD. If a number of consecutive values are summed then the degrees of freedom are increased and the consistency of the estimate is improved. This improvement is offset by a poorer frequency resolution. The compromise used in the plots included here is such that the best frequency resolution possible is used while keeping about 50 degrees of freedom.

The header logs and PSD plots for 8 sets of data are included in this report. The selected data includes generally head sea conditions or close approach to Copper Harbor, Michigan. NOAA had a wave buoy near Copper Harbor, Michigan and some of that data is used for comparison. Some of the data sets show the vessel springing as evident in the accelerometer results.



(See Appendix F for detailed flow diagram and copy of program)

FLOW CHART
DATA REDUCTION

FIGURE 8

The plots show the PSD's of the Collins Radar, the NRL radar and the vertical accelerometer measurements transformed to displacement by double integration. Double integration will cause the derived values of displacement for the low frequencies to be too large. Any noise in the acceleration measurement will be emphasized at the very low frequencies. The unknown constants of integration also show up as very large values in the lowest frequency band. Therefore, the PSD estimate of displacement at the lowest frequency resolved should be ignored.

VESSEL MOTION COMPENSATION

A large ore carrier like the CORT has very small movements in pitch, roll and heave under most sea conditions. The corrections to the radar spectral components by the accelerometer measurements are likewise small. For example, an examination of the radar PSD and the vertical displacement as measured by the double integration of the accelerometer data show that the largest displacement PSD is about one percent of the radar PSD. The amplitude ratio is the square root of the PSD ratio or ten to one.

The report "Wavemeter Data Reduction Method and Initial Data from the SL-7 Containership" (reference 5) by John Dalzell uses the following equation to relate the various components of encounter spectrum.

$$Sgg(We) = Srr(We) + Szz(We) + 2Crz(We)$$

$Sgg(We)$ = encounter spectrum of waves

$Srr(We)$ = encounter spectrum of corrected radar range

$Szz(We)$ = spectrum of heave motion via the accelerometer

$Crz(We)$ = Co-spectrum of radar with heave

If $Szz(We)$ is very small compared with $Srr(We)$ then $Crz(We)$ will also be small. Thus, the approximation

$$Sgg(We) = Srr(We)$$

is reasonably good for this case.

The PSD plots show $Szz(We)$ to be about one percent of $Srr(We)$, therefore, both $Szz(We)$ and $Crz(We)$ are small compared with $Srr(We)$. Therefore, the PSD of the radar range will be a good approximation to the encounter PSD of the vessel and the waves.

DISCUSSION OF RESULTS

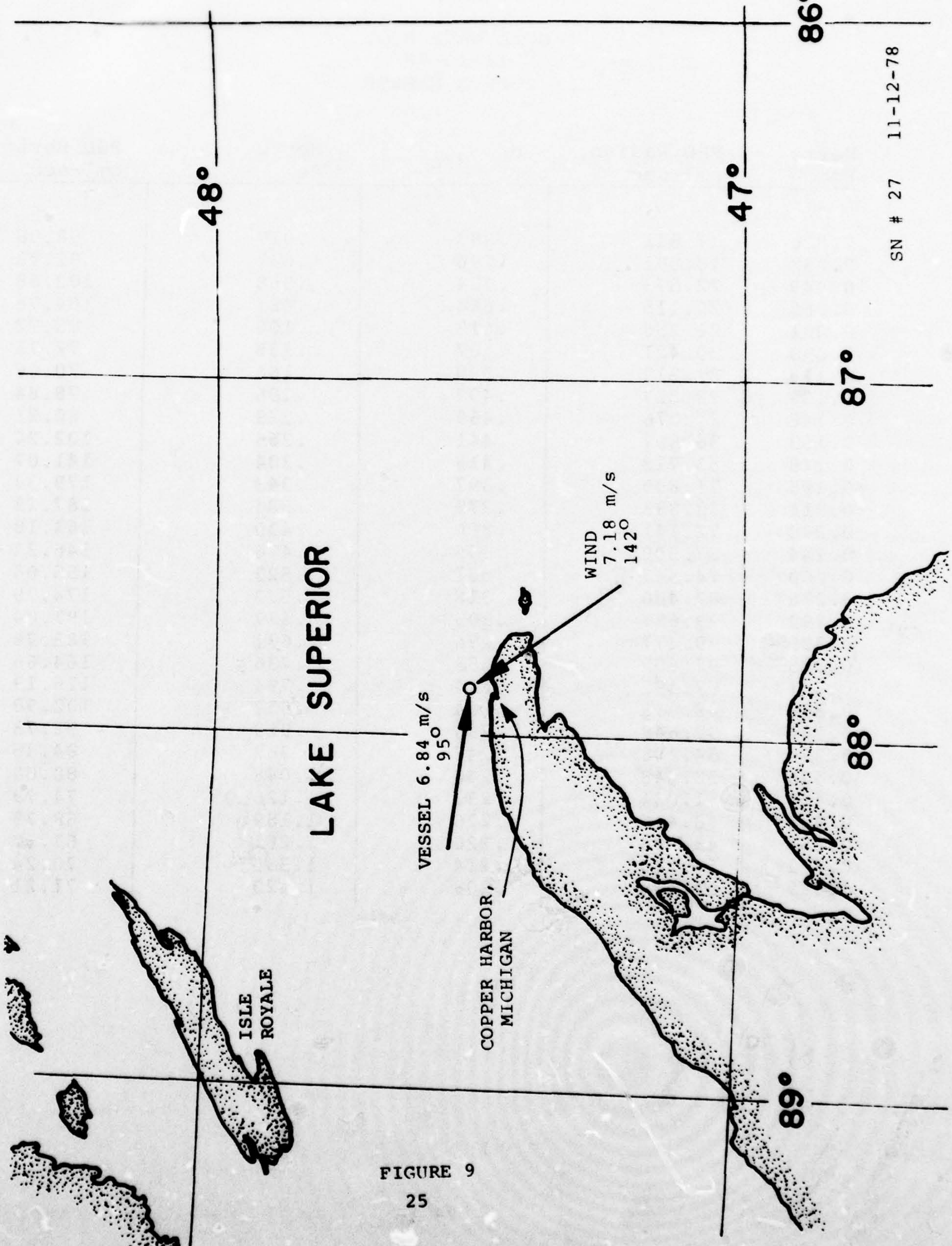
A comparison of the significant wave heights (SWH) listed in Table 3 show the visual estimates to be lower than the radar estimate five times and higher three times. The small SWH (less than about one meter) have the largest percent difference in the estimates. A comparison of the SWH as measured by the two radars for the three cases the NRL radar was working show a variation of about ten percent. The NRL transmitter was not working for some of the early data runs, thus of the eight sets reduced for this report, only runs 27, 29, and 30 have both radars working.

The plots of Power Spectral Density (PSD) all have about 50 degrees of freedom for each estimate which says that the 80% confidence interval is 1.5 db wide. They are plotted on a full scale of 10,000 cm^2-second. Larger values of full scale were needed to display numbers 14 and 30. The values of PSD of the vertical displacement calculated from the accelerometer data were multiplied by 100 so that they could be plotted on the same scale as the radars. The vertical displacement is a narrow band response near 0.3 Hertz frequency. The amplitude of the springing in runs 6, 7, 10, 14, 23, and 30 is about one percent of the variance of the PSD of the waves as measured by the radar at the same frequency.

Run number 27 was near the NOAA wave buoy at Copper Harbor, Michigan. The buoy data was transformed into encounter spectra taking into account the observed angle between the vessel and the waves as recorded on the log found in Appendix B.

Figure 9 is a map of the region around Copper Harbor. It shows the vessel heading East with an off shore wind from the South-East. The buoy is about 2 miles from the shore and the vessel is about 5 miles from the shore. The fact that the buoy measures a half meter SWH and the ship radar indicatesabout one meter SWH is due to the longer fetch (distance) over which the wind blows off the shore to the vessel. Figure 10 is a plot of the PSD of the two radars, the buoy data transformed to encounter spectra, and the vertical displacement. The scale has been reduced to better show the small values of PSD.

Table 4 is the NOAA data in the first two columns. The frequency is wave frequency and the PSD is normalized by the resolution bandwidth in radians. The last two columns are the data transformed to encounter frequency spectra and normalized by the resolution bandwidth in Hertz. The encounter direction was 25^{o} off the starboard bow.



LAKE SUPERIOR
ISLE ROYALE
VESSEL 6.84 m/s
95°
COPPER HARBOR, MICHIGAN
WIND
7.18 m/s
142°
48°
47°
89°
88°
87°
86°
SN # 27 11-12-78

FIGURE 9

TABLE 4

NOAA WAVE BUOY
11-10-78
COPPER HARBOR

Hertz Fo	PSD Radian cm^2-sec	dfo/dfe	Hertz Fe	PSD Hertz cm^2-sec
0.016	17.841	.883	.017	98.98
0.033	18.581	.796	.037	92.93
0.049	22.573	.724	.058	102.68
0.065	25.115	.664	.081	104.78
0.081	22.256	.613	.106	85.72
0.098	20.421	.567	.135	72.75
0.114	21.219	.530	.165	70.66
0.130	23.327	.497	.196	78.84
0.146	27.276	.468	.229	80.21
0.163	36.897	.441	.266	102.24
0.179	53.713	.418	.304	141.07
0.195	71.895	.397	.343	179.34
0.211	78.833	.378	.384	187.23
0.288	72.141	.360	.430	163.18
0.244	67.508	.345	.476	146.34
0.260	74.567	.331	.523	155.08
0.276	87.480	.318	.573	174.79
0.293	99.687	.305	.627	191.04
0.309	99.477	.294	.681	183.76
0.325	92.602	.283	.736	164.66
0.341	67.492	.274	.794	116.19
0.358	62.036	.264	.857	102.90
0.374	57.648	.256	.919	92.73
0.390	54.138	.248	.982	84.36
0.406	53.048	.240	1.048	80.00
0.423	51.084	.233	1.120	74.79
0.439	48.446	.226	1.189	68.79
0.455	48.698	.220	1.261	67.32
0.471	52.240	.214	1.335	70.24
0.489	54.485	.208	1.420	71.21

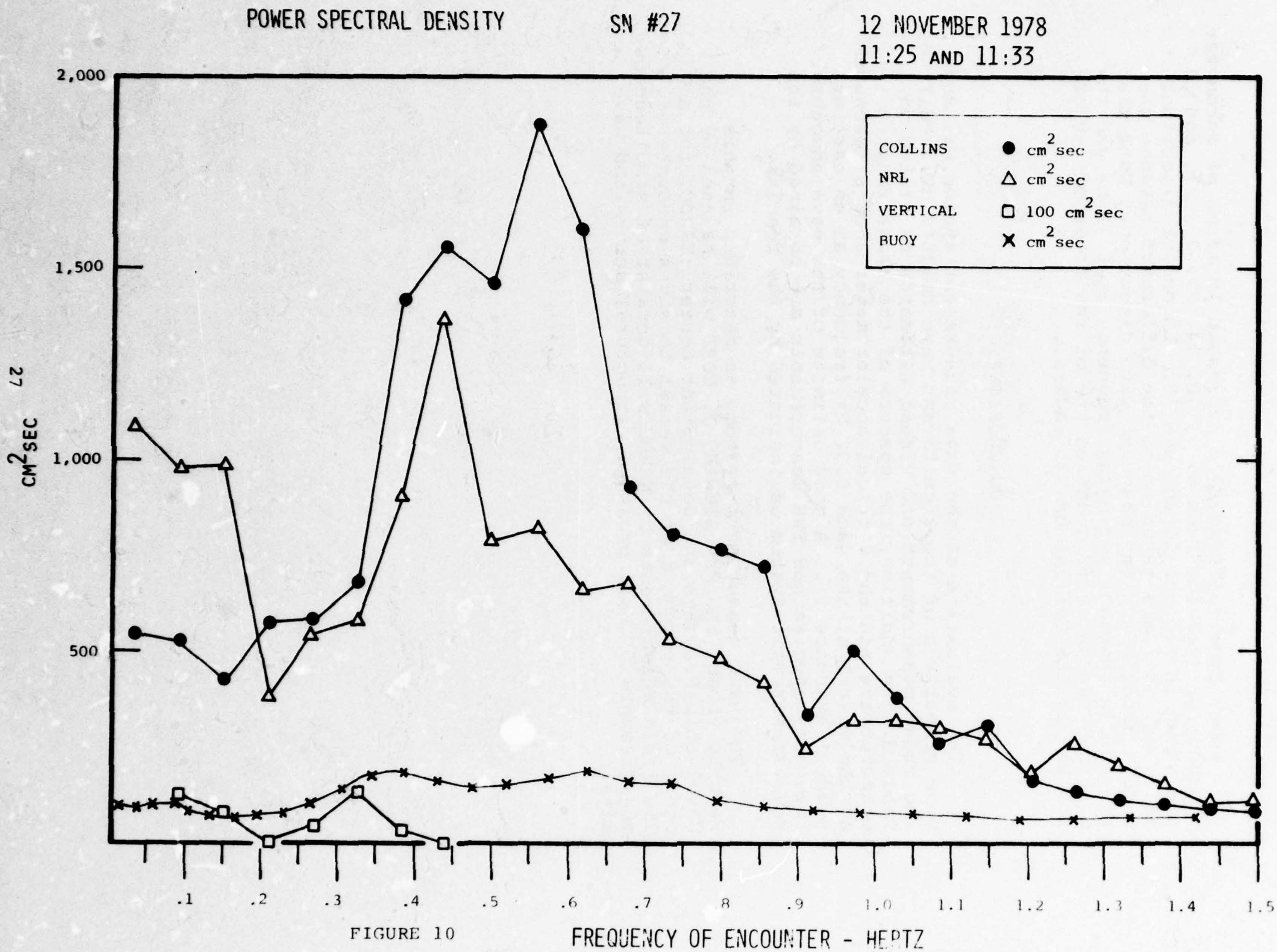

POWER SPECTRAL DENSITY
SN #27
12 NOVEMBER 1978
11:25 AND 11:33
2,000
1,500
1,000
500
CM^2SEC
COLLINS cm^2sec
NRL cm^2sec
VERTICAL 100 cm^2sec
BUOY cm^2sec
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
1.5
FREQUENCY OF ENCOUNTER - HERTZ

FIGURE 10

Power Spectral Densities expressed in terms of encounter frequencies (fe) for runs 6, 7, 10, 14, 23, 27, 29, and 30 are shown in figures 11 through 18. Encounter directions (c.f. eg. (8)) are taken to be the difference between the ship's heading and the observed wave direction. Note that the ship's resonant springing frequency is 0.32 Hz and the critical encounter frequencies are of the order of 1.0 or 1.5 Hz for the Collins or NRL radars.

CONCLUSIONS

The evaluation of the wave measurement system was done by a comparison of the significant wave heights derived from the radar measurements and visual estimates as listed in Table 3. In addition, the spectra of the radar range measurements and the vertical accelerometer show a resonance of the vessel at the same 0.32 Hz frequency as an earlier study (reference 1). A good estimate of the wave encounter frequency spectra and SWH measurements are obtained by the wave measurement system as indicated by the results.

The wave measurement system, as described in this report, aboard the M/V STEWART J. CORT will be used by the Naval Ship Research and Development Center (NSRDC) for a study of the response of the vessel to waves encountered. The field measurements by NSRDC will consist of simultaneous measurements of hull pressure, structural stress and wave data.

APPENDIX B

TABLE B-1

SERIAL NO. 6

GREAT LAKES WAVE HEIGHT PROJECT

DATE: 11 Oct 78 TIME: 19:06:05

DURATION OF RUN IN MINUTES IS	20
NORTH LATITUDE (DD MM)	47 40
WEST LONGITUDE (DD MM)	87 50
VESSEL'S SPEED (MPH - XX.X)	15.3
VESSEL'S HEADING (DEGREES)	100
VESSEL'S DRAFT (FEET)	0
WIND DIRECTION (DEGREES)	180
WIND SPEED (KNOTS)	16
WAVE DIRECTION (DEGREES)	195
WAVE HEIGHT (FEET)	5

REMARK LINE - UP TO 60 CHARACTERS

DRAFT FORWARD27-2, MID 27-3, AFT 27-4

REMARK LINE - UP TO 60 CHARACTERS

SL-7 RADAR NOT WORKING, 10.5 MILES OFF COPPER HARBOR

REMARK LINE - UP TO 60 CHARACTERS

PROG INT 2 TIMES 7:25 & 7:30 DARK, WAVES OBS GUESSES

POWER SPECTRAL DENSITY SN # 6 11 OCTOBER 1978 1906 HOURS

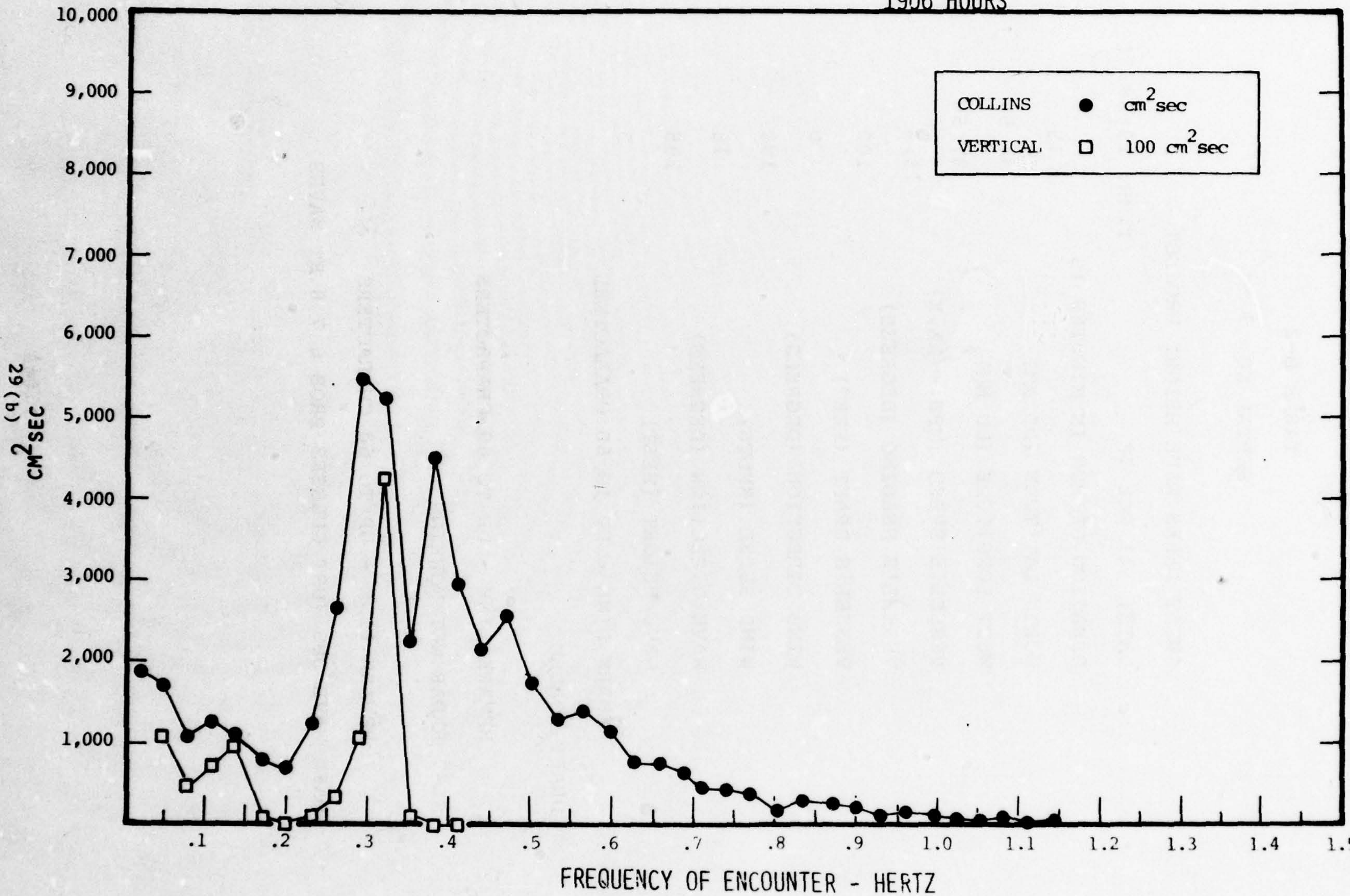


FIGURE 11

TABLE B-2

SERIAL NO. 7

GREAT LAKES WAVE HEIGHT PROJECT

DATE: 11 Oct 78 TIME: 19:39:31

DURATION OF RUN IN MINUTES IS	15
NORTH LATITUDE (DD MM)	47 50
WEST LONGITUDE (DD MM)	87 50
VESSEL'S SPEED (MPH - XX.X)	15.3
VESSEL'S HEADING (DEGREES)	100
VESSEL'S DRAFT (FEET)	0
WIND DIRECTION (DEGREES)	180
WIND SPEED (KNOTS)	16
WAVE DIRECTION (DEGREES)	195
WAVE HEIGHT (FEET)	5

