

AD-A062 141

TELEDYNE SYSTEMS CO NORTHRIDGE CALIF
SAINT MARYS RIVER LORAN-C. PRECISION GUIDANCE SYSTEM. VOLUME I.--ETC(U)
FEB 77

F/G 17/7

DOT-CG-61419-A

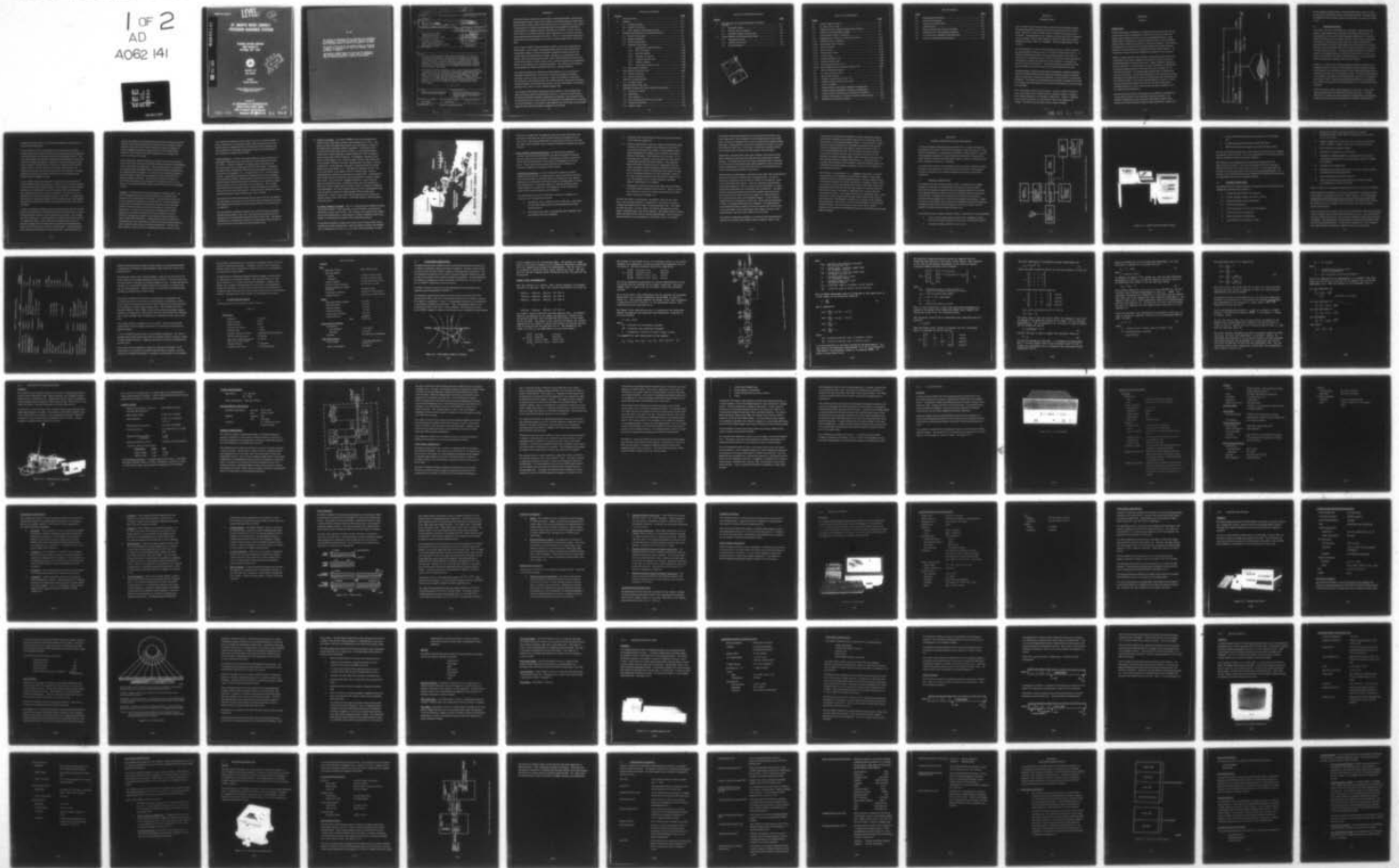
UNCLASSIFIED

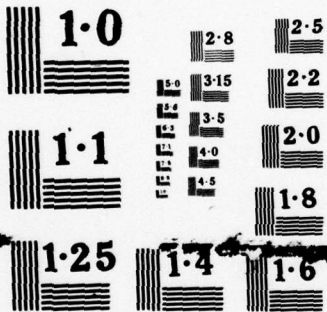
TSC-60133

USCG-D-57-77-VOL-1

NL

1 OF 2
AD
A062 141





NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

REPORT NO. CG-D-57-77

LEVEL

12
SC

AD A062141

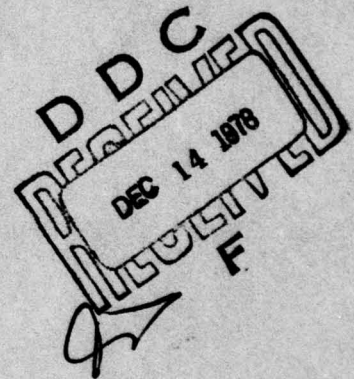
ST. MARYS RIVER LORAN-C PRECISION GUIDANCE SYSTEM

TELEDYNE SYSTEMS COMPANY
19601 Nordhoff St.
Northridge, Calif. 91324



FEBRUARY 1977
FINAL REPORT

VOLUME 1
SYSTEM DEFINITION



Document is available to the U.S. public through the
National Technical Information Service,
Springfield, Virginia 22161

Prepared for
U.S. DEPARTMENT OF TRANSPORTATION
UNITED STATES COAST GUARD
Office of Research and Development
Washington, D.C. 20590

403 589

12 11 013
JOB

DDC FILE COPY

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 necessarily 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-57-77-VOL-1

Technical Report Documentation Page

1. Report No. CG-D-57-77 ¹		2. Government Accession No.		3. Recipient's Catalog No.	
6	4. Title and Subtitle St. Marys River Loran-C Precision Guidance System, Volume I. System Definition.			5. Report Date 11 February 1977	
				7. Performing Organization Code	
7. Author(s)			8. Performing Organization Report No. 14 TSC-60133-12 141p.		
9. Performing Organization Name and Address Teledyne Systems Company 19601 Nordhoff Street Northridge, California 91324			10. Work Unit No. (TRAFS) VOL-1	11. Contract or Grant No. DOT-CG-61419-A	
12. Sponsoring Agency Name and Address Department of Transportation United States Coast Guard Office of Research and Development Washington, DC 20590			13. Type of Report and Period Covered 9 Final Report.		14. Sponsoring Agency Code G-DOE-4/TP54
15. Supplementary Notes					