REMARK LINE - UP TO 60 CHARACTERS

DRAFT LOADED

REMARK LINE - UP TO 60 CHARACTERS

SL-7 RADAR NOT WORKING

REMARK LINE - UP TO 60 CHARACTERS

DARK WAVE OBS JUST GUESSES PROB 6 7 8 FT WAVES

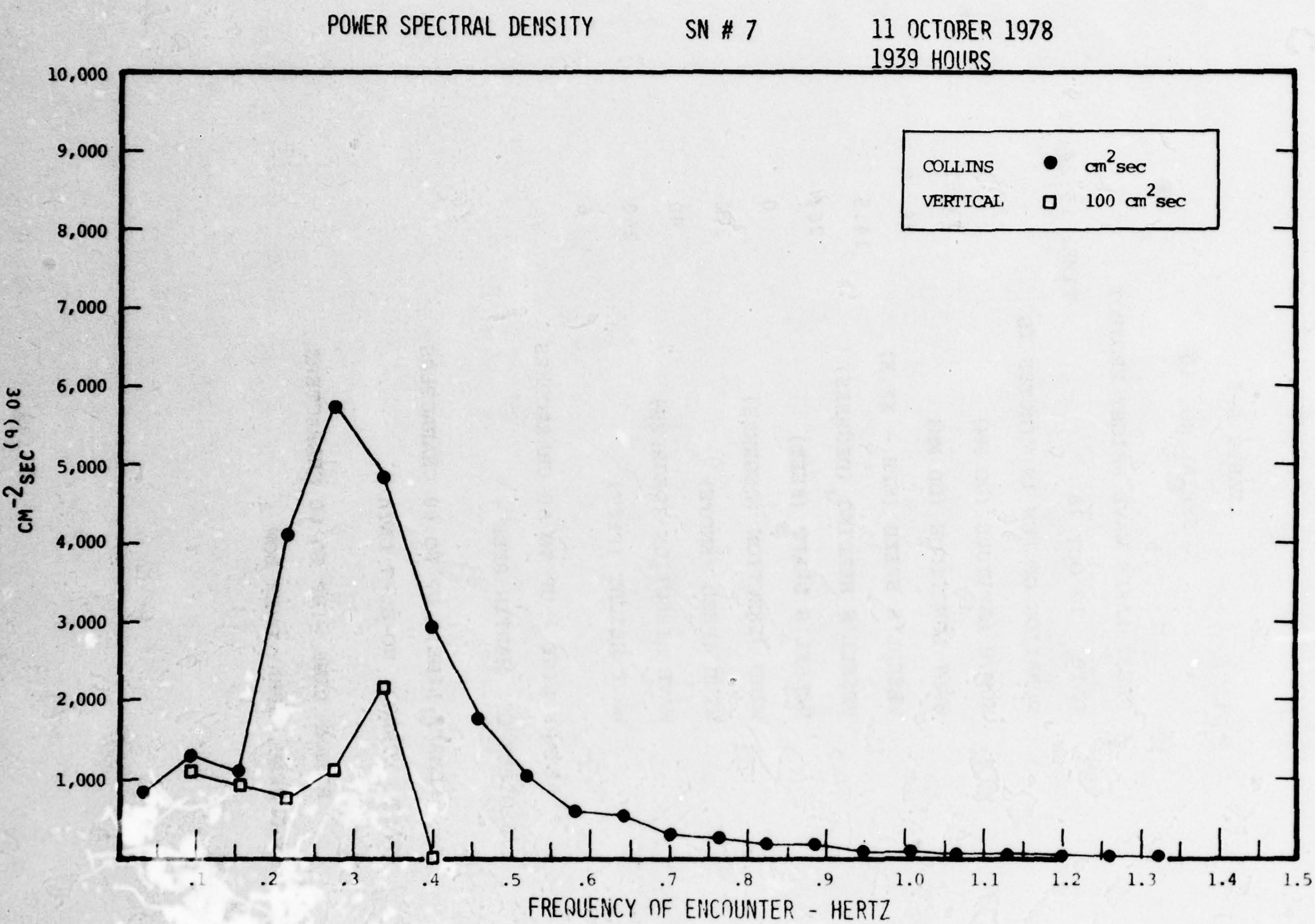

POWER SPECTRAL DENSITY
SN # 7
11 OCTOBER 1978
1939 HOURS
COLLINS
$cm^2 sec$
VERTICAL
$100\ cm^2 sec$
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
$CM^{-2}SEC^{(q)}$ OE
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
1.5
FREQUENCY OF ENCOUNTER - HERTZ

FIGURE 12

TABLE B-3

SERIAL NO. 10

GREAT LAKES WAVE HEIGHT PROJECT

DATE: 12 OCT 78 TIME: 15:24:19

DURATION OF RUN IN MINUTES IS	20
NORTH LATITUDE (DD MM)	45 52
WEST LONGITUDE (DD MM)	84 9
VESSEL'S SPEED (MPH - XX.X)	14.5
VESSEL'S HEADING (DEGREES)	264
VESSEL'S DRAFT (FEET)	0
WIND DIRECTION (DEGREES)	270
WIND SPEED (KNOTS)	40
WAVE DIRECTION (DEGREES)	260
WAVE HEIGHT (FEET)	6

REMARK LINE - UP TO 60 CHARACTERS

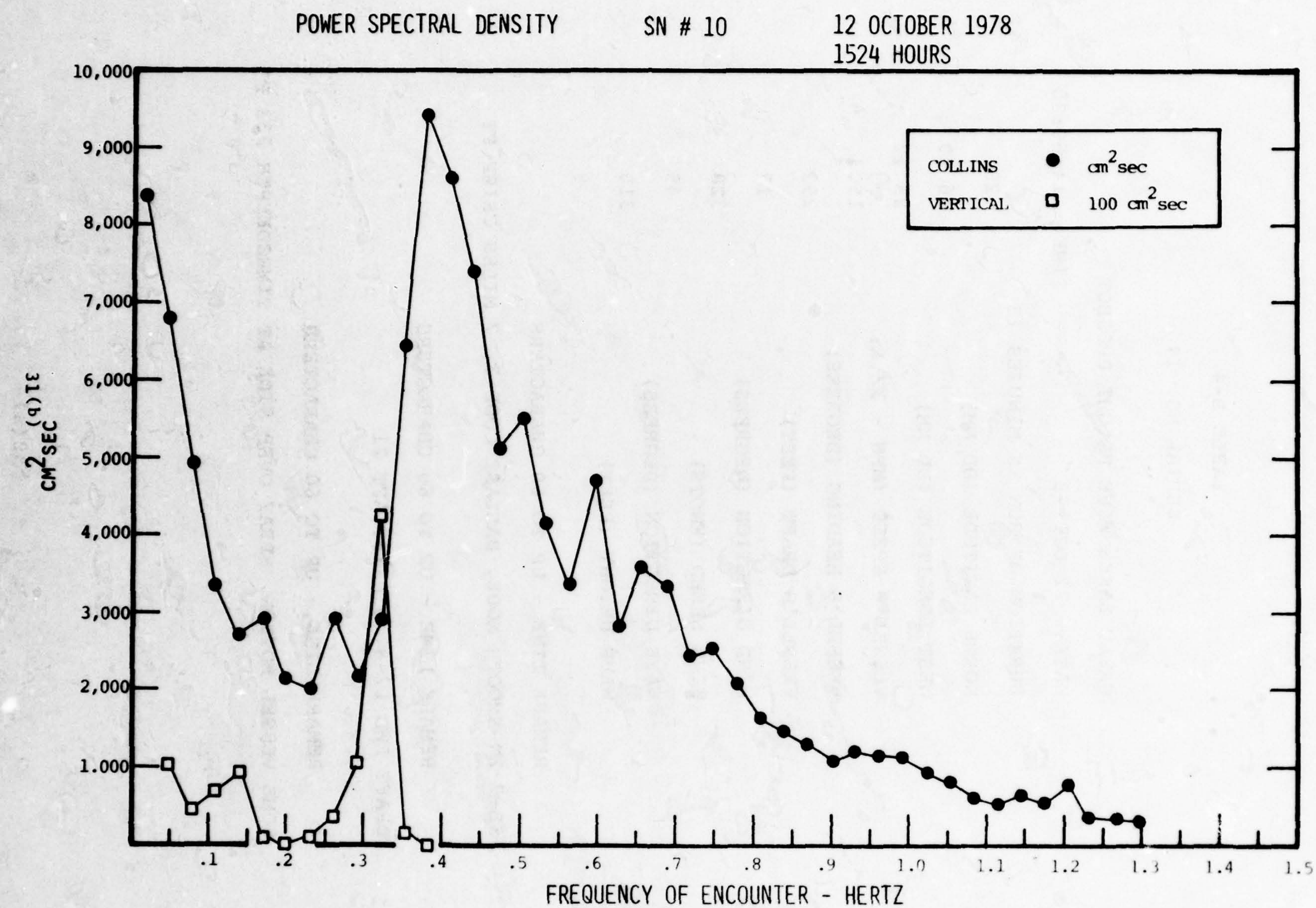
1.6 MILES OFF MARTIN REEF

REMARK LINE - UP TO 60 CHARACTERS

DRAFT, LOADED, NO SL-7 DATA

REMARK LINE - UP TO 60 CHARACTERS

HEAD SEAS, SPRAY OVER BOW



POWER SPECTRAL DENSITY
SN # 10
12 OCTOBER 1978
1524 HOURS
COLLINS $cm^2 sec$
VERTICAL 100 $cm^2 sec$
$CM^2 SEC$
31(b)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1.000
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
1.5
FREQUENCY OF ENCOUNTER - HERTZ

FIGURE 13

TABLE B-4

SERIAL NO. 14

GREAT LAKES WAVE HEIGHT PROJECT

DATE: 22 OCT 78 TIME: 14:50:33

DURATION OF RUN IN MINUTES IS	20
NORTH LATITUDE (DD MM)	46 50
WEST LONGITUDE (DD MM)	85 12
VESSEL'S SPEED (MPH - XX.X)	15.4
VESSEL'S HEADING (DEGREES)	292
VESSEL'S DRAFT (FEET)	17
WIND DIRECTION (DEGREES)	320
WIND SPEED (KNOTS)	35
WAVE DIRECTION (DEGREES)	310
WAVE HEIGHT (FEET)	8

REMARK LINE - UP TO 60 CHARACTERS

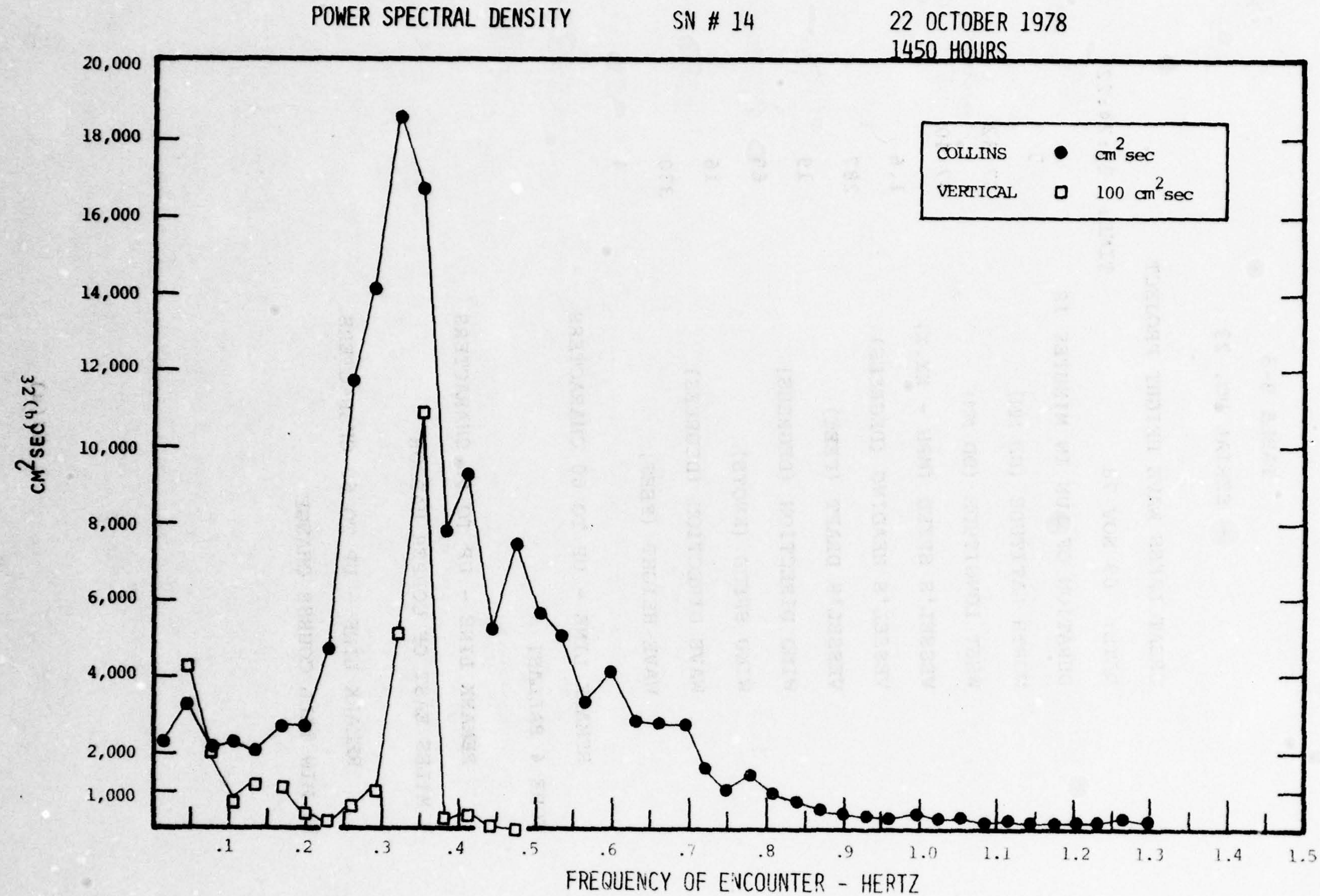
SL-7 IN SMOOTH MODE, BALLAST CODE 3, 7 MILES CRISP PT

REMARK LINE - UP TO 60 CHARACTERS

DRAFT FWD 17-6, MID 19, AFT 21

REMARK LINE - UP TO 60 CHARACTERS

SOME VESSEL MOTION, SPRAY OVER SIDE AT TIMESDEEPTH 233 FT



POWER SPECTRAL DENSITY
SN # 14
22 OCTOBER 1978
1450 HOURS
COLLINS cm²sec
VERTICAL 100 cm²sec
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
1,000
CM²SEC(4)32
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
1.5
FREQUENCY OF ENCOUNTER - HERTZ

FIGURE 14

TABLE B-5

SERIAL NO. 23

GREAT LAKES WAVE HEIGHT PROJECT

DATE: 09 NOV 78 TIME: 21:24:22

DURATION OF RUN IN MINUTES IS	5
NORTH LATITUDE (DD MM)	47 32
WEST LONGITUDE (DD MM)	87 40
VESSEL'S SPEED (MPH - XX.X)	1.6
VESSEL'S HEADING (DEGREES)	287
VESSEL'S DRAFT (FEET)	19
WIND DIRECTION (DEGREES)	65
WIND SPEED (KNOTS)	16
WAVE DIRECTION (DEGREES)	330
WAVE HEIGHT (FEET)	4

REMARK LINE - UP TO 60 CHARACTERS

CODE 4 BALLAST

REMARK LINE - UP TO 60 CHARACTERS

7 MILES EAST OF COPPER HARBOR

REMARK LINE - UP TO 60 CHARACTERS

10 MIN TILL COURSE CHANGE

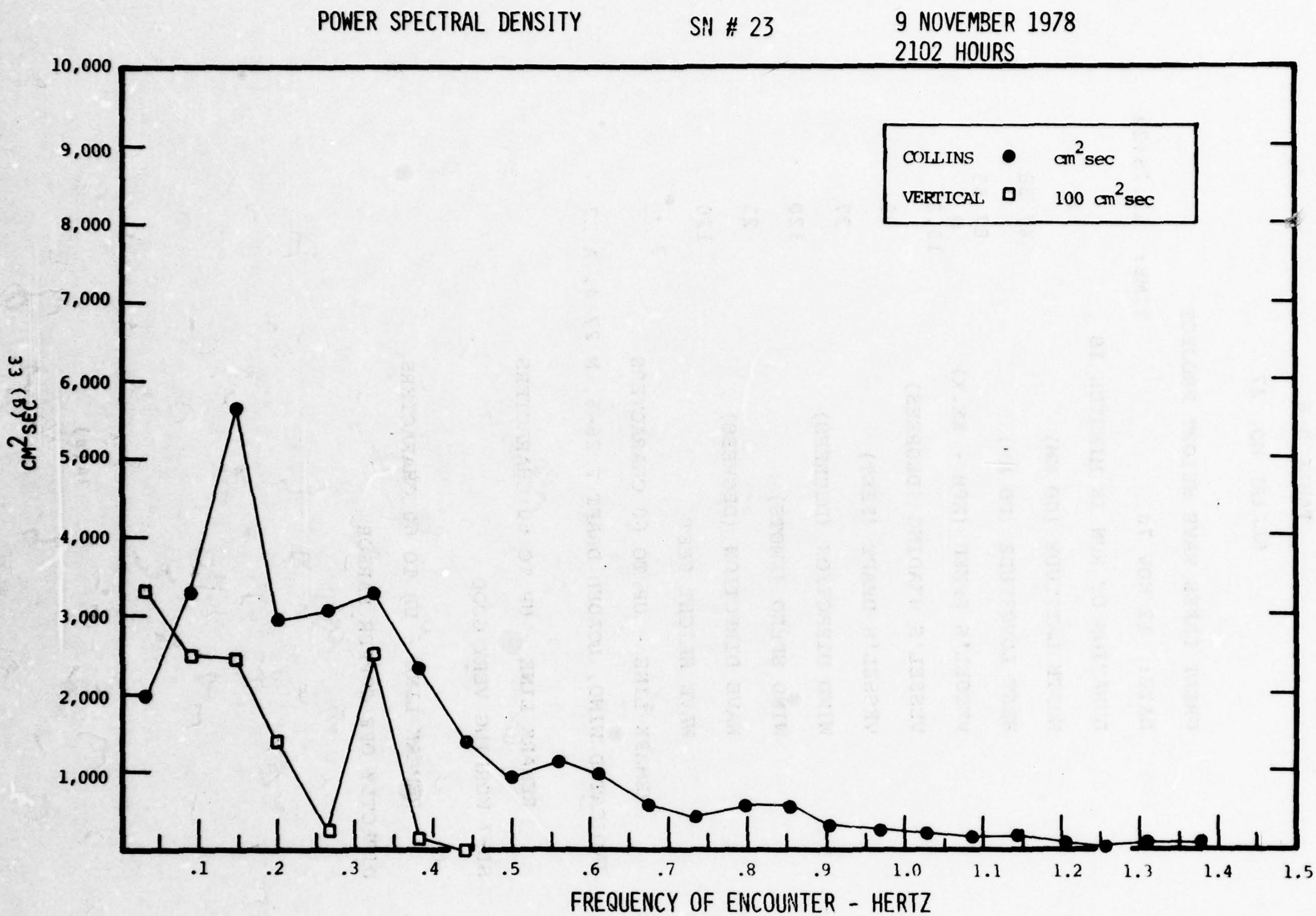

POWER SPECTRAL DENSITY
SN # 23
9 NOVEMBER 1978
2102 HOURS
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
CM2SEC(g) 33
COLLINS cm2sec
VERTICAL 100 cm2sec
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
1.5
FREQUENCY OF ENCOUNTER - HERTZ

FIGURE 15

TABLE B-6

SERIAL NO. 27

GREAT LAKES WAVE HEIGHT PROJECT

DATE: 12 NOV 78 TIME: 11:25:22

DURATION OF RUN IN MINUTES IS
4

NORTH LATITUDE (DD MM)
47 38

WEST LONGITUDE (DD MM)
87 55

VESSEL'S SPEED (MPH - XX.X)
15.3

VESSEL'S HEADING (DEGREES)
95

VESSEL'S DRAFT (FEET)
27

WIND DIRECTION (DEGREES)
120

WIND SPEED (KNOTS)
25

WAVE DIRECTION (DEGREES)
120

WAVE HEIGHT FEET
3

REMARK LINE - UP TO 60 CHARACTERS

INDICATED WIND, LOADED DRAFT F 26-6, N 27-4, A 27

REMARK LINE - UP TO 60 CHARACTERS

SL-7 WORKING VERY GOOD

REMARK LINE - UP TO 60 CHARACTERS

DIRECTLY OFF COPPER HARBOR

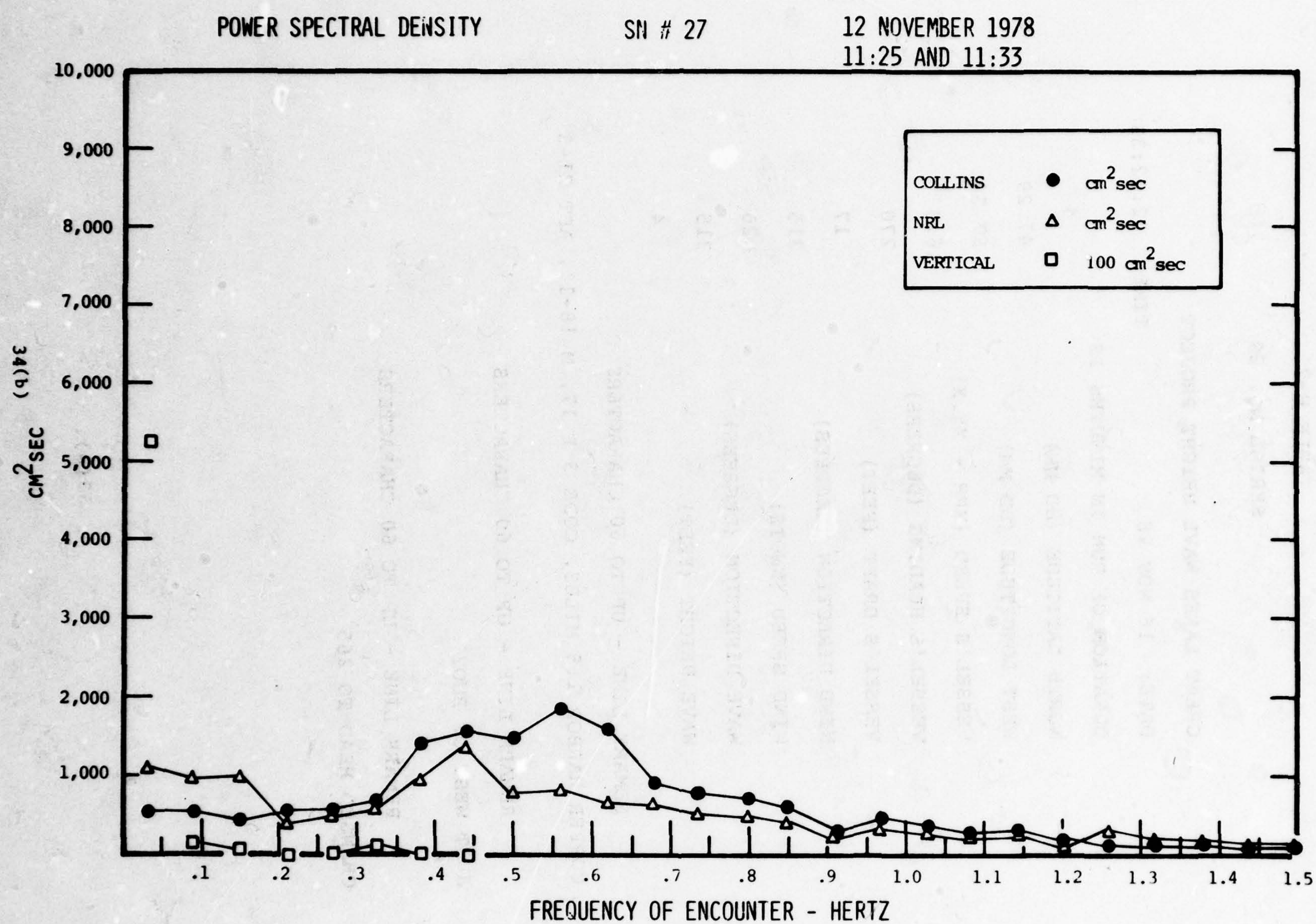


FIGURE 16

34(b)

TABLE B-7

SERIAL NO. 29

GREAT LAKES WAVE HEIGHT PROJECT

DATE: 16 NOV 78 TIME: 22:52:33

DURATION OF RUN IN MINUTES IS	4
NORTH LATITUDE (DD MM)	47 29
WEST LONGITUDE (DD MM)	87 54
VESSEL'S SPEED (MPH - XX.X)	16.3
VESSEL'S HEADING (DEGREES)	270
VESSEL'S DRAFT (FEET)	17
WIND DIRECTION (DEGREES)	315
WIND SPEED (KNOTS)	20
WAVE DIRECTION (DEGREES)	315
WAVE HEIGHT (FEET)	4

REMARK LINE - UP TO 60 CHARACTERS

COPPER HARBOR 1.5 MILES, CODE 3 F 17, M 18-11, AFT 21-3

REMARK LINE - UP TO 60 CHARACTERS

JUST WEST OF BUOY

REMARK LINE - UP TO 60 CHARACTERS

CHANGED HEAD TO 265

POWER SPECTRAL DENSITY SN # 29 16 NOVEMBER 1978 2213 HOURS

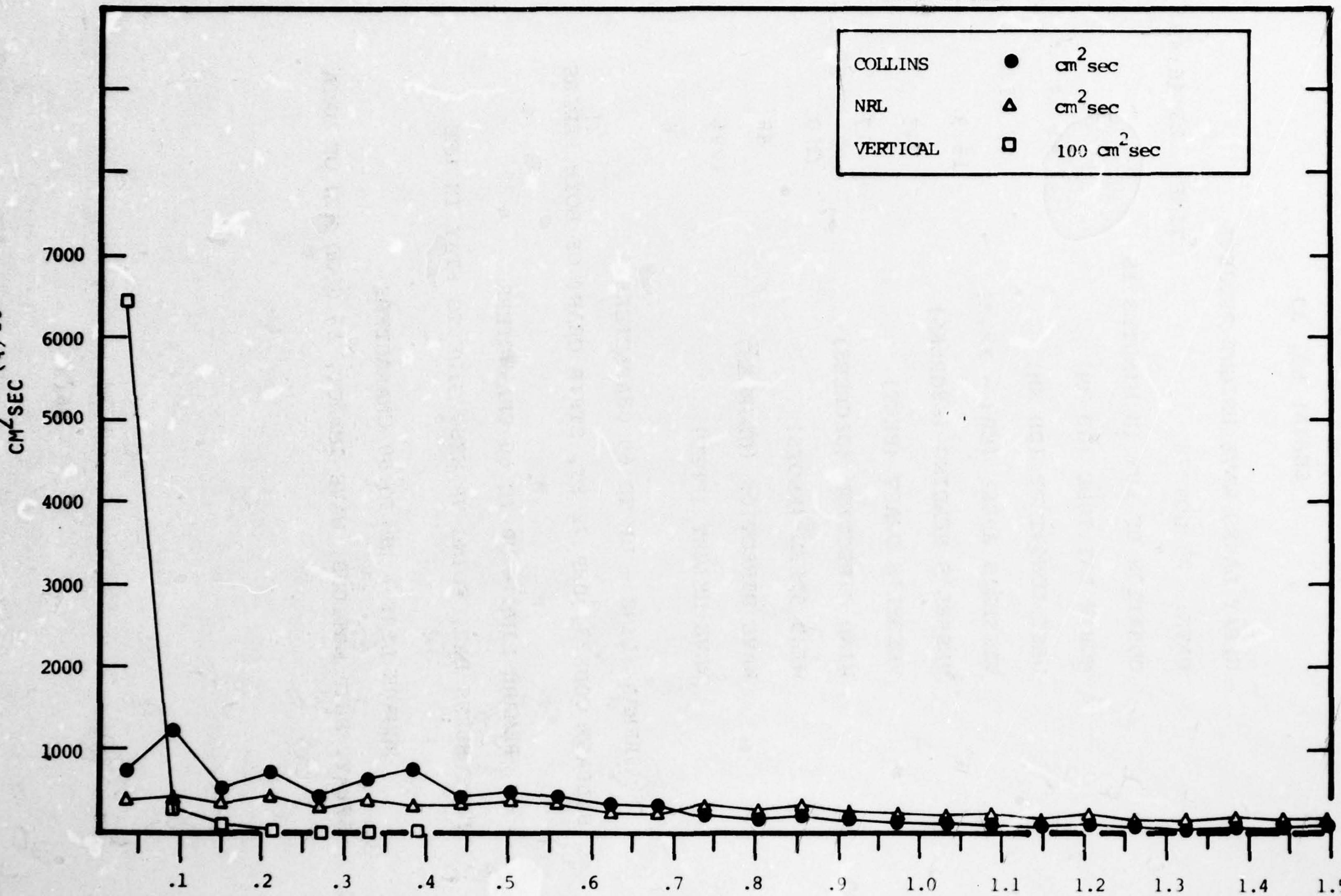


FIGURE 17

TABLE B-8

SERIAL NO. 30

GREAT LAKES WAVE HEIGHT PROJECT

DATE: 23 NOV 78 TIME: 23:46:49

DURATION OF RUN IN MINUTES IS	15
NORTH LATITUDE (DD MM)	41 44
WEST LONGITUDE (DD MM)	87 11
VESSEL'S SPEED (MPH - XX.X)	15.3
VESSEL'S HEADING (DEGREES)	343
VESSEL'S DRAFT (FEET)	17
WIND DIRECTION (DEGREES)	310
WIND SPEED (KNOTS)	40
WAVE DIRECTION (DEGREES)	290
WAVE HEIGHT (FEET)	6

REMARK LINE - UP TO 60 CHARACTERS

BALLAST CODE 3, DEP 72 FT, STRIP CHART OF BOTH RADARS

REMARK LINE - UP TO 60 CHARACTERS

LEFT BURNS HAR, GOING UP WEST SIDE TO STAY IN LEE

REMARK LINE - UP TO 60 CHARACTERS

SPRAY, SHIP MOTIONS, WAVE IMPACT, 15 GOOD MIN OF DATA

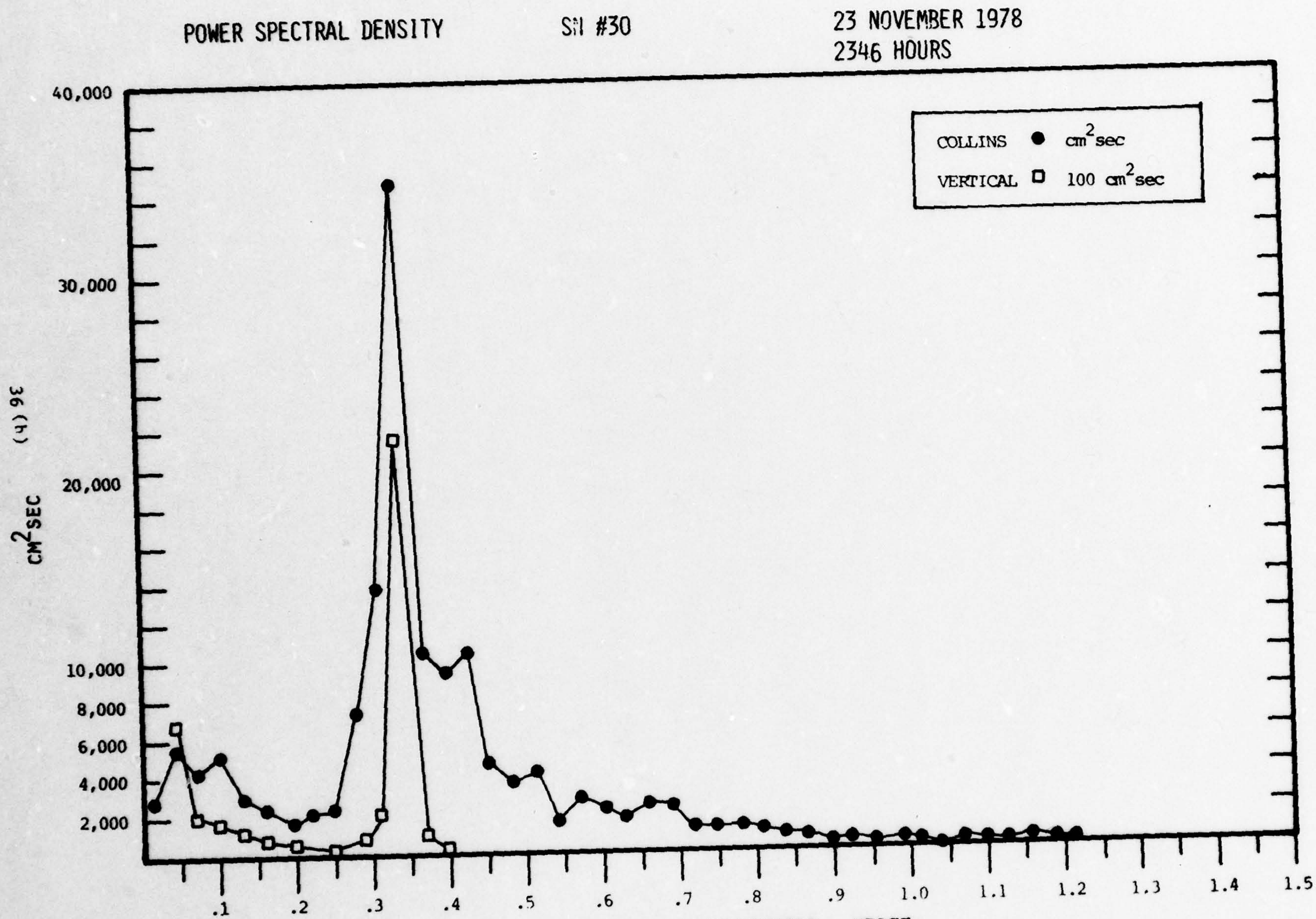


FIGURE 18

36 (h)

APPENDIX A

TABLE A-1

SUMMARY OF OPERATIONS ABOARD THE VESSEL

March 1978

* Installation of System

April 1978

* Installation of cable connectors
* Initial check of system on vessel

June 1978

* Return computer to Washington, D.C. PHASE I

July & August 1978

* Calibrate System while in drydock
* Attach longer boom for bow radar

October & November 1978

* Collect data

April 1979

* Install longer boom for Collins Radar

May & June 1979 PHASE II

* Trial run

October 1979

* Repair NRL Radar Transmitter

APPENDIX B

LOG SHEETS FOR REDUCED DATA

(Reduced Data Sheets were transferred to their associated PSD plot. Page numbers 39 - 46 is maintained here for continuity)

OLD page #	NEW page #
39	29(a)
40	30(a)
41	31(a)
42	32(a)
43	33(a)
44	34(a)
45	35(a)
46	36(a)

APPENDIX C

NRL RADAR SYSTEM

The NRL radar's high resolution of 30 centimeters is obtained by using a very narrow pulse of 2 nanoseconds. Figure C-1 is a block diagram of the radar system. The important system characteristics are listed in Table C-1.