16. Abstract <p>A Loran-C Precision Guidance System with the capability to be used as a research and development tool was designed and assembled for the purpose of examining the feasibility of using Loran-C to navigate ore carriers in the St. Marys River. The system consists of a Loran-C receiver, a mini-computer, a mini data station for displaying navigational data, a flexible disk system, a 17-inch graphics unit for displaying a prestored representation of the St. Marys River, and a gyrocompass interface unit for interfacing with ship's gyrocompass.</p> <p>The system was initially installed on the U.S. Coast Guard Cutter NAUGATUCK, a 110-foot tug boat, for calibration, verification, and demonstration, in conjunction with a special four-station Loran-C "Mini-Chain" on the St. Marys River. Later the system was installed on the USCGC MACKINAW, a 290-foot icebreaker, for further evaluation and demonstration. Positional jitter of 50 to 75 feet (2dRMS, 95%) was achieved. Additional testing will be done aboard an ore carrier to determine how well the system meets the Coast Guard's accuracy objective of ± 25 feet maximum cross-track error 95% of the time.</p>					
17. Key Words Precision Navigation, Mini-Chain, Loran-C, Restricted Waterways			18. Distribution Statement Document is available to the U.S. Public through the National Technical Information Service, Springfield, Virginia 22161		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 141	22. Price

Form DOT F 1700.7 (8-72)

Reproduction of completed page authorized

403 589

JOB

ABSTRACT

This Final Report contains all relevant data on the implementation, development and operation of the St. Marys River LORAN-C Precision Guidance System which was built under Contract DOT-CG-61419A for the U. S. Coast Guard. The system is being used as a research and development tool to evaluate the feasibility of using LORAN-C to navigate vessels, especially ore carriers, in the St. Marys River which is a restricted waterway where channels are very narrow and many navigational aids are removed in the winter. The U. S. Coast Guard's objective in this project is the determination of a vessel's position within 25 feet, 95% of the time.

The St. Marys LORAN Precision Guidance System project was organized into three phases: (1) the design and implementation phase interfaced equipments and detailed software, (2) the testing phase verified the design concepts and mechanization through laboratory testing, calibration, and verification field testing, and (3) the demonstration phase, which included demonstrations aboard Coast Guard vessels on the St. Marys River, provided qualitative and quantitative data as to the validity of the concepts and design. The system has been demonstrated aboard the USCGC MACKINAW during ice breaking missions.

The report documents the signal processing hardware (1) as an overview of functional characteristics, (2) in terms of signal processing and filtering dynamics, and (3) in terms of electrical design and mechanical construction. The hardware so described includes the LORAN Receiver and Antenna Assembly, the Minicomputer, the Flexible Disk System, the Mini Data Station, the Graphics Interface Unit, and the 17-inch Graphics Display Unit.

The computer DOS III (Disk Operating System) software, which performs the major processing tasks of initialization at turn-on, continuous LORAN signal processing and Kalman filtering, displaying and updating a representation of the St. Marys River on a 17-inch screen, and displaying navigational data for steering on a 12-inch display, is described in flow diagrams and by the basic mechanization equations from which the software programs were derived.

TABLE OF CONTENTS

<u>Section</u>		<u>Page</u>
1	INTRODUCTION	1-1
2	LORAN C	2-1
	2.1 LORAN Evolution	2-3
	2.2 LORAN C Coverage	2-7
	2.3 Basic LORAN C Positioning Accuracy	2-9
3	SYSTEM CONFIGURATION AND DESCRIPTION	3-1
	3.1 Physical Description	3-1
	3.2 System Capabilities	3-4
	3.3 System Specifications	3-8
	3.4 Functional Description	3-10
	3.4.1 Microlocator LORAN Receiver	3-19
	3.4.2 MX-21 Computer	3-20
	3.4.3 Mini Data Station	3-29
	3.4.4 Flexible Disc System	3-42
	3.4.5 Graphics Interface Unit	3-46
	3.4.6 Graphics Display	3-54
	3.4.7 Gyrocompass Interface Unit	3-60
	3.5 Operational Commands	3-64
4	SOFTWARE CONFIGURATION	3-68
	4.1 Software Operation	4-1
	4.2 Memory Allocation	4-12
5	DISPLAY CONFIGURATION	5-1
	5.1 Graphics Display	5-6
6	SYSTEM ERROR ANALYSIS	6-1
7	SYSTEM CALIBRATION AND VERIFICATION TESTS	7-1
	7.1 Summary of Results	7-1
	7.2 Installation	7-2
	7.3 Data Analysis	7-4
	7.4 Static Repeatability and Accuracy Tests	7-4
	7.5 Waypoint Calibration	7-8
	7.6 Dynamic Tests	7-13

TABLE OF CONTENTS (Continued)

<u>Section</u>		<u>Page</u>
8	RELIABILITY OF LORAN PRECISION GUIDANCE SYSTEM	8-1
8.1	Reliability History	8-1
8.2	Primary Power Problems	8-1
8.3	Reliability Design Considerations	8-4
9	CONCLUSIONS AND RECOMMENDATIONS	9-1
9.1	Operational Results	9-1
9.2	Graphics Assessment	9-2
9.3	Recommendations	9-3

ACCESSION for White Section Buff Section

NTIS
 DOC
 HANDED
 AS 1 JAN 1971

BY REGULAR NON-REGULAR ABILITY CASES SPECIAL

AT

LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
2-1	Typical LORAN-C Signal	2-2
2-2	St. Marys River Chain	2-8
3-1	LORAN Precision Guidance System Block Diagram	3-2
3-2	LORAN Precision Guidance System	3-3
3-3	Three-Station LORAN C Geometry	3-10
3-4	Simplified Block Diagram of System Operation	3-13
3.4-1	LORAN Receiver Assembly	3-20
3.4-2	Microlocator Block Diagram	3-23
3.4-3	MX-21 Computer	3-30
3.4-4	Data Formats	3-37
3.4-5	Flexible Disc System	3-46
3.4-6	Track Format	3-49
3.4-7	Graphics Interface Unit	3-54
3.4-8	Graphics Display Unit	3-60
3.4-9	Gyrocompass Interface Unit	3-64
3.4-10	Block Diagram of Gyrocompass Interface Unit	3-66
4-1	DOS III Functional Diagram	4-2
4-2	St. Marys Program Flow	4-6
5-1	Normal CRT Display	5-2
5-2	Graphics Display (Scale Factor of 4)	5-8
5-3	Graphics Display (Scale Factor of 20)	5-9
5-4	Track-Up Display	5-11
7-1	Present Position Distribution (Standard Configuration)	7-6
7-2	Present Position Distribution (Modified Configuration)	7-7
7-3	Present Position Distribution with Rubidium Oscillation	7-10
7-4	Dynamic Performance of LORAN Precision Guidance System	7-14
7-5	Deviation from Reference System	7-15