TABLE C-1

Wavelength	3 Centimeters
Pulse Width	2 Nanoseconds
Peak Transmitted Power	100 Watts
Pulse Repetition Rate	8000 per second
Antenna Diameter	60 Centimeters
Receiver Noise Figure	7 db
Equivalent Pulse Processing Rate	80 per second

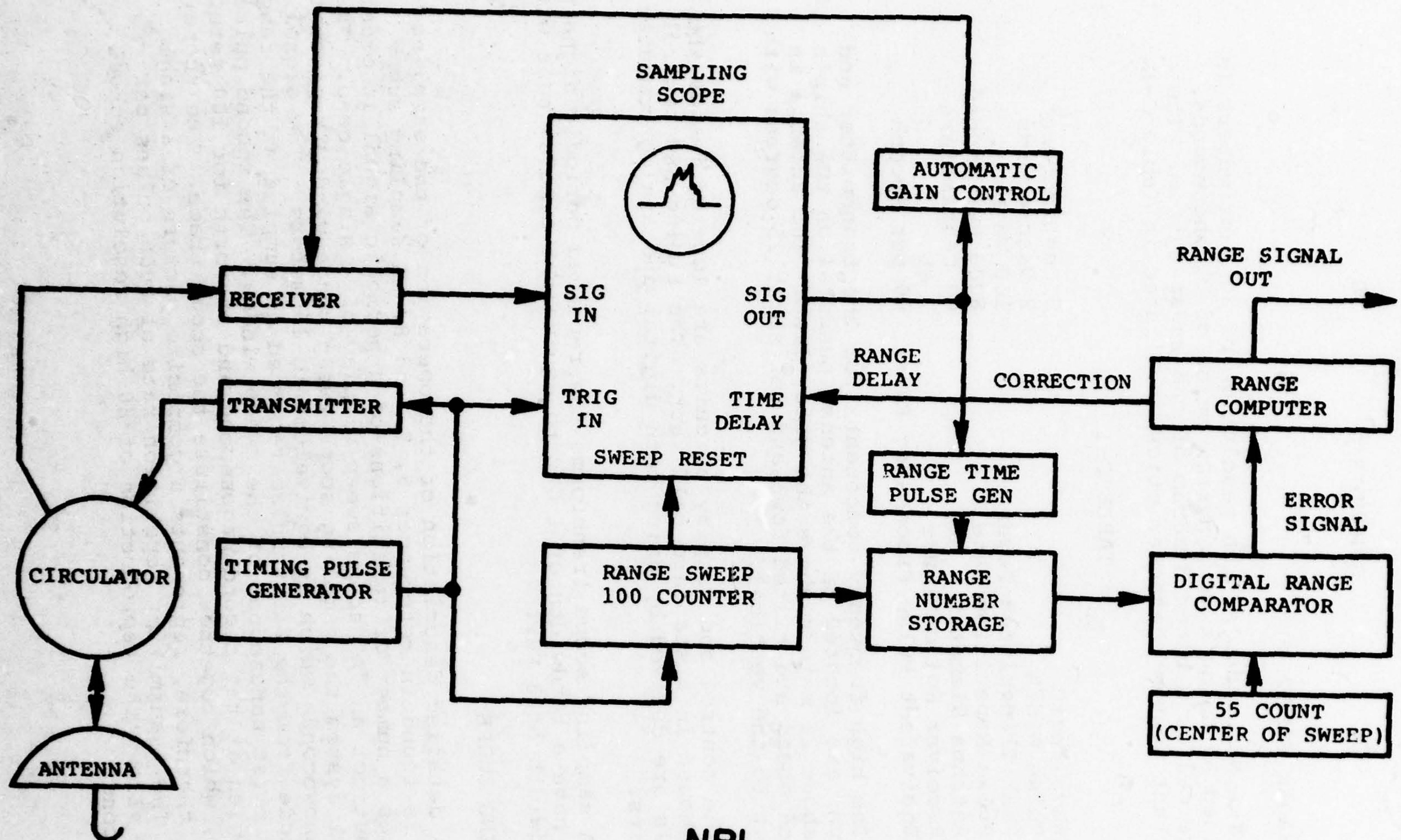
The high frequency components for the transmitter and receiver are located on the antenna pedestal on the ship's deck about 21 meters above the water line. The antenna is pointed ahead and tilted down and out about 25 degrees with respect to the vertical.

The control and display circuits are located inside the pilot house in a standard half rack. The timing and control signals are derived by using both digital and analog computer circuits.

A sampling scope transforms the received periodic signals which have a bandwidth of 1 GHz to equivalent time signals with a bandwidth of 8 KHz.

SAMPLING SCOPE

A detailed description of the operation of the sampling scope is found in references 6, 7, and 8. A sampling scope requires a number of repetitions of a periodic signal in order to construct an "A" scope sweep display of a single echo. In the NRL system the sampling scope sweep range window represents 100 nanoseconds which is equivalent to 15 meters. The signal amplitude from the first pulse returned is sampled at the range of the first nanosecond of the sweep window. The second pulse is sampled at the second nanosecond and so forth for 100 return pulses, which together constitute the scope trace. The scope sweep, therefore, represents a composite picture of a single echo. The transmitter repetition rate of 8000 pulses per second allows the reproduction of 80 high resolution echoes per second.



NRL
RADAR SYSTEM

FIGURE C-1

AUTOMATIC GAIN CONTROL

The block diagram for the automatic gain control is shown in Figure C-2. The amplitude of the return has rapid changes of about 100 Hz. The average amplitude also changes because of the changing aspect angle of the antenna beam and the water surface. This changes the amplitude of average return signal by about ten to one. The AGC circuit controls the RF gain of the receiver through a voltage controlled pin diode attenuator and can compensate for average amplitude changes of about 10 Hz, but the more rapid fading of the pulse is not corrected by the AGC.

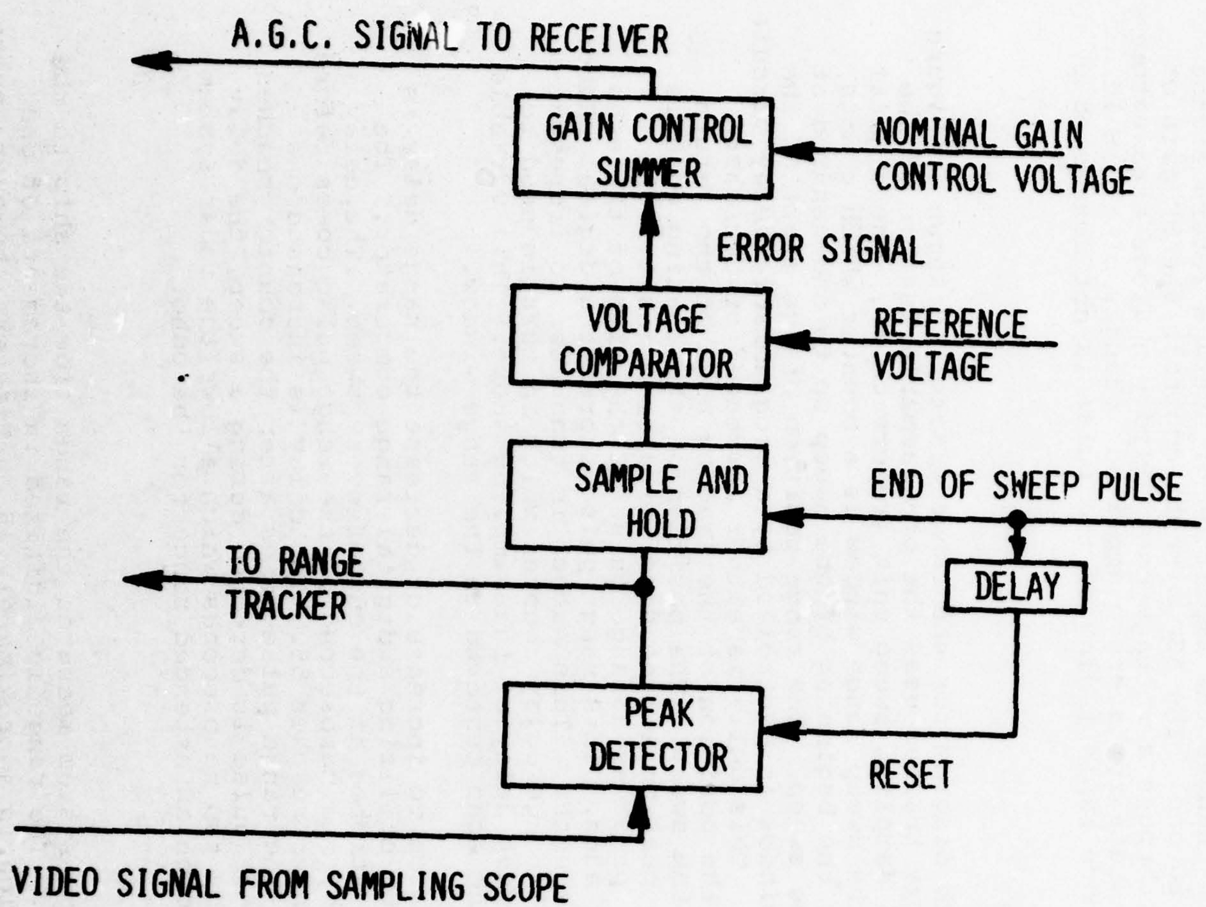
RANGE TRACKER

The block diagram for the range tracker is shown in Figure C-3. The range tracker uses the programmable feature of the Tektronix 3T5 sampling sweep unit (reference 8). The digital control for the sweep range window is a counter which counts from zero for the beginning of the sweep up to one-hundred at the end of the sweep. The range position of the start of the sweep range window is controlled by a programmable delay circuit in the scope. This delay is either increased or decreased depending on the position of the leading edge of the return pulse within the sweep. The position of the leading edge is detected by a peak amplitude discriminator circuit. The discriminator produces a range pulse at the time of the echo pulse leading edge. This range pulse stores the digital number in the range counter. This number is then used to increment a bi-directional range delay counter which in turn is used to program the sweep delay of the sampling scope. This variable delay keeps the echo centered in the range window.

The decision to increase or decrease the range delay is accomplished by utilizing a digital range comparator. The comparator is strobed at the end of every sweep. The delay is decreased by one nanosecond if the range pulse comes before the range counter reaches 55. The delay is increased one nanosecond if the range pulse comes after the counter reaches 55. If no range pulse is detected during a sweep, the delay is increased by two nanoseconds which allows the radar system to search through an extended range for the echo.

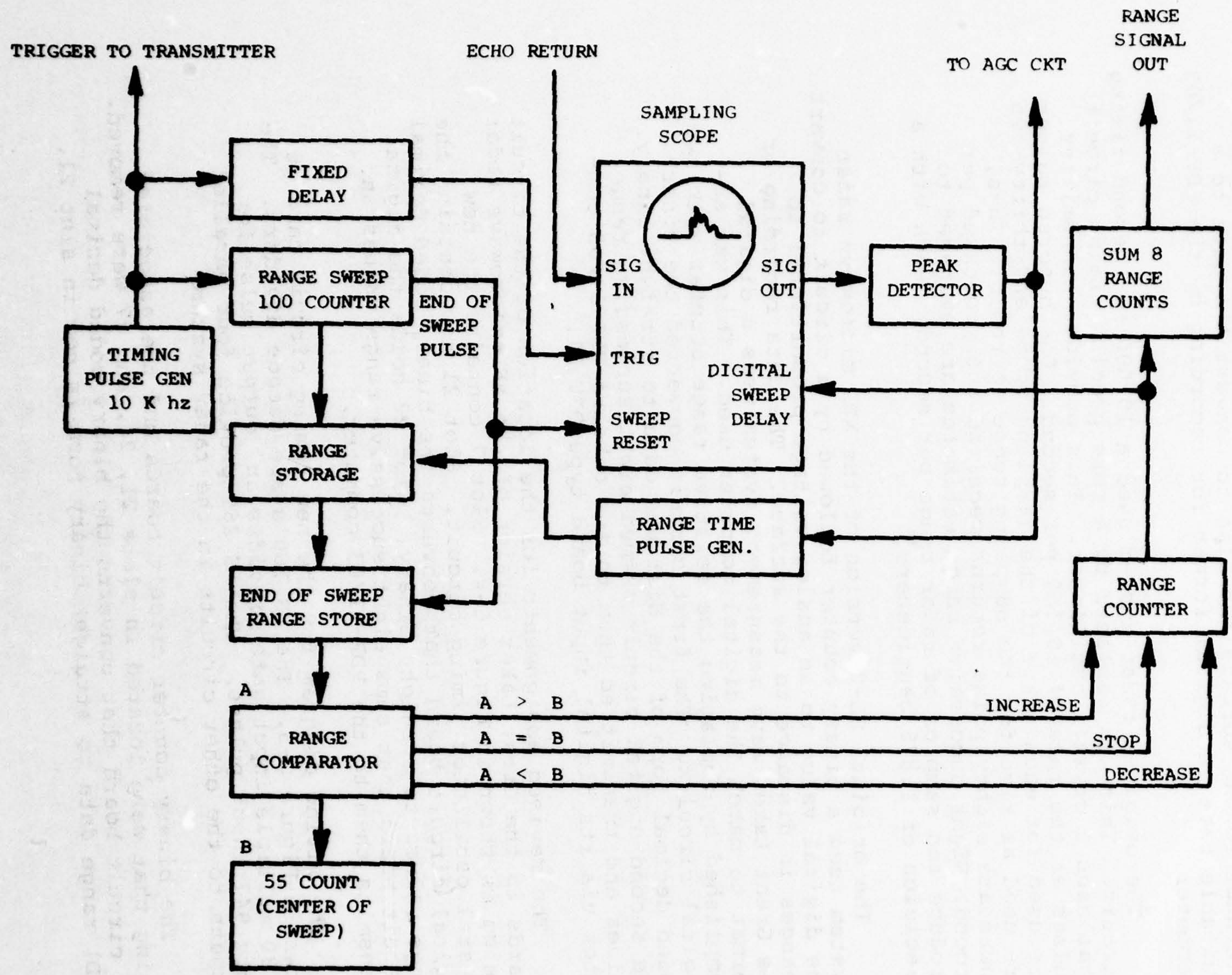
CONCLUSION

This radar system measures the range from the ship to the ocean surface. The range is digitized in increments of one nanosecond which is approximately 15 centimeters, however, pulse jitter and the uncertainty of locating the leading edge of the echo reduces the range accuracy to about 30 centimeters. Information about the ocean wave heights can be obtained by subtracting the independently measured range changes due to the ship's motion from the radar data.



AUTOMATIC GAIN CONTROL

FIGURE C-2



RANGE TRACKER

FIGURE C-3

NRL RADAR SYSTEM MODIFICATIONS

The NRL microwave radar, originally designed to measure ocean waves from a SL-7 class containership, was modified for operations aboard the 1000 foot Great Lakes ore vessel. The modifications provide for the measurement of the total distance to the surface and also to convert the data to a suitable rate in digital format for recording by the PDP-11/03 computer.

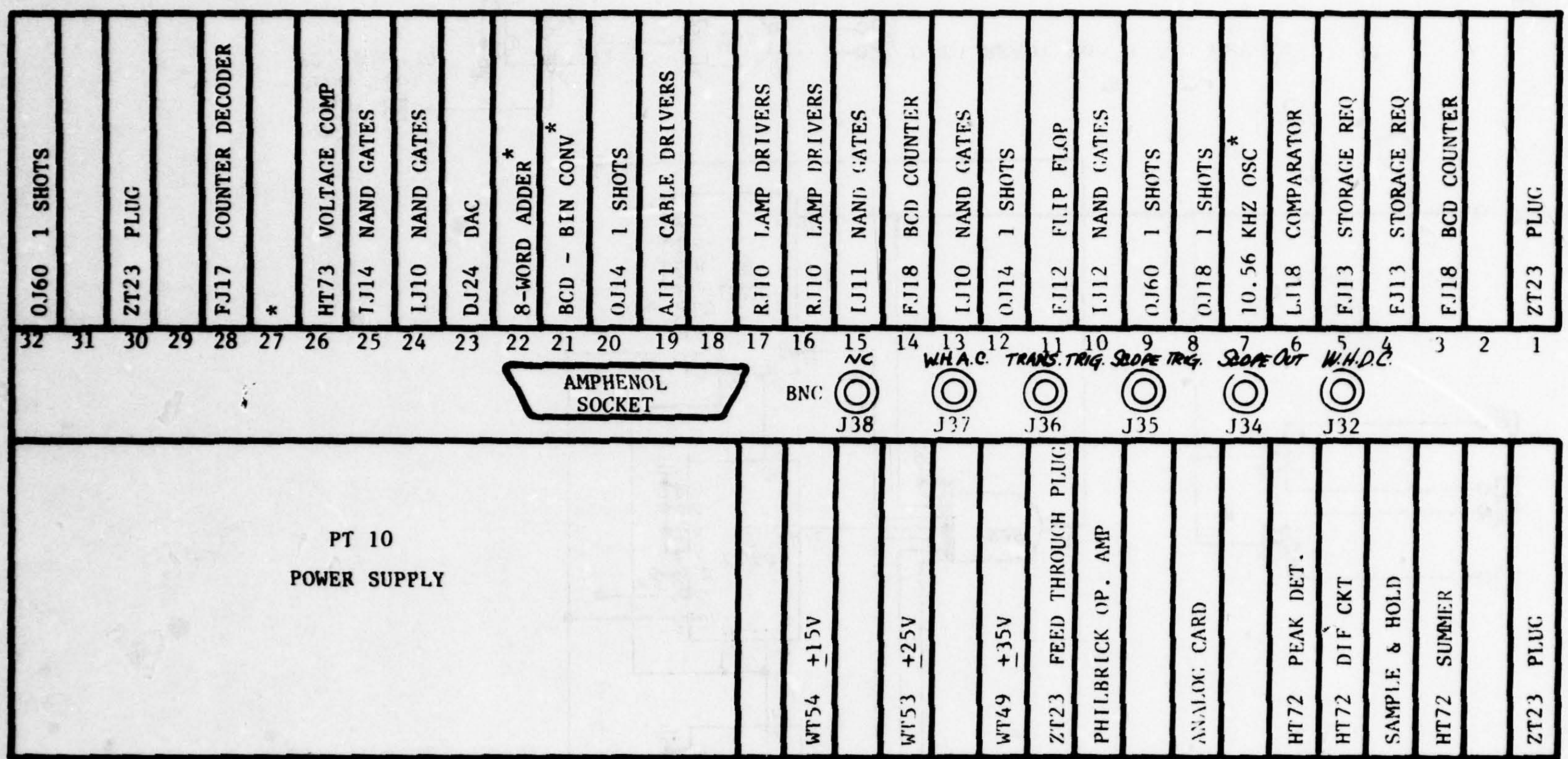
The original radar system used a 10,000 per second timing circuit. This was replaced by a more precise timing circuit that uses a crystal oscillator. This provides transmitter pulses at the rate of 10,560 per second. One hundred pulses are used for each trace of the sampling scope and thirty-two are used as time for the sampling scope to reset. Thus, there are eighty pulse returns received and processed per second. Eight successive range estimates are averaged to produce ten samples of radar range per second, each with a precision of 1.875 centimeters.

The original SL-7 version of the NRL microwave radar system used a binary counter followed by a circuit to convert the digital value to an analog voltage proportional to changes in distance to the surface. The data recording of the Great Lakes wave measurement system uses a digital format to match the digital computer used. This was accomplished by replacing the relative range counter with two digital circuits. The first circuit converted the binary coded decimal form of the distance data to straight binary. The second digital circuit summed eight successive range values and transmitted them to the onboard PDP-11/03 computer via its digital input board type DRV 11.

The revised assignments for the location of the circuit boards in the Great Lakes version of the NRL microwave radar system is shown in Figure C-4. Slot 7 contains the new crystal oscillator timing circuit. Slot 21 now contains the digital circuit board that converts the binary coded decimal range values to straight binary. Slot 22 holds the digital circuit board that sums eight successive range values and transmits them to the PDP-11/03 computer.

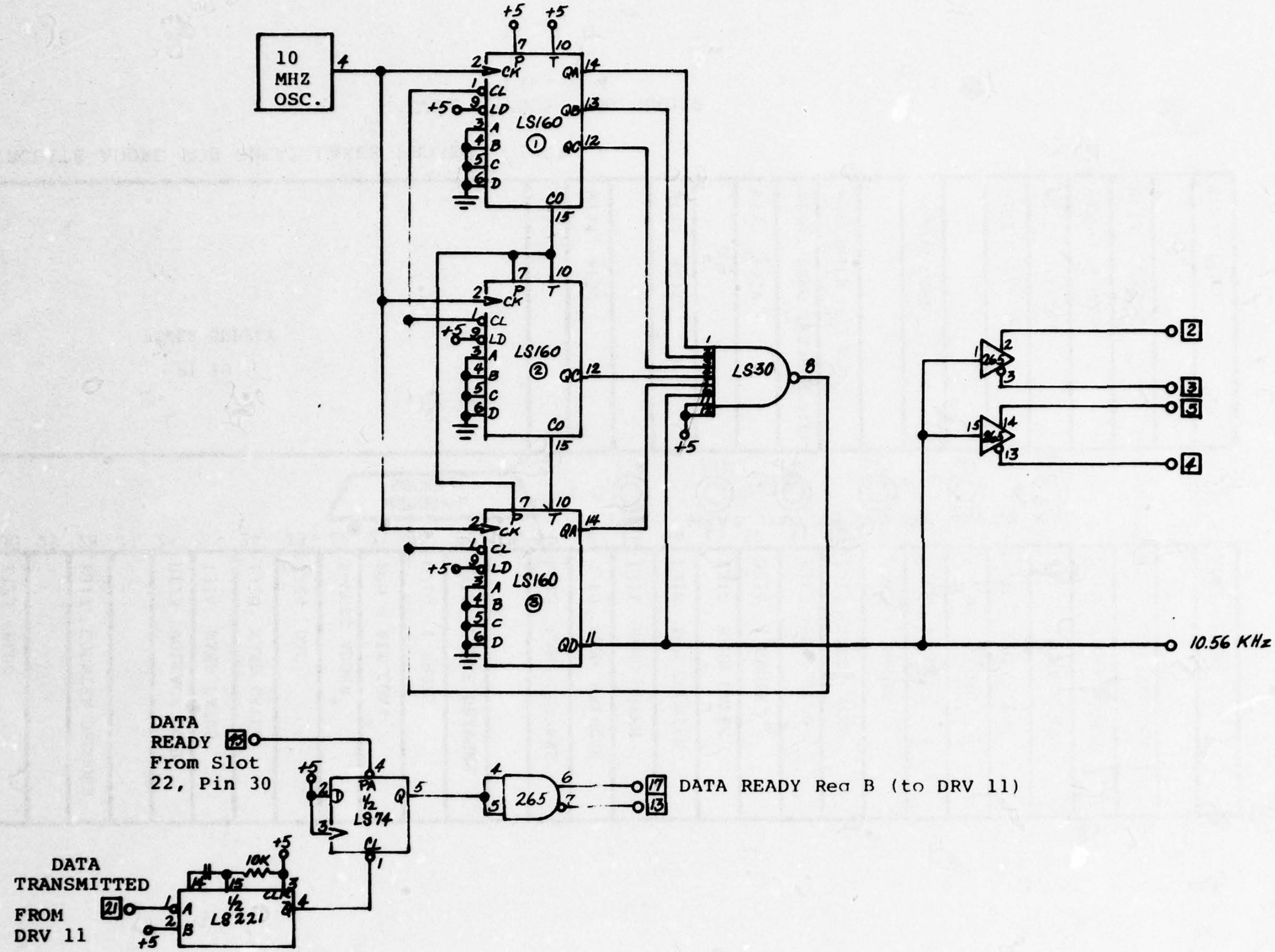
The wiring diagram for the new timing circuit card is shown in Figure C-5. The LS 160's are decade dividers. The LS 30 multiple input gate provides an output pulse for every 947 input pulses. The LS 265 provide four parallel outputs to the other circuits in the radar system.

The binary counter circuit boards and the associated wiring that were located in slots 21, 22, and 27 were removed. The circuit board that converts the binary coded decimal (BCD) range data to straight binary form is now in slot 21.



*NEW CIRCUITS ADDED FOR GREAT LAKES PROJECT, 1978

CARD LAYOUT, NRL RADAR
Fig. C-4



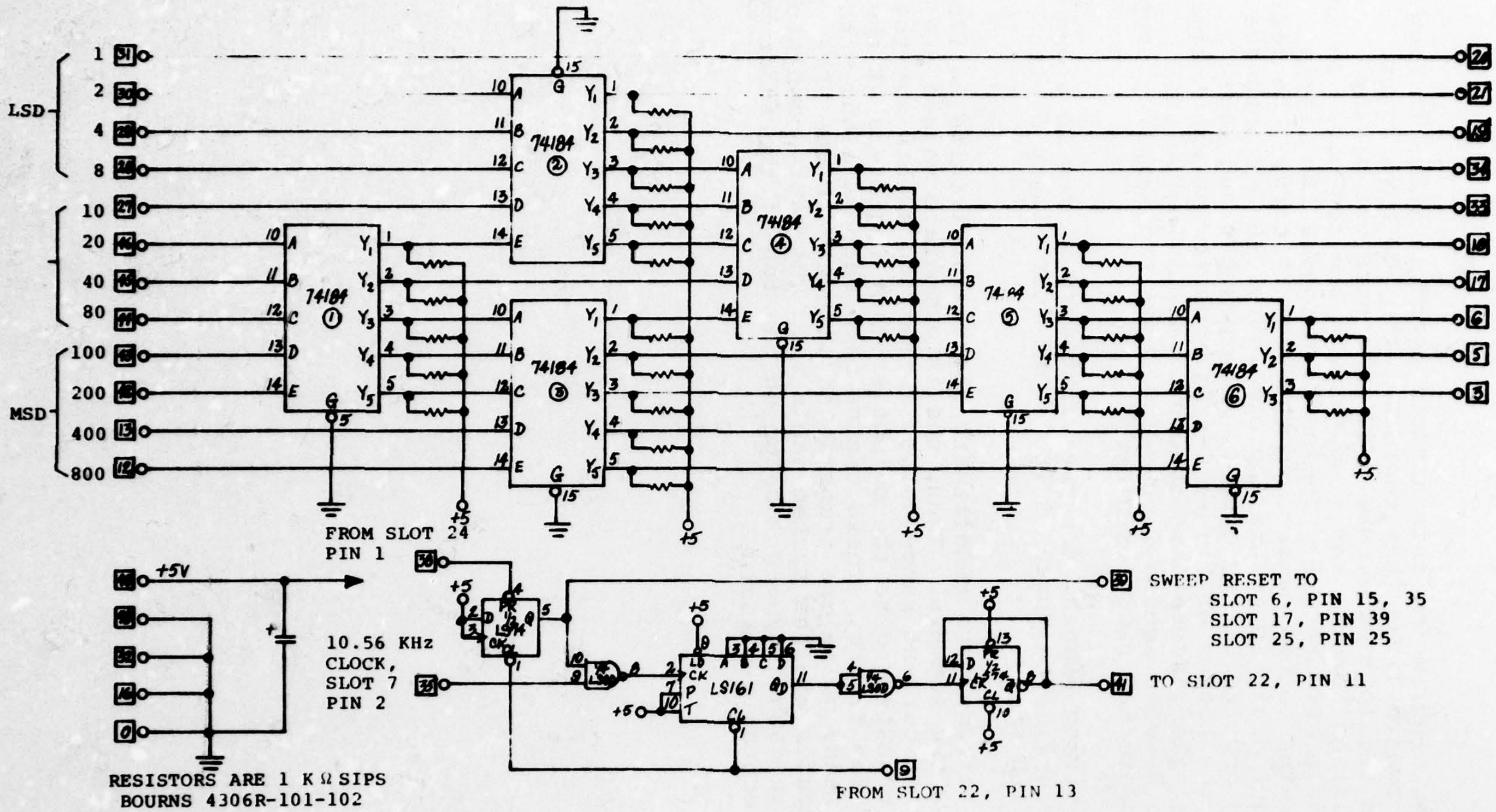
10.56 KHz OSCILLATOR

Fig. C-5

The wiring diagram for this circuit board is shown in Figure C-6. The twelve lines that represent the BCD numbers are inputs on the left of Figure C-6. The straight binary representation for the range appears as the ten wires on the right side of Figure C-6. The numbers inside the little squares refer to pin numbers on the circuit card. The least significant digit is at the top of Figure C-6 for both the BCD input and the binary output. The counter and logic gates at the bottom of Figure C-6 provide for an exact time between sampling scope data sweeps of 32 timing pulses. This time between sweeps is used to reset the sampling scope and to update the range counter.

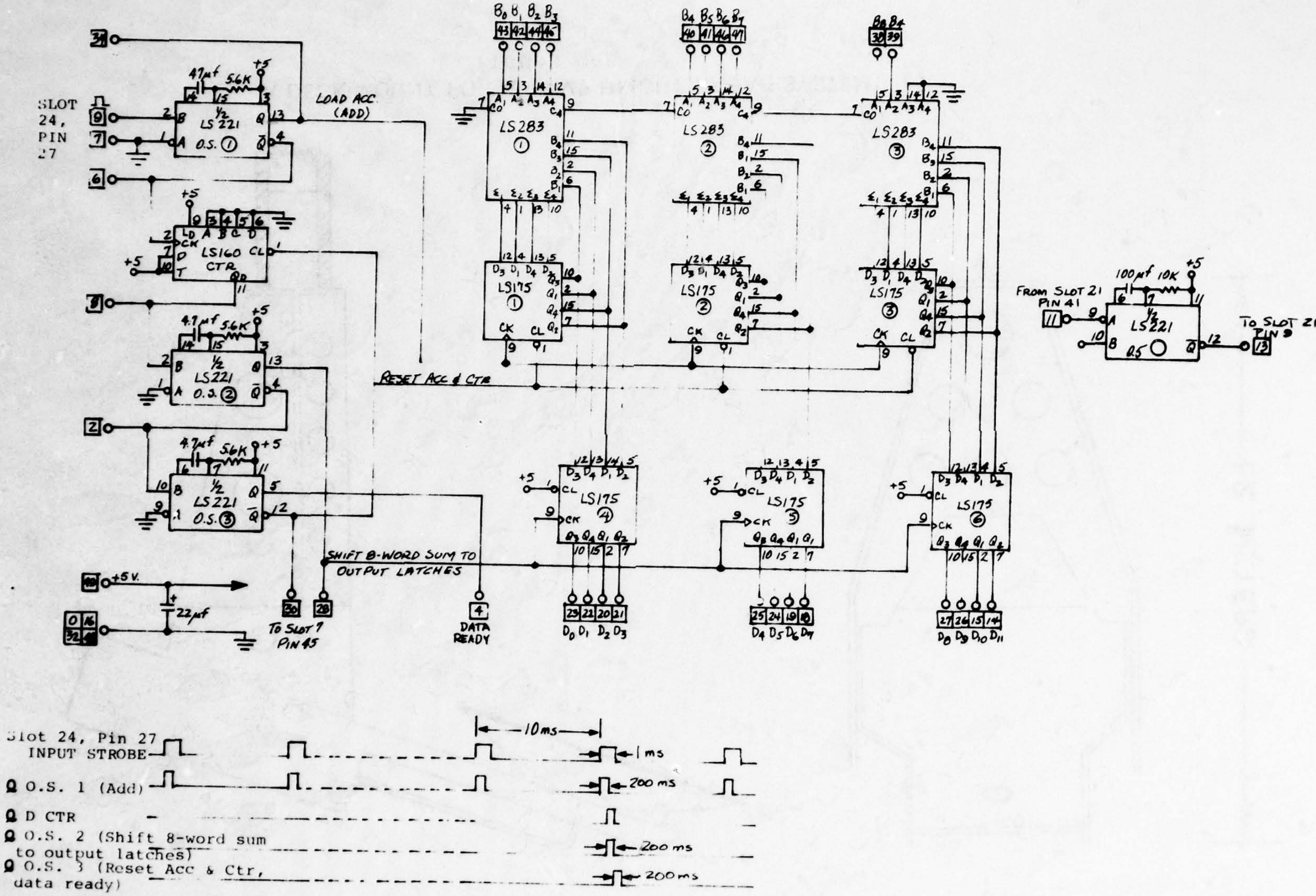
The wiring diagram for the eight-word summer is shown in Figure C-7. The three LS 283's are four binary digit summers with carry.

The intermediate results are stored in circuits LS 175 just below the summers. Thus, the intermediate values are added to the current range value. After the eighth sum the value is transferred to the output storage registers at the bottom of the figure. These twelve data outputs along with the data ready pulse are transmitted directly to the PDP-11/03 computer via the system cable VI. The cable connector is a 25 pin cannon type-D located on the top of the radar system electronic chassis.



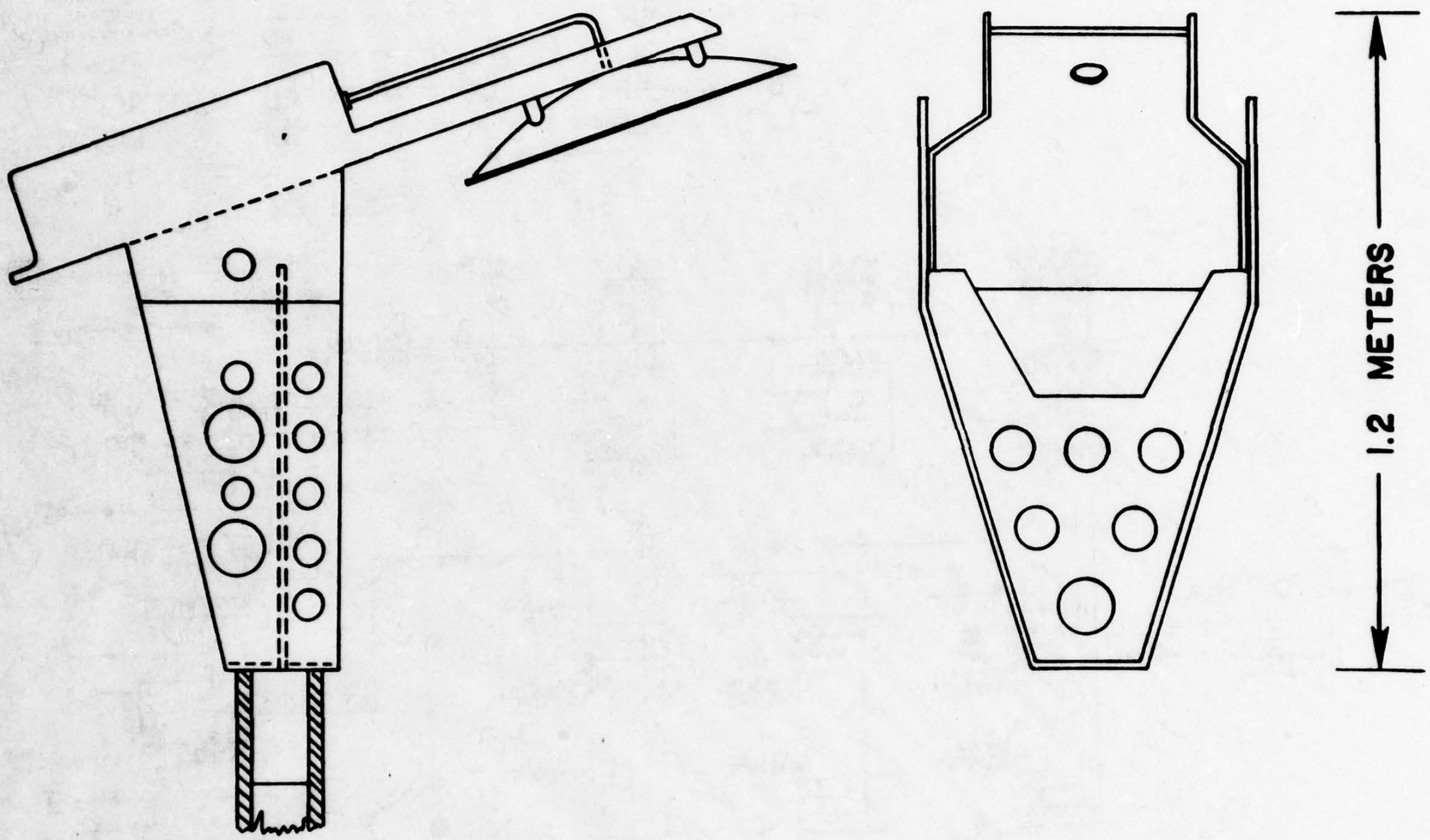
BCD TO BINARY CONVERTER

Fig. C-6



8 WORD ADDER

Fig. C-7



A DECK MOUNT FOR A WAVE HEIGHT RADAR SYSTEM
FIGURE C-8

APPENDIX D

WAVE MEASUREMENT SYSTEM INTERCONNECTIONS

The electrical cables that connect the principal components of the wave measurement system with the PDP-11/03 computer are shown in Figure D-1. The NRL microwave radar chassis, the signal distribution chassis, and the PDP-11/03 computer are located in the pilot house. The NRL microwave radar transceiver and a pair of accelerometers are mounted on top of the pilot house. The Collins radar horns and another pair of accelerometers are mounted on a 4.5 meter long boom over the bow at the main deck. The Collins radar and electronic circuits are contained in a weather proof chassis at the bow. Tables D-1 through D-7 identify cable signal allocations.