LIST OF TABLES

<u>Table</u>		<u>Page</u>
3-1	Navigational Parameters	3-6
3-2	System Specifications	3-8
5-1	Summary of LORAN States	5-5
6-1	LORAN Errors	6-2
7-1	Static Positional Data Taken at Dockside	7-5
7-2	Positional Data With Rubidium Oscillator.	7-9
7-3	St. Marys River Waypoint Calibration Data.	7-11
8-1	History of Malfunctions and Failures	8-2

SECTION 1
INTRODUCTION

For a number of years mariners have needed a precision guidance system that would allow them to safely traverse restricted waters such as those of the St. Marys River where channel varies in width from 300 feet to over 2,000 feet. During periods of low visibility and when other aids to navigation are not available, such as when buoys are removed during winter months, shipping essentially comes to a standstill. This has a great impact on the economy.

The national policy on marine radionavigation states that LORAN-C will be the radionavigation system for the U.S. Coastal Confluence Zone (CCZ). To maintain compatibility between CCZ and restricted water areas, the U.S. Coast Guard is conducting a series of tests in the area of the St. Marys River in Michigan to examine the feasibility of using LORAN-C to navigate ore carriers in the St. Marys River. They have installed an experimental four station LORAN-C Mini Chain to provide coverage along the river area.

Teledyne Systems Company designed and implemented a shipboard LORAN-C Precision Guidance System that is capable of providing precision navigation which is being used to evaluate the feasibility of using LORAN-C for precision navigation. The system has the flexibility and functional capability to be used as a research and development tool in the future development of precise navigation techniques.

This Final Report consists of two volumes. Volume 1, System Definition, gives a description of the LORAN Precision Guidance System's configuration, software operation, and navigation capabilities. Volume 2, Software, has a detailed description of each software routine (flow diagram and listing). Procedures are provided to make program changes.

SECTION 2

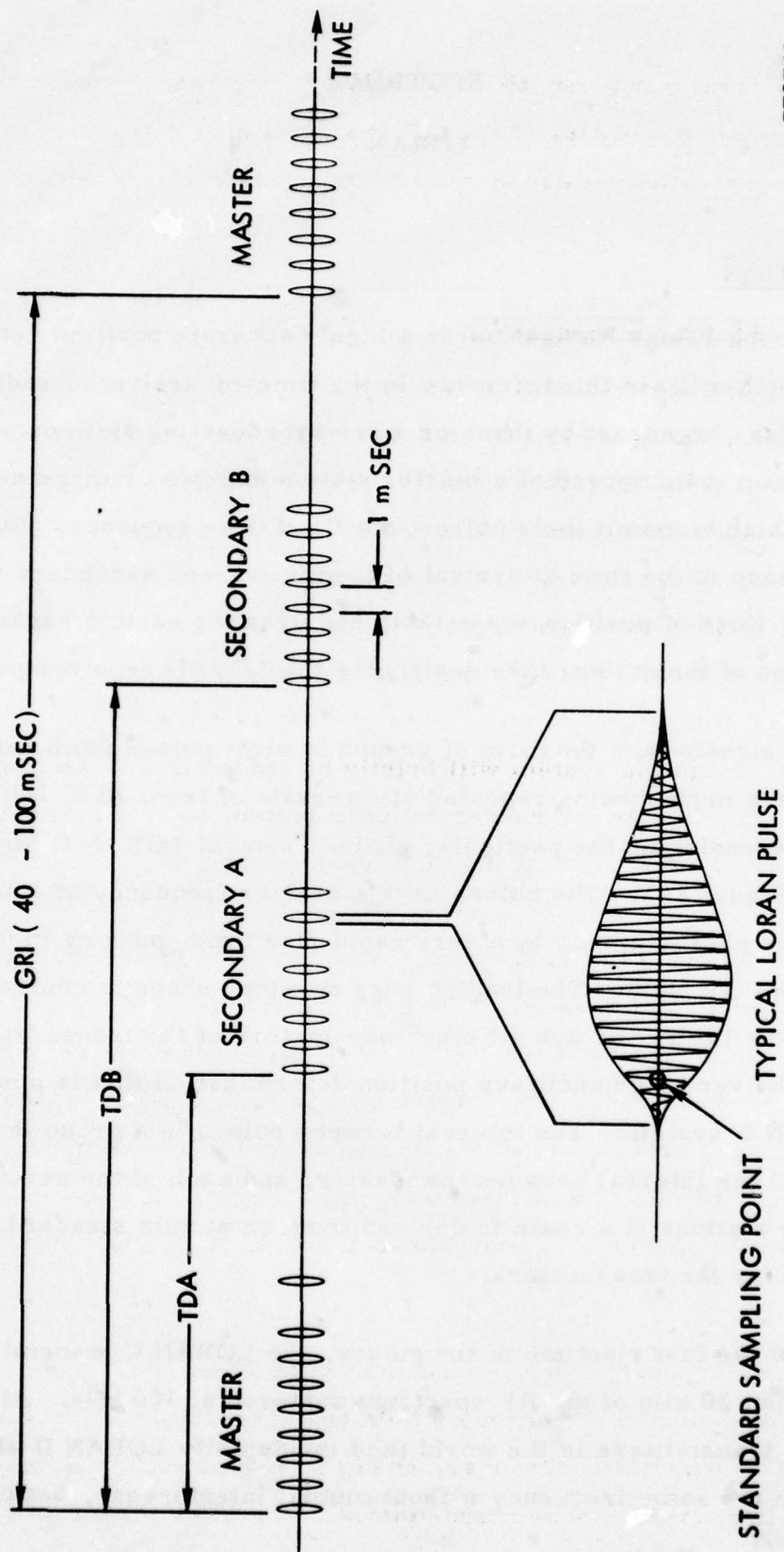
LORAN C

DESCRIPTION

LORAN (Long Range Navigation) is a highly accurate position determining system which utilizes the difference in the time-of-arrival of radio frequency pulses broadcast by three or more broadcasting stations. Each LORAN chain is composed of a master station and two or more secondary stations which transmit their pulses in a fixed time sequence. By measuring the difference in the time of arrival of the master and secondary pulses, hyperbolic lines of position are established over the earth's surface. The intersection of these lines then designates the LORAN receiver position.

LORAN C signals take the form of groups of eight pulses from each of the transmitters in the chain, repeated at intervals of from 40 to 100 milliseconds depending on the particular chain. Typical LORAN C signals are shown in Figure 2-1. The pulses have a carrier frequency of 100 kHz and an envelope characterized by a very rapid rise time, peaking in 6 or 7 cycles from the start. The leading edge envelope shape is controlled to very precise limits, as are all other parameters of the transmitter chains, allowing the very high accuracy position determination that is possible with the LORAN C system. The interval between pulses in a group is 1 millisecond and the interval between the master, and each of the several secondary stations in a chain is derived from an atomic standard, as is all timing for the transmitters.

Because of the fast risetime of the pulses, the LORAN C transmissions occupy about 20 kHz of the RF spectrum centered at 100 kHz. All LORAN C transmitters in the world (and incidentally LORAN D also) operate on the same frequency without mutual interference, because they



T78768

Figure 2-1. Typical LORAN C Signals

all have different group repetition intervals (GRIs) which enable the transmissions from a particular chain to be uniquely identified. Because of this, the LORAN Precision Guidance System can operate in any area with LORAN C or D.

2.1 LORAN EVOLUTION

In the thirty years since work began on a long range, pulsed navigation system, major changes have taken place in the form of the signals, the mechanization of the receivers and the primary applications. Operating frequencies have gone from 2 MHz to 100 kHz, receivers have progressed from manual, analog devices which only used envelope information to automatic digital sets which employ phase and envelope data, and recently, there has been considerable commercial interest in what was for a number of years a military system. The step-by-step development of LORAN as a precision navigation system will briefly be traced in this section. The intent is to familiarize the reader with the system as it is now constituted and the coverage and capabilities that are now available.