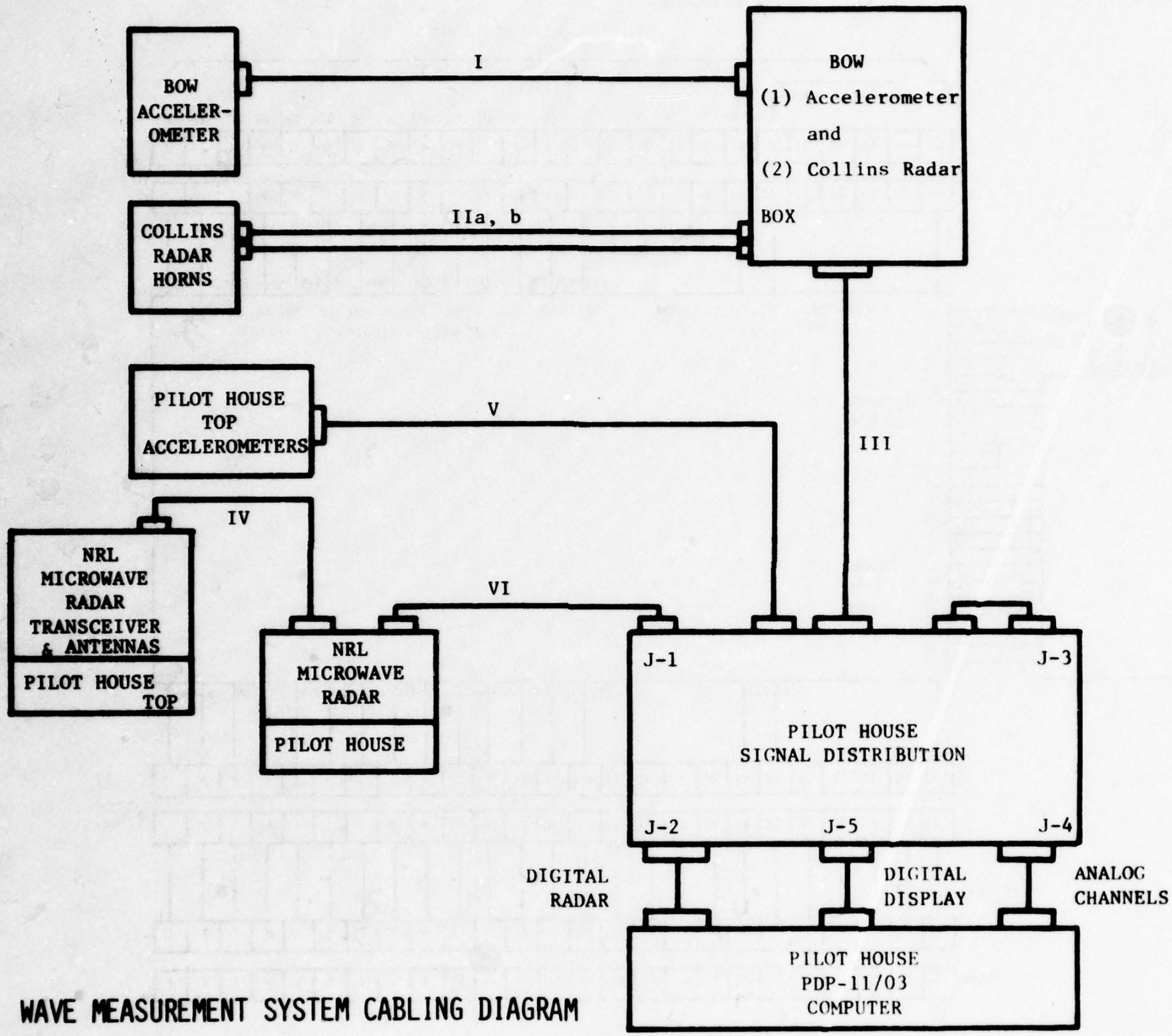
Figure D-2 is the wiring within the signal distribution chassis in the pilot house. The digital values of NRL radar range are on jack J-1. These are directed to jack J-2 and the computer when the test-operate switch is in the operate position. The analog voltage signals as defined in Table D-7 are directed to the computer via the multiple pole T-bar switch when the test-operate switch is in the operate position.

The test generator contains a digital counter that increases one count ten times a second. The digital form of the counter is recorded by the computer instead of the NRL radar signal when the test-operate switch is in the test position. The digital value is also converted to an analog voltage and directed to all the analog inputs of the computer when the test-operate switch is in the test position. Normally the test-operate switch is always in the operate position. If a test of the computer recording is needed, the switch is placed in the test position and the computer should record via the DRV-11 input a count that increased by one each sample until the full scale value is reached, at which time the count resets the zero and starts over again. The analog inputs on the ADV-11 should follow in a similar stair step fashion.

NOTE: PDP-11/03 Real-Time I/O OPTIONS

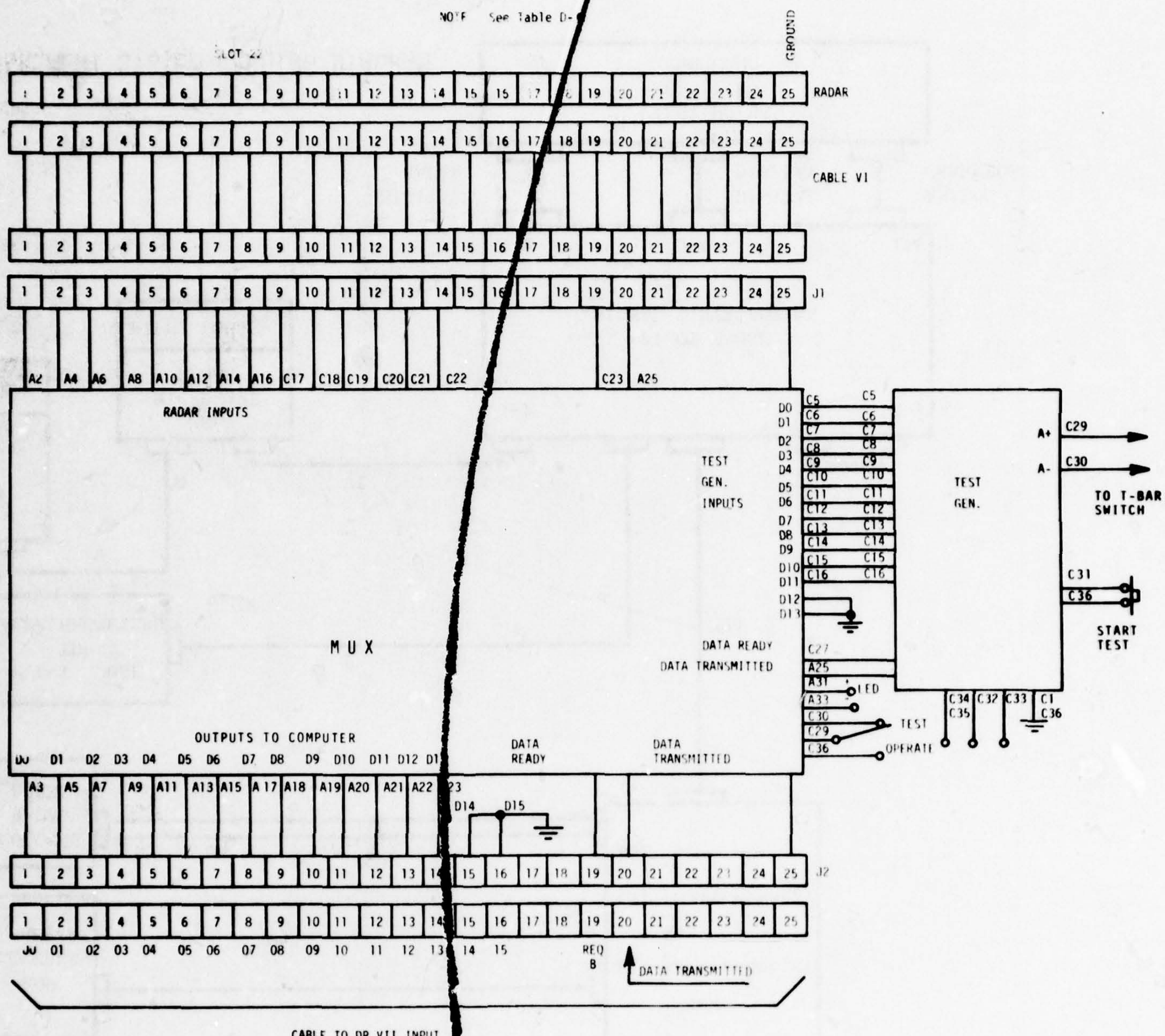
DRV-11 : Parallel line interface unit. 16-bit diode input; 16-bit latched drive output. Protocol & control signal. Board size 21.6 cm X 12.7 cm. Mounting Code: Single 11/o3 slot.

ADV-11 : 12-bit, 16 channel single ended or 8 channel quasi-differential analog - digital converter.

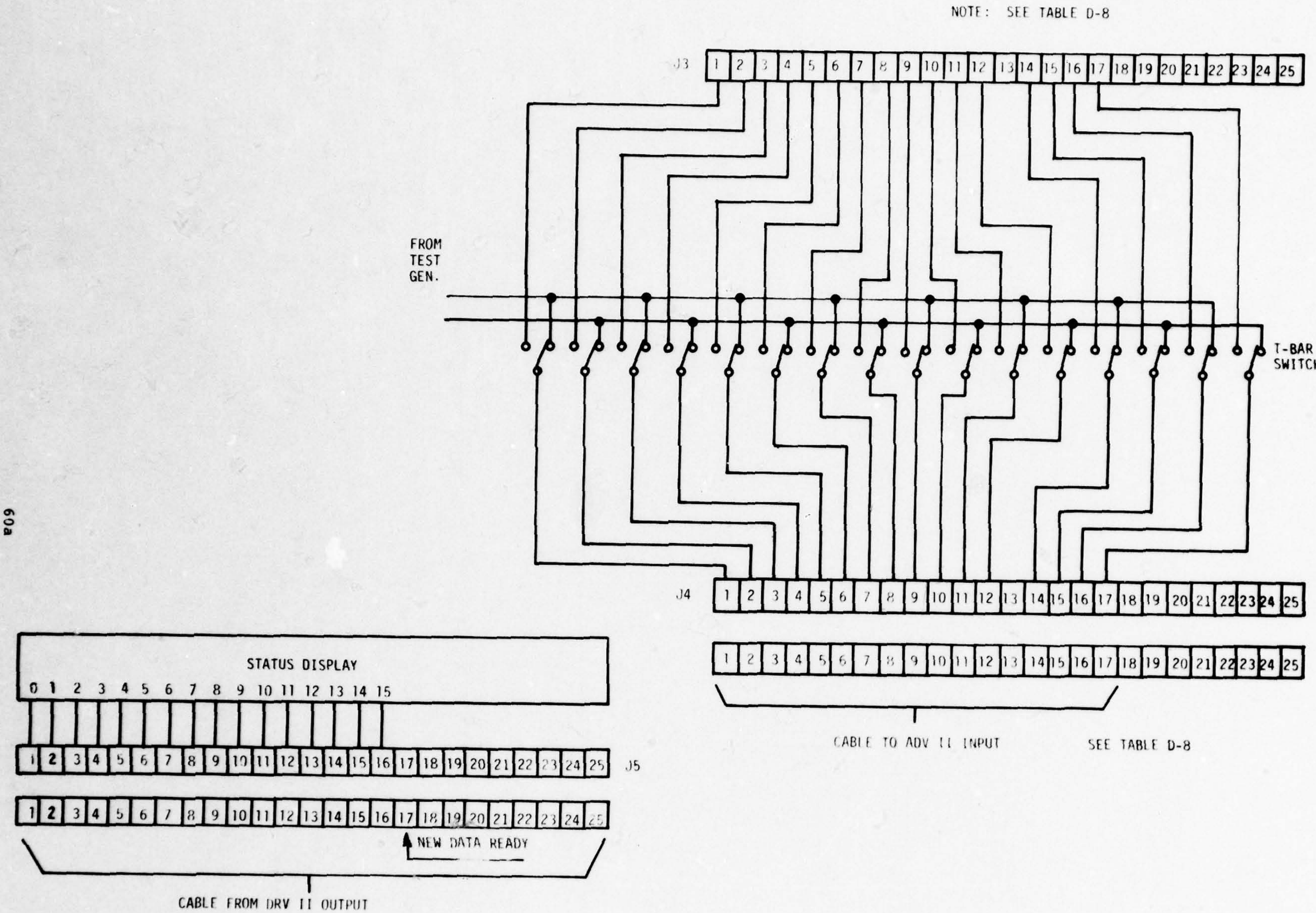


WAVE MEASUREMENT SYSTEM CABLING DIAGRAM

Fig. D-1



TEST PANEL WIRING
Fig. D-2



TEST PANEL WIRING

Fig. D-2

TABLE D-1

CABLE I

A	+6VDC
B	Ground
C	Bow vertical accelerometer - Low
D	Bow vertical accelerometer - High
E	Bow horizontal accelerometer - Low
F	Bow horizontal accelerometer - High

TABLE D-2

CABLE II a, b

These are two co-ax cables that connect the Collins radar to the transmitter antenna and to the receiver antenna.

TABLE D-3

CABLE III

A & R	115 vac
B & P	115 vac
F	Collins low return indicator
G	Chassis GND.
J	Collins radar range
K	Chassis GND.
U	Bow vertical accelerometer - High
V	Bow vertical accelerometer - Low
c	Bow horizontal accelerometer - High
b	Bow horizontal accelerometer - Low

TABLE D-4

Cable IV

PIN	SIGNAL
1	Spare Ground
2	Shield Ground
3	Transmitter Power, +700 VDC
4	Shield Ground
5	Therostat
6	Transmitter Power, +280 VDC
7	+12 VDC
8	Transmitter Power, -5 VDC
9	Receiver Gain Control Return, Ground
10	Starboard, SPARE
11	Port, SPARE
12	Low Voltage Power Ground
13	+12 VDC Sense
14	Phone Ground, SPARE
15	Transmitter Power Ground
16	Receiver Gain Control
17	Phone, SPARE
18	110 VAC Common
19	-12 VDC Sense
20	-12 VDC
21	110 VAC Hot
22 (Co-Ax)	Transmitter Trigger Pulse
23 (Co-Ax)	Delayed Scope Trigger
24 (Co-Ax)	Video Signal Return

TABLE D-5

CABLE V

PIN	SIGNAL
A	Chassis Ground
B	Horizontal Accelerometer
D	Vertical Accelerometer
R	Chassis Ground
F	110 VAC
G	110 VAC

TABLE D-6

CABLE VI
25 PIN
CANNON TYPE 'D'

PIN	SIGNAL
1	B_0
2	B_1
3	B_2
4	B_3
5	B_4
6	B_5
7	B_6
8	B_7
9	B_8
10	B_9
11	B_{10}
12	B_{11}
13	"Three Missing Range Pulses"
14	"50 Missing Range Pulses"
15	SPARE
16	SPARE
17	SPARE
18	SPARE
19	DATA READY
20	DATA TRANSMITTED
21	SPARE
22	SPARE
23	SPARE
24	SPARE
25	GROUND

TABLE D-7

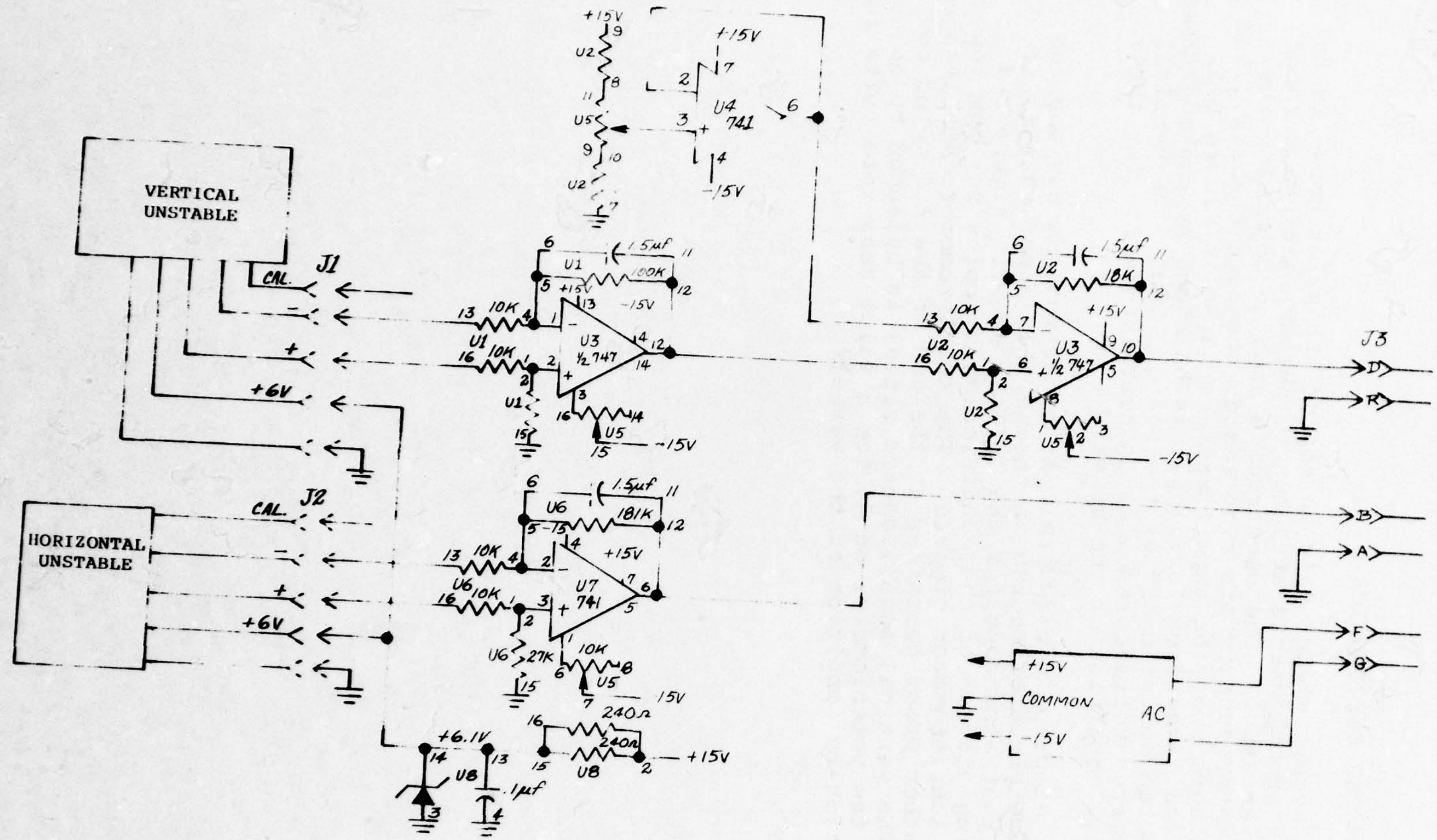
J-3 and J-4

PIN	SIGNAL
1	Bow vertical accelerometer - High
2	Bow vertical accelerometer - Low
3	Bow vertical accelerometer - High
4	Bow horizontal accelerometer - Low
5	SPARE
6	SPARE
7	Pilot House Top vertical accelerometer - High
8	Pilot House Top vertical accelerometer - Low
9	Pilot House Top horizontal accelerometer - High
10	Pilot House Top horizontal accelerometer - Low
11	Collins Radar Range Signal - High
12	Collins Radar Range Signal - Low
13	Not Used
14	Collins Radar Signal Strength - High
15	Collins Radar Signal Strength - Low
16	SPARE
17	SPARE