LORAN A - In 1940, the U. S. National Defense Research Committee was assigned a project to develop a LONG-RANGE precision navigation system. It was planned to use synchronized pairs of pulse-type transmitting stations separated by distances of several hundred miles. The project was assigned to the Radiation Laboratory of the Massachusetts Institute of Technology in the summer of 1941. Experimental transmitting stations were located at U. S. Coast Guard facilities near Montauk Point, N. Y., and Fenwick Island, Delaware.

Trials in moving vehicles were undertaken in June 1942. A four station chain was inaugurated for extended field trials in October. In January 1943 the U. S. Coast Guard was assigned the responsibility of operating the LORAN A transmitters which transmitted in the 1800 to 2000 kHz band.

LORAN A accuracies were \pm 0.5 mile line-of-position error and 1 to 2 mile position fixing error.

It was recognized early in the program that a low frequency LORAN system would provide improved accuracy and greatly extended navigational coverage during the day and night with fewer transmitting stations. The first experimental low frequency LORAN system (operating at 180 kHz and called LF LORAN) was placed in operation in 1945 with transmitting stations at Cape Cod, Massachusetts, Cape Fear, North Carolina, and Key Largo, Florida. Monitor stations for overwater observations were installed at Bermuda, the Azores, Puerto Rico, and Trinidad. Overland signals were observed at monitor stations in Ohio and Minnesota and aboard specially equipped aircraft.

The LF LORAN system was basically an extension of the techniques of 2 MHz LORAN to the lower frequency. However, the LF stations operated in synchronized triplets instead of pairs, and in addition to pulse envelope matching, the individual RF cycles of the master and secondary pulses were displayed on the user's receiver-indicator. The receivers were designed to provide for visual match of pulses and cycles. A rough match was made first using the envelopes of the two pulses (as in 2 MHz LORAN) and then a fine measurement made by matching selected RF cycles within each pulse.

In 1946, all equipment installed in the experimental East Coast LF LORAN system was transferred to the northwest section of Canada where it served the requirements of special Arctic maneuvers in the area. Upon completion of the maneuvers, a joint Canadian-United States project was initiated to evaluate the system. Nine fixed-monitor stations and a number of specially equipped aircraft were placed in operation and comprehensive tests were carried out over a period of many months. These operational tests, together with results of the East Coast tests, showed that the LF

system could operate with substantially longer baselines than was feasible with the 2 MHz system and that the 24-hours service coverage overland would be of the order of two-thirds of that of sea water (as against an almost negligible overland coverage provided by the existing 2 MHz LORAN). The accuracy achieved was equivalent to an average LOP error of 160 feet at 750 miles.

On the other hand, operators found they could not select the correct pair of RF cycles more than about 75 percent of the time without prior knowledge of the correct pulse envelope delay. The resulting positional ambiguities were operationally unacceptable and the system was judged unsatisfactory for general purpose navigation. To correct these positional ambiguities, work was begun in 1946 on the development of cycle identification and phase-measuring techniques. This work was carried out jointly by government and industry and culminated in the field tests of a low frequency, cycle-matching LORAN system called CYCLAN (CYCLE matching LorAN).

CYCLAN - CYCLAN was the first fully automatic LORAN system. The cyclic ambiguity problem was solved through the use of pulse transmissions on two frequencies 20 kHz apart. (180 and 200 kHz were used at first, followed by operation on 160 and 180 kHz.) Slope matching on the first 50 microseconds of the pulse was followed by cycle matching within the pulse envelope for precise determination of arrival time-differences. Incorrect cycle-matching at one frequency was readily apparent by an obvious mismatch at the second frequency utilized. CYCLAN coverage was limited to the groundwave regions and gave a range of about 1000-1500 miles. Operational tests with CYCLAN were complicated by serious interference problems involving broadcast stations and aeronautical radio beacons on adjacent frequencies. The tests did show, however, that the RF cycle-identification problem could be solved.

Very significant progress was also made in the area of instrumentation. It became necessary to seek another solution when the Atlantic City (1947) Radio Conference designated the 90-110 kHz band (20 kHz bandwidth) for the development of long range navigational systems CYCLAN required a total bandwidth of approximately 40 kHz.