ACCELEROMETER ELECTRONICS

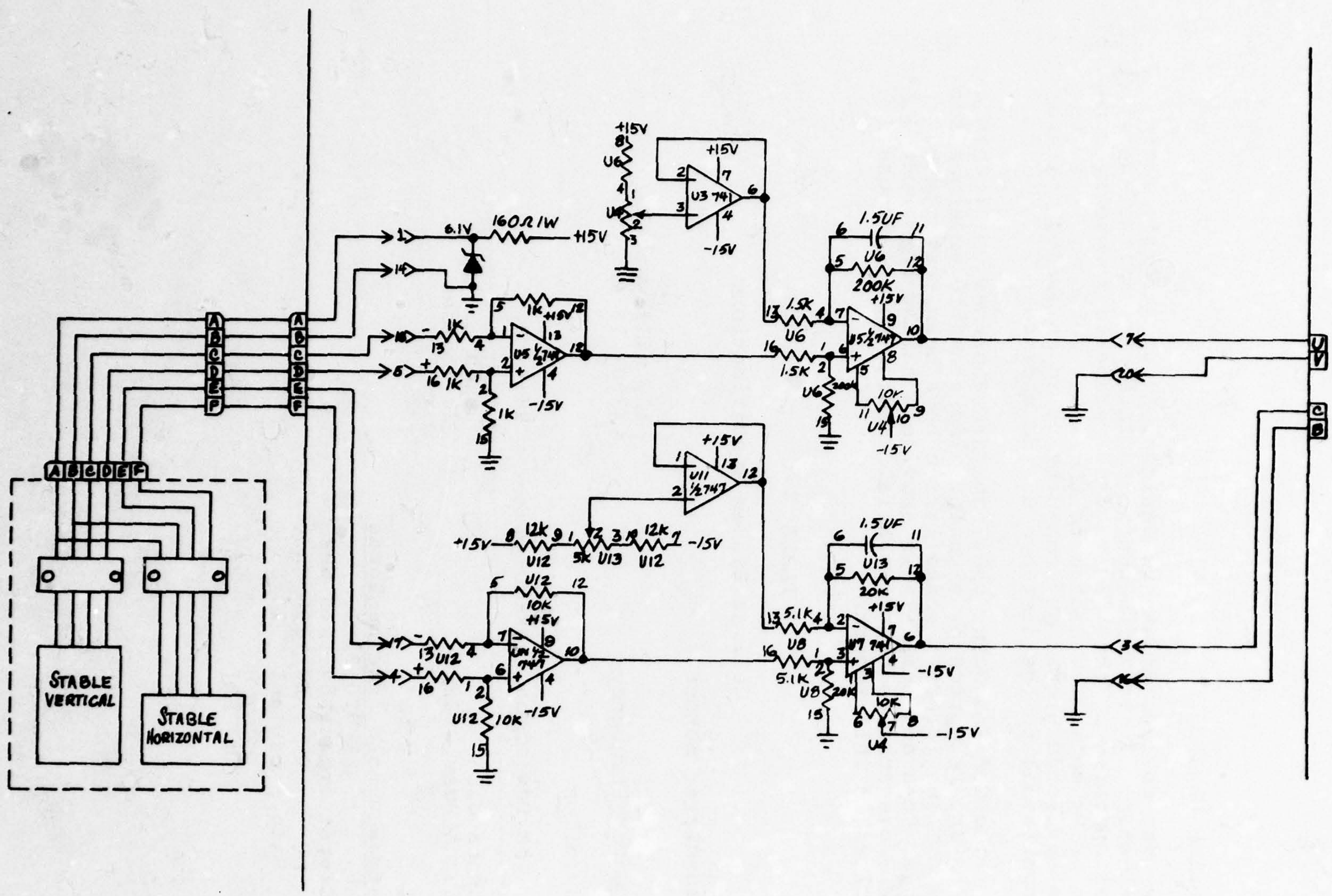
The accelerometer pair on top of the pilot house is in a weather proof chassis attached to the NRL microwave radar transceiver stand. The electronics used to condition the accelerometer outputs are also inside the same chassis. The wiring diagram for the amplifiers are shown in Figure D-3. The vertical accelerometer signal is balanced by the adjustment of the poteniometer on U5 of the board. Thus, the vertical accelerometer voltage recorded is near zero volts for the stationary condition of the vessel.

The electronic circuits that condition the bow mounted accelerometers are located in the weather proof chassis at the bow that also contains the Collins Radar. Figure D-4 is the wiring diagram of the conditioning circuits for the bow mounted accelerometer signals. The accelerometers are located in a weather proof container at the end of the 4.5 meter bow boom. The vertical accelerometer signal is balanced by adjustment of the poteniometer on 44 for a value near zero volts for the stationary condition of the vessel.



PILOT HOUSE TOP ACCELEROMETER SIGNAL CONDITIONING WIRING

Fig. D-3



BOW BOOM ACCELEROMETER SIGNAL CONDITIONING WIRING

Fig. D-4

APPENDIX E

COLLINS RADAR

The Collins Radar was designed as an aircraft radio altimeter. It is a frequency modulated transmitted-receiver that operates in the 4250 to 4350 megahertz frequency range. The radar beams the signal to the water surface, receives the reflected signal and converts it to an analog voltage proportional to the distance to the surface.

The Collins Radar uses separate antennas for transmissions and reception of signals. The standard antennas for the Collins aircraft installation have been replaced by larger horn antennas. These provide a narrow beam width and therefore achieve better spatial resolution as discussed earlier in this report.

TABLE E-1

Collins System Specifications

Transmitter output	
Power	150 milliwatts
Center Frequency	4300 ± 15 MHz
Modulation	
FM Deviation Peak-to-peak	98.4 MHz
Antenna Gain	20 db
Antenna Beam Width	20 degrees

<u>Systron Donner Antenna Horns</u>

Model # DBK-520-20-1	
Center frequency	4.3 GHz
BW	100 MHz
Gain - nominal	20 db

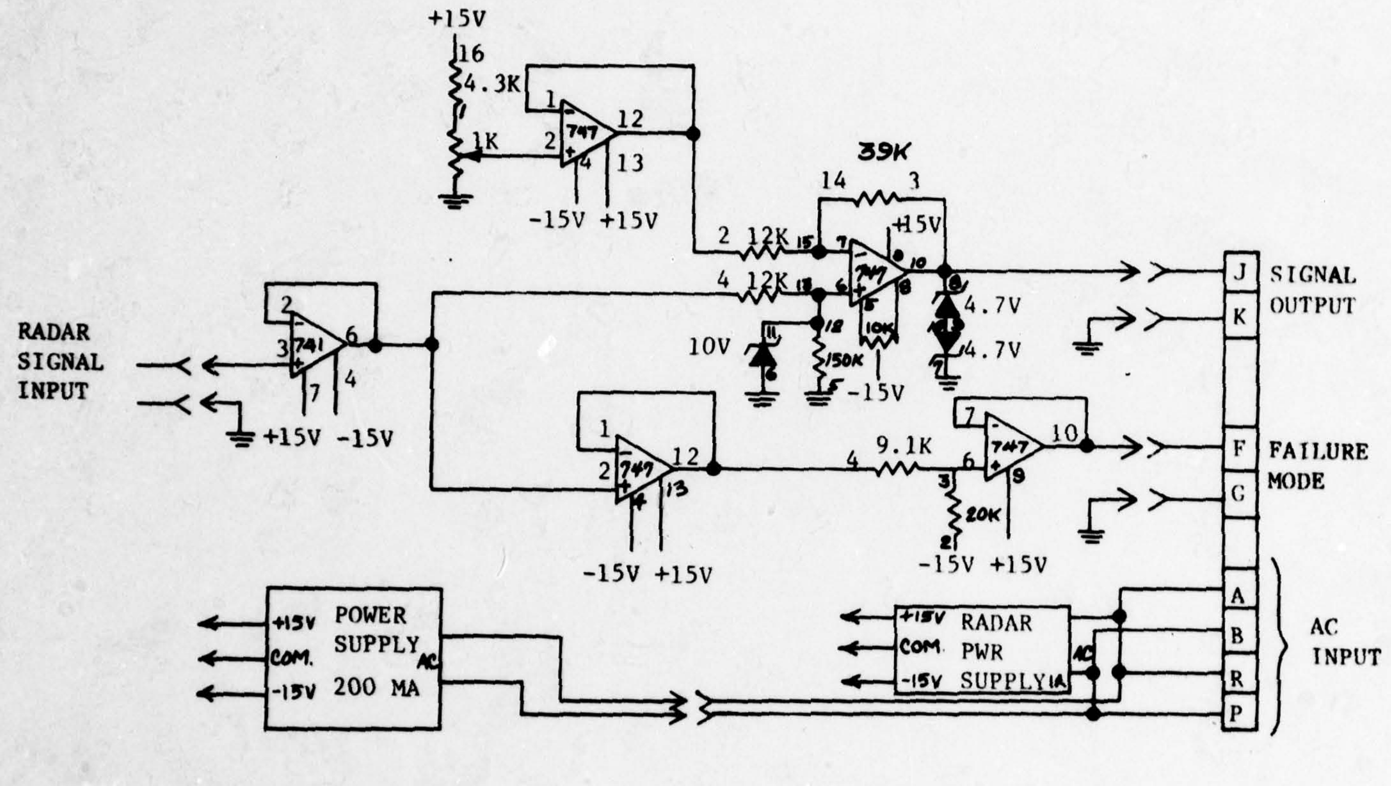
COLLINS RADIO CO.
Radar Altimeter (860F-2)
ALT-50

TABLE E-2

CHARACTERISTIC	SPECIFICATION
Transmitter Output	
Power	150 milliwatts
Center Frequency	4300 ± 15 MHz
Modulation	
Selectable Frequency	100 or 105 Hz
FM deviation Peak to Peak	
100 Hz modulation	98.4 MHz
105 Hz modulation	93.7 MHz
Type of Service	Continuous
Altitude Output	
Analog characteristics	
-20 to 500 feet	20 millivolts per foot (30 cm)
Analog Accuracy	+2 feet (60 cm) or ±2% whichever is greater
Analog Time Constant	0.09 ± 0.01 second
Environmental Specifications	
Operating temperature range	
860F-2 Radio Altimeter	-54 to 71^{o}C
Relative Humidity	95%
Cooling	Convection
Vibration	Conforms to DO-138 Category JN
Shock	
operational	6g
crash safety	15g
Primary Power Requirements	+22 to +34 V dc, 17 watts
Case Dimensions.....Height 3.5 in.(8.9 cm),	width 3.585 in.(9.1 cm) length 13.905 in. (35.3 cm)
Unit Weight	5.2 pounds (2.34 kg)

COLLINS RADAR WIRING

The wiring for the Collins Radar power and signal conditioning circuits are shown in Figure E-1. The offset potentiometer at the top of the figure is adjusted to produce an output to the computer near zero volts for the antenna horns mounted at the end of the bow shown viewing the surface while in port.

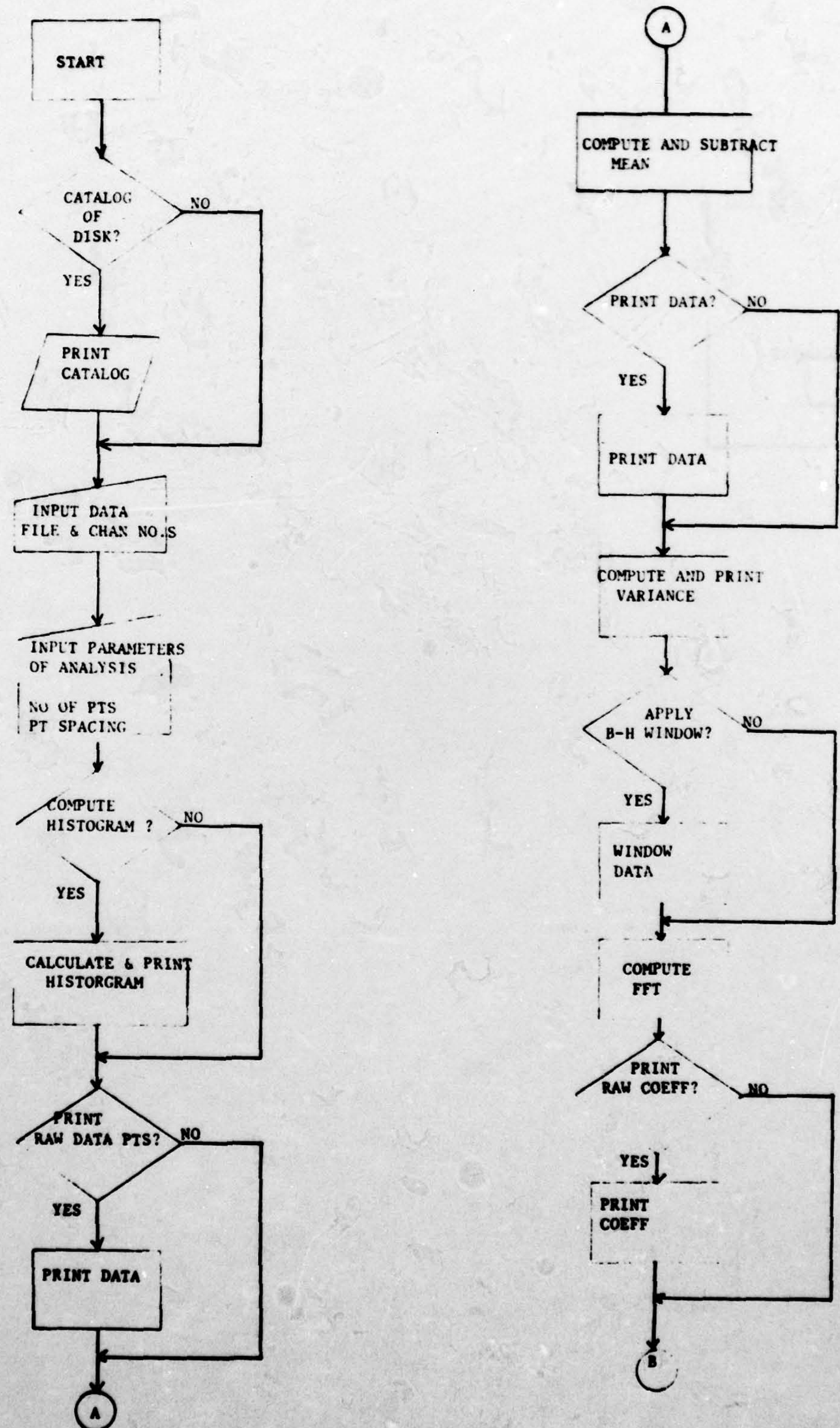


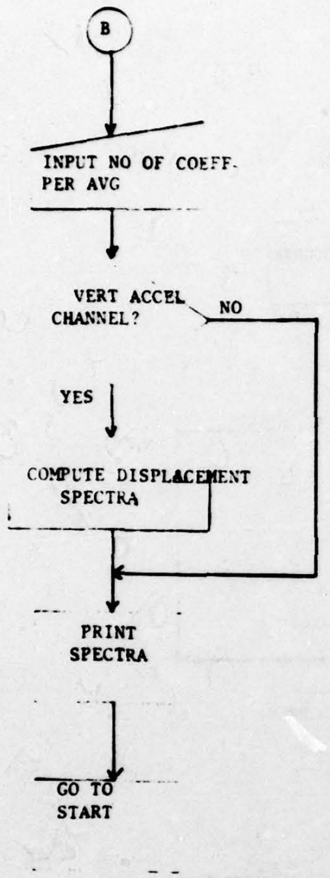
COLLINS RADAR SIGNAL CONDITIONING WIRING

Fig. E-1

APPENDIX F

FLOW DIAGRAM for M/V CORT Data Analysis Program




B
INPUT NO OF COEFF.
PER AVG
VERT ACCEL
CHANNEL?
NO
YES
COMPUTE DISPLACEMENT
SPECTRA
PRINT
SPECTRA
GO TO
START

```
C
C
C
C       CORT DATA ANALYSIS PROGRAM FOR THE 78-79 MEASUREMENT SEASON
C            WRITTEN BY DAVID A. WALDEN
C                OFFICE OF RESEARCH AND DEVELOPMENT
C                U. S. COAST GUARD
C
C
C       NOTE: ALL CALCULATIONS AND RESULTS ARE IN COMPUTER COUNTS
C             (I.E. THERE IS NO CONVERSION TO ENGINEERING UNITS)
C
C
        DIMENSION INDIG(256),INALG(8,256),X(2049),Y(2049)
        DIMENSION INPUT(2304),UL(22),NLIM(22,9)
        DIMENSION IDATE(9),ITIME(8),ILAT(2),ILONG(2),LKUP(10)
        EQUIVALENCE (HEADER,IDATE),(HEADER(5),ITIME),(INAME,INAM)
        EQUIVALENCE (HEADER(10),IDURAT),(HEADER(11),ILAT)
        EQUIVALENCE (HEADER(13),ILONG),(HEADER(15),SPEED)
        EQUIVALENCE (HEADER(17),IHEAD),(HEADER(18),IDRAFT)
        EQUIVALENCE (HEADER(19),IWNDIR),(HEADER(20),IWNDSP)
        EQUIVALENCE (HEADER(21),IWAVDR),(HEADER(22),IWAVHT)
        EQUIVALENCE (INPUT,INDIG),(INPUT(257),INALG)
        LOGICAL*1 NAMA(9)
        COMMON/BLK1/INPUT
        BYTE IDATE,ITIME
        INTEGER*2 HEADER(256),INAME(40),NAME(4),BLOCK
        DATA INAME/3RDX1,3RRDD,3RA0 ,3RDAT,3RDX1,3RRDD,3RA1 ,3RDAT,3RDX1,
       13RRDD,3RA2 ,3RDAT,3RDX1,3RRDD,3RA3 ,3RDAT,3RDX1,3RRDD,3RA4 ,3RDAT,
       23RDX1,3RRDD,3RA5 ,3RDAT,3RDX1,3RRDD,3RA6 ,3RDAT,3RDX1,3RRDD,
       33RA7 ,3RDAT,3RDX1,3RRDD,3RA8 ,3RDAT,3RDX1,3RRDD,3RA9 ,3RDAT/
900     FORMAT (' ',I6,5X,8I6)
901     FORMAT (/)
910     FORMAT (' ',10X,'GREAT LAKES WAVE HEIGHT PROJECT'//)
911     FORMAT ('+',10X,'DATE',3X,9A1,9X,'TIME',3X,8A1,/)
912     FORMAT (' ',10X,'DURATION OF RUN IN MINUTES IS',3X,$)
913     FORMAT (' ',I2)
914     FORMAT (' ',10X,'NORTH LATITUDE (DD MM)',9X,$)
915     FORMAT (' ',I2,1X,I2)
916     FORMAT (' ',10X,'WEST LONGITUDE (DD MM)',9X,$)
917     FORMAT (' ',F4.1)
918     FORMAT (' ',10X,27HVESSEL'S SPEED (MPH - XX.X),3X,$)
919     FORMAT (' ',10X,26HVESSEL'S HEADING (DEGREES),5X,$)
920     FORMAT (' ',I3)
921     FORMAT (' ',10X,21HVESSEL'S DRAFT (FEET),11X,$)
922     FORMAT (' ',10X,'WIND DIRECTION (DEGREES)',7X,$)
923     FORMAT (' ',10X,'WIND SPEED (KNOTS)',14X,$)
924     FORMAT (' ',10X,'WAVE DIRECTION (DEGREES)',7X,$)
925     FORMAT (' ',10X,'WAVE HEIGHT (FEET)',14X,$)
926     FORMAT ('       REMARK LINE -  UP TO 50 CHARACTERS')
927     FORMAT (' ',32A2)
        CALL LOCK
        IFET = IFETCH(INAME)
        IF(IFET.NE.0)  STOP 'FATAL ERROR FETCHING HANDLER'
        ICHAN=IGETC()
        PI=3.14159265
        TYPE 931
931     FORMAT(' WANT CATALOG OF DISK? TYPE 0 FOR NO, 1 FOR YES',5X,$)
        ACCEPT 932,ISW
```

```
932     FORMAT(I3)
        IF(ISW.EQ.0)GO TO 501
C
C       *********** PRINT OUT LISTING OF ALL HEADER RECORDS ON DISK
C
        CALL CLOSEC(ICHAN)
        DO 1 II=1,10
        ICHAN=IGETC()
        DO 21 J=1,4
        JJ=(II-1)*4+J
21      NAME(J)=INAME(JJ)
        CALL R50ASC(9,NAME,NAMA)
        TYPE 909,NAMA
909     FORMAT(' '/////80('*')//' FILE NAME=',9A1)
        LKUP(II)=LOOKUP(ICHAN,NAME)
        TYPE 948,LKUP(II)
948     FORMAT(' NO OF BLOCKS=',I6)
        IF(LKUP(II).LT.0)GO TO 501
        TYPE 910
        ICODE=IREADW(256,HEADER,1,ICHAN)
        TYPE 911, IDATE,ITIME
        TYPE 912
        TYPE 913, IDURAT
        TYPE 914
        TYPE 915, ILAT
        TYPE 916
        TYPE 915, ILONG
        TYPE 918
        TYPE 917, SPEED
        TYPE 919
        TYPE 920, IHEAD
        TYPE 921
        TYPE 913, IDRAFT
        TYPE 922
        TYPE 920, IWNDIR
        TYPE 923
        TYPE 913, IWNDSP
        TYPE 924
        TYPE 920, IWAVDR
        TYPE 925
        TYPE 913, IWAVHT
        TYPE 926
        TYPE 927,    (HEADER(I),I=33,64)
        TYPE 926
        TYPE 927,    (HEADER(I),I=65,96)
        IJ=LKUP(II)-1
        ICODE=IREADW(256,HEADER,IJ,ICHAN)
        TYPE 926
        TYPE 927,(HEADER(I),I=1,32)
        CALL CLOSEC(ICHAN)
1       CONTINUE
C
C       *********** SELECT PARAMETERS FOR ANALYSIS
C
501     CONTINUE
2       CALL CLOSEC(ICHAN)
        TYPE 933
933     FORMAT(' TYPE 1 FOR PROCEED, 0 FOR DONE',3X,$)
        ACCEPT 932,ISW
        IF(ISW.EQ.0)GO TO 999
```

```
        TYPE 934
934     FORMAT(' SELECT DATA FILE, TYPE 0-9',3X,$)
        ACCEPT 932,ISW
        DO 30 I=1,4
        II=ISW*4+I
30      NAME(I)=INAME(II)
        ICHAN=IGETC()
        IL=LOOKUP(ICHAN,NAME)
        ICODE=IREADW(256,HEADER,1,ICHAN)
        TYPE 911,IDATE,ITIME
        TYPE 9341
9341    FORMAT(' CHOSE NO OF POINTS,TYPE 8-12',/,
        1       T10,'8  =   256',/,
        2       T10,'9  =   512',/,
        3       T10,'10 =  1024',/,
        4       T10,'11 =  2048',/,
        5       T10,'12 =  4096',3X,$)
        ACCEPT 932,IN
        IJ=2**(IN-1)+1
        DO 43 I=1,IJ
        X(I)=0.
43      Y(I)=0.
        K=0
        TYPE 950
950     FORMAT(' TYPE 1 FOR EVERY POINT (DT=.1 SEC),2 FOR
        1 EVERY OTHER POINT (DT=.2 SEC)',3X,$)
        ACCEPT 932,IDT
        IS=IDT*2
        IRECDS=0
        NRECDS=2**IN/256*IDT
        IF(NRECDS*9.GT.IL)GO TO 997
        TYPE 954
954     FORMAT(' TYPE 1 FOR HISTOGRAM, 0 FOR NO',/,
        1' (ONLY AVAIL IF CHAN 0 SELECTED)',3X,$)
        ACCEPT 932,IHSW
        TYPE 935
935     FORMAT(' SELECT CHANNEL NO, TYPE 0-8',/,T10,'0 = SL-7 RADAR',/,
        1       T10,'1 = ROLL',/,
        2       T10,'2 = V STAB',/,
        3       T10,'3 = H STAB',/,
        4       T10,'4 = V UNSTAB',/,
        5       T10,'5 = H UNSTAB',/,
        6       T10,'6 = COLLINS ALT',/,
        7       T10,'7 = COLLINS ERROR SIG',/,
        8       T10,'8 = SPARE',3X,$)
        ACCEPT 932,ICSW
        BLOCK=2
        IF(ICSW.GT.0)GO TO 31
        IE=0
        DO 48 I=1,22
        UL(I)=I*200.
        DO 48 J=1,9
48      NLIM(I,J)=0
32      ICODE=IREADW(2304,INPUT,BLOCK,ICHAN)
        IRECDS=IRECDS+1
        IF(IRECDS.GT.NRECDS) GO TO 1200
        IF(IHSW.NE.1)GO TO 55
C
C       ********** CALCULATE HISTOGRAM
C
```

```
      DO 53 KK=1,256,IDT
      DO 49 I=1,21
      IF(INDIG(KK).GT.UL(I))GO TO 49
      NLIM(I,1)=NLIM(I,1)+1
      GO TO 50
49    CONTINUE
      NLIM(22,1)=NLIM(22,1)+1
50    DO 52 J=1,8
      DO 51 I=1,21
      IF(INALG(J,KK).GT.UL(I))GO TO 51
      NLIM(I,J+1)=NLIM(I,J+1)+1
      GO TO 52
51    CONTINUE
      NLIM(I,J+1)=NLIM(I,J+1)+1
52    CONTINUE
53    CONTINUE
C
C     ********** CORRECT NRL RADAR RANGE
C
55    CONTINUE
      DO 33 J=1,256,IS
      K=K+1
      X(K)=INDIG(J)
      IF(X(K).GT.3000)X(K)=X(K)-4096
      IF(X(K).GT.10000)IE=IE+1
      JJ=J+IDT
      Y(K)=INDIG(JJ)
      IF(Y(K).GT.3000)Y(K)=Y(K)-4096
      IF(Y(K).GT.10000)IE=IE+1
33    CONTINUE
C
C     **********
C
      BLOCK=BLOCK+9
      GO TO 32
31    ICODE=IREADW(2304,INPUT,BLOCK,ICHAN)
      IRECDS=IRECDS+1
      IF(IRECDS.GT.NRECDS)GO TO 1200
      DO 34 J=1,256,IS
      K=K+1
      X(K)=INALG(ICSW,J)
      JJ=J+IDT
      Y(K)=INALG(ICSW,JJ)
34    CONTINUE
      BLOCK=BLOCK+9
      GO TO 31
1200  CONTINUE
      IF(ICSW.GT.0)GO TO 1201
      IF(IHSW.NE.1)GO TO 56
C
C     ********** PRINT OUT HISTOGRAM
C
      DO 54 I=1,22
      TYPE 952,(UL(I)-200.),UL(I)
952   FORMAT(' ',2F8.0)
      TYPE 953,(NLIM(I,J),J=1,9)
953   FORMAT('+',T25,9I8)
54    CONTINUE
56    CONTINUE
C
```

```
C         ********** PRINT NRL RADAR ERROR COUNTERS "IE"
C
          TYPE 936,IE
936       FORMAT(' IE=',I10)
1201      CONTINUE
C
C         ********** PRINT OUT RAW DATA POINTS
C
          TYPE 937
937       FORMAT(' INPUT NO OF POINTS TO PRINT',5X,$)
          ACCEPT 932,NP
          NP=NP/2
          IF(NP.EQ.0)GO TO 37
          TYPE 938,(X(I),Y(I),I=1,NP)
938       FORMAT(' ',10F12.4)
37        CONTINUE
          T=0.
          TNO=2**IN
          NOM=2**(IN-1)
          TYPE 946,IN,TNO,NOM
946       FORMAT(' IN=',I4,'  TNO= ',F6.1,'  NOM=',I4)
C
C         ********** CALCULATE AND PRINT MEAN
C
          DO 35 I=1,NOM
35        T=T+(X(I)+Y(I))/TNO
          TYPE 947,T
947       FORMAT(' MEAN=',F12.2)
          TV=0.0
C
C         ********** CALCULATE AND PRINT VARIANCE BASED ON TIME HISTORY
C
          DO 36 I=1,NOM
          X(I)=X(I)-T
          Y(I)=Y(I)-T
36        TV=TV+X(I)**2/TNO+Y(I)**2/TNO
          TYPE 951,TV,TV**.5
951       FORMAT('0BASED ON TIME HISTORY, VARIANCE=',F15.3,
          1 3X,'RMS=',F15.3)
C
C         ********** PRINT OUT POINTS WITH MEAN SUBTRACTED
C
          TYPE 937
          TYPE 939
939       FORMAT('+(ZERO MEAN)'5X,$)
          ACCEPT 932,NP
          IF(NP.EQ.0)GO TO 38
          NP=NP/2
          TYPE 938,(X(I),Y(I),I=1,NP)
38        CONTINUE
          INM=IN-1
C
C         ********** APPLY B-H WINDOW, IF DESIRED
C
          TYPE 949
949       FORMAT(' APPLY 3 TERM BLACKMAN-HARRIS WINDOW? 0 FOR NO,
          1 1 FOR YES',3X,$)
          ACCEPT 932,IW
          IF(IW.NE.1)GO TO 45
          DO 44 I=1,NOM
```

```
      N=2*(I-1)
      X(I)=(.42323-.49755*COS(2*PI*N/TNO)
     1 +.07922*COS(2*PI*2*N/TNO))*X(I)
      N=2*(I-1)+1
      Y(I)=(.42323-.49755*COS(2*PI*N/TNO)
     1 +.07922*COS(2*PI*2*N/TNO))*Y(I)
44    CONTINUE
45    CONTINUE
C
C     ********** CALL FFT SUBROUTINE
C
      CALL DWFFT(X,Y,INM)
C
C     ********** PRINT RAW FFT COEFFICIENTS
C
      TYPE 940
940   FORMAT(' INPUT NO OF RAW COEFF TO PRINT',5X,$)
      ACCEPT 932,N
      IF(N.EQ.0)GO TO 39
      DO 40 I=1,N
      IF(I.GT.NOM)GO TO 39
      TYPE 941,I-1,(I-1)/(TNO*.1*IDT),X(I),Y(I),(X(I)**2.+Y(I)**2.)**.5
941   FORMAT(' ',I5,4F12.3)
40    CONTINUE
39    CONTINUE
C
C     ********** SELECT NUMBER FOR FREQUENCY SMOOTHING
C                PRINT RESULTS
C
      TYPE 942
942   FORMAT(' INPUT NO OF COEFF PER FREQ AVG',5X,$)
      ACCEPT 932,NF
      TYPE 943
943   FORMAT(' INPUT NO OF FREQ AVG TO PRINT',5X,$)
      ACCEPT 932,NPR
      AT=0.
      DO 46 I=2,NOM
      AT=AT+(X(I)**2.+Y(I)**2.)/2.
46    CONTINUE
      DO 41 I=1,8000,NF
      AA=0.
      DO 42 II=1,NF
      IF(I+II.GT.NOM)GO TO 997
      AA=AA+(X(I+II)**2.+Y(I+II)**2.)/2
42    CONTINUE
      TYPE 944,I,I+NF-1,(I+(NF-1)/2.)/(TNO*.1*IDT),AA
      IF(ICSW.LT.2)GO TO 47
      IF(ICSW.GT.5)GO TO 47
      TRL=(TNO*.1*IDT)/(I+(NF-1)/2.)
      AMF=(TRL/(2.*PI))**4
      AD=AA*AMF
      TYPE 995,AD
995   FORMAT('+',T43,F15.4)
47    CONTINUE
944   FORMAT(' ',2I5,F12.3,3X,F15.5)
      IF(I/NF.GT.NPR)GO TO 997
41    CONTINUE
997   TYPE 998
998   FORMAT(' NOT ENOUGH POINTS')
      TYPE 996,AT,AT**.5
```

```
936     FORMAT('OTOTAL VARIANCE=',F15.3,3X,'RMS=',F15.3,///)
C
C       ********** LOOP TO BEGINNING OF PROGRAM
C
        GO TO 2
999     CALL CLOSEC(ICHAN)
        CALL IFREEC(ICHAN)
        STOP 'ALL DONE'
        END
```

```
C
C
C        FAST FOURIER TRANSFORM ALGORITHM
C             (REF: BICE, PETER K., "SPEED UP THE FFT",
C                  ELECTRONICS DESIGN, APRIL 25,1970)
C             ADAPTED BY: DAVID A. WALDEN
C
C
         SUBROUTINE DWFFT(X,Y,IG)
         INTEGER G,G1
         DIMENSION X(1),Y(1)
         G=IG
         N=2**G
         P=8*ATAN(1.)/N
         DO 4 I=1,N
         X(I)=X(I)/N
         Y(I)=Y(I)/N
4        CONTINUE
         DO 9 L1=1,G
         L=L1-1
         G1=2**(G-L-1)
         M=0
         L2=2**L
         DO 9 I=1,L2
         R1=M/G1
         K1=INT(R1)
         K2=0
         DO 5 K=1,G
         R2=K1/2
         K3=K1-2*INT(R2)
         K1=INT(R2)
         IF(K3.EQ.0)GO TO 5
         K2=K2+2**(G-K)
5        CONTINUE
         Y1=COS(P*K2)
         Y2=-SIN(P*K2)
         DO 7 J=1,G1
         Y3=X(M+G1+1)*Y1-Y(M+G1+1)*Y2
         Y4=X(M+G1+1)*Y2+Y(M+G1+1)*Y1
         X(M+G1+1)=X(M+1)-Y3
         Y(M+G1+1)=Y(M+1)-Y4
         X(M+1)=X(M+1)+Y3
         Y(M+1)=Y(M+1)+Y4
         M=M+1
7        CONTINUE
         M=M+G1
9        CONTINUE
         DO 10 L3=1,N
         I=L3-1
         K1=I
         K2=0
         DO 11 K=1,G
         R4=K1/2
         K3=K1-2*INT(R4)
         K1=INT(R4)
         IF(K3.EQ.0)GO TO 11
         K2=K2+2**(G-K)
11       CONTINUE
         IF(K2.GE.I)GO TO 10
```

```
      RK3=X(I+1)
      X(I+1)=X(K2+1)
      X(K2+1)=RK3
      RK3=Y(I+1)
      Y(I+1)=Y(K2+1)
      Y(K2+1)=RK3
10    CONTINUE
      L5=N/2+1
      DO 13 I=1,L5
      K=I-1
      J=I-2
      A=X(I)+X(N-J)
      B=(Y(I)+Y(N-J))*COS(K*P/2)-(X(I)-X(N-J))*SIN(K*P/2)
      C=Y(I)-Y(N-J)
      D=(Y(I)+Y(N-J))*SIN(K*P/2)+(X(I)-X(N-J))*COS(K*P/2)
      X(I)=(A+B)/2
      Y(I)=(C-D)/2
      X(N-J)=(A-B)/2
      Y(N-J)=(-C-D)/2
13    CONTINUE
      RETURN
      END
```

AD-A083 647 NAVAL RESEARCH LAB WASHINGTON DC F/G 8/8
GREAT LAKES WAVE HEIGHT RADAR SYSTEM.(U)
NOV 79 D L HAMMOND MIPR-Z-70099-7-817597-A
UNCLASSIFIED USCG-D-6-80 NL

2 OF 2
AD A
083647

REFERENCES

1. "Hull Vibration Evaluation of Great Lakes Ore Carrier M/V STEWART J. CORT", Milton O. Critchfield, Naval Ship Research and Development Center, N234, January 1973

2. "Analysis of High Level Bending Stresses on Two Great Lakes Ore Ships", Roland E. Schauer and Gary P. Antonides, Naval Research and Development Center, SAD-87E-1962, July 1974

3. "SL-7 Instrumentation Program Background and Research Plan", W.J. Siekierka, R.A. Johnson, and CDR C.S. Loosmore, USCG (SSC-259), AD-A021337, 1976

4. "A Report on Shipboard Waveheight Radar System", D. Chen and D. Hammond, AD-A049349, 1977

5. "Wavemeter Data Reduction Method and Initial Data for the SL-7 Containership", J.F. Dalzell, (SSC-278), 1978

6. Oscilloscope, Type 568/R568, Instruction Manual, Tektronix, Incorporated

7. Dual Trace Sampling Unit, Type 35-1, Instruction Manual, Tektronix, Incorporated

8. Programmable Sampling Sweep, Type 3T5, Instruction Manual, Tektronix, Incorporated

9. ALT-50, Radio Altimeter System, Instruction Book, Collins Radio Company.