CYTAC/LORAN C - In 1952, work began under government contract on a long range, automatic ground-reference tactical bombing system known as CYTAC. A pulsed, hyperbolic navigation system operating in the 90-110 kHz band was an integral part of the CYTAC system. Equipment development was completed by 1955 and three transmitting stations were constructed at Forestport, N. Y., Carolina Beach, N. C., and Carrabelle, Florida. Tests with the navigational component of the system throughout 1956 showed that automatic instrumentation could solve the RF cycle identification problem and could measure time-difference in a hyperbolic system with an average error of a few tenths of a microsecond. The coverage area extended from the Atlantic Ocean to the Mississippi River and from the Great Lakes to the Gulf of Mexico. Monitor stations installed at widely separated locations collected data during a year of testing.

The results of the tests demonstrated that the system was not only capable of a high degree of precision, but also that the laws controlling its accuracy were sufficiently well known to permit sound predictions of accuracy prior to installation.

The initial system installation at Cape Fear, North Carolina; Carrabelle, Florida; and Forestport, New York, was extensively evaluated over the eastern part of the United States during the period 1952-1955. The results indicated that it was possible to obtain a fix repeatability within 250 feet or less over an area of more than one million square miles.

2.2 LORAN C Coverage - An operational requirement was developed for a highly accurate long range maritime radio navigation aid in 1957. The stated accuracy and range requirements were considerably in excess of the capabilities of existing LORAN A equipment. On the basis of the results of the CYTAC tests referred to above, it was believed that this requirement could be satisfied by implementing the CYTAC concepts as well as some of the CYTAC equipment. Consequently, equipment from stations at Forestport, N. Y., and Carrabelle, Florida, was transferred to new stations - Martha's Vineyard, Massachusetts, and Jupiter, Florida, respectively. These stations, operating in conjunction with the existing station at Carolina Beach, N.C., were placed in operation in 1957. The U.S. Coast Guard, in accordance with U.S. Federal Laws, assumed responsibility for operation of the stations in August 1958. Comprehensive tests by both surface and airborne units showed that the original concepts were sound. The new system, designated LORAN C, was at that time placed on operational status. Evaluation of this chain was conducted in 1958 over an area roughly defined by Natal, Brazil, Trinidad, the Bahamas and Newfoundland. For peak radiated powers of 60 kw, the groundwave and first hop skywave ranges were approximately 1500 and 2300 miles, respectively. Second, third, and fourth hop skywaves were monitored at various distances up to 3435 miles. World wide LORAN C will be possible in the near future.

St. Marys LORAN C Coverage - The U. S. Coast Guard has installed an experimental Mini-LORAN C chain operating on rate 4930 (GRI = 49,300 μ s) for evaluation on the St. Marys River. The coverage area includes the St. Marys River from Whitefish Bay in Lake Superior to Detour Passage in Lake Huron. Figure 2-2 illustrates the locations of the transmitting stations.

To provide the desired coverage in all areas of the St. Marys River, and to provide the accuracy required for a precision guidance system, four stations (two in Canada and two in the U.S.), are used, each transmitting 100 watts.

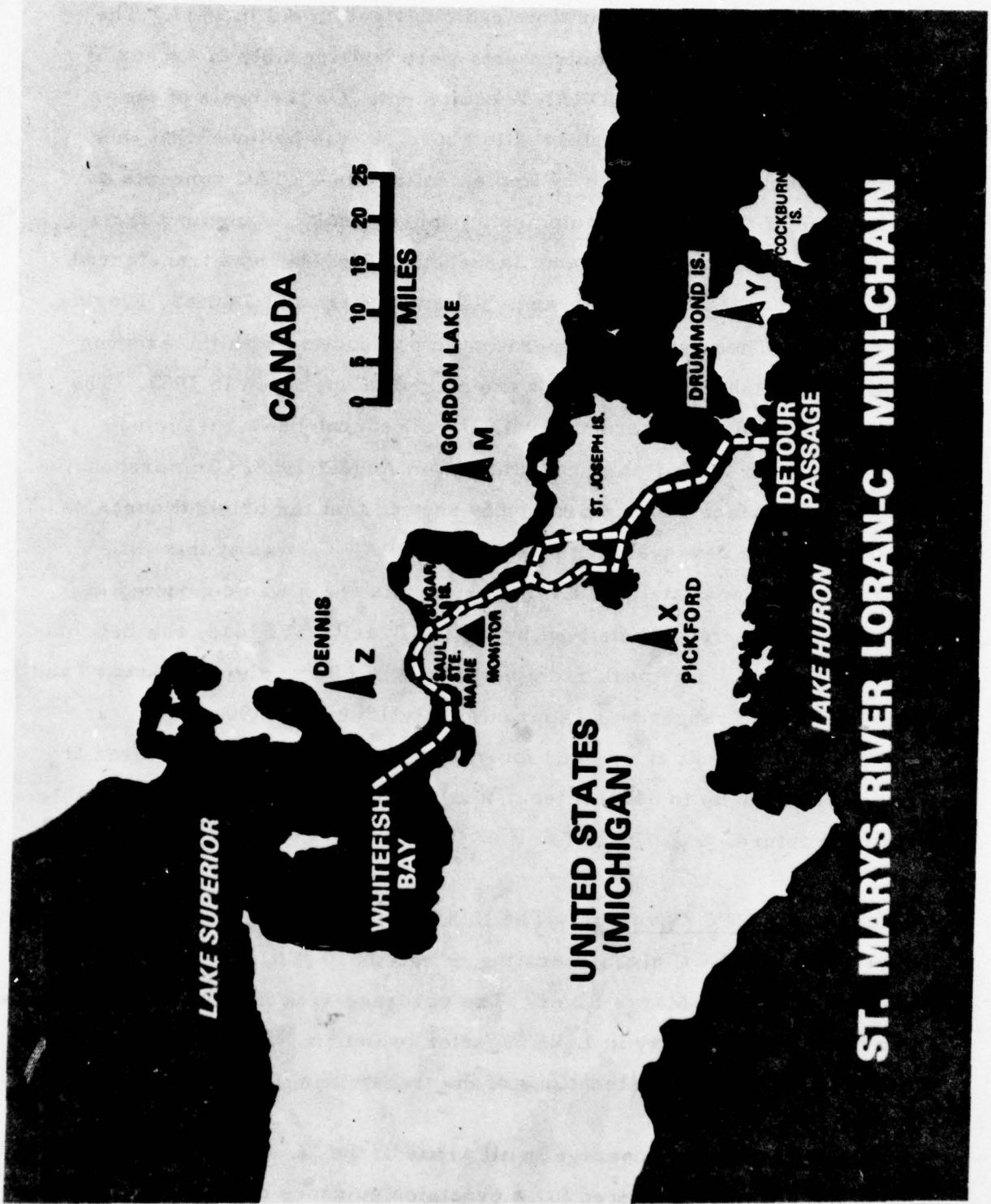


Figure 2-2. St. Marys River Chain

Within the coverage area, the signal-to-noise at the peak of the pulse from the master and at least two of the secondary stations is designed to be at least +3 dB. Each transmitting station is continuously monitored at the Sault Ste. Marie monitor station, and is remotely controlled to maintain the required accuracy.

2.3 Basic LORAN C Positioning Accuracy - As with all radio navigation systems, the ultimate accuracy that is available with LORAN C depends upon the signal-to-noise ratio (SNR), the geometrical dilution of precision (GDOP) and the predictability of the velocity of propagation in time and space. These external factors which affect the use of LORAN C for precision navigation are considered in this section.

LORAN RF Environment - The RF environment in which the LORAN signals must be received is contaminated in various ways which ultimately limit the performance of any radio system to a greater or lesser degree, depending on the properties of the basic system, and steps taken to combat such contamination. Of all radio navigation systems developed to date, LORAN appears to be optimum in this respect for the RF environment found in most restricted waterways and harbors.

The contamination of the RF environment, and hence of signals to be received, can be categorized as follows:

- a. Atmospheric noise, caused by cosmic radio noise, noise from sun and radio emitting stars, and thunderstorms and other natural sources.
- b. Man-made noise, which is unintentional radio frequency noise generated by electrical equipment.

- c. Intentional radio transmissions other than those desired which exit on adjacent frequencies.
- d. Skywave contamination, which is a replica of the desired signal reflected from the ionosphere that is delayed by from 40 to over 200 microseconds with respect to the groundwave (direct signal) depending on the height of the ionosphere and distance from the transmitter. This reflection can, of course, occur more than once resulting in multi-hop skywaves, which can be considerably delayed from the groundwave. The amplitude, delay and number of skywaves varies considerably with time of day, atmospheric (and ionospheric) conditions and distance from transmitter, but they are generally much greater at night, and at considerable distances from the transmitter. Stations in a Mini LORAN chain such as St. Marys River LORAN C are very close together, up to 70 miles maximum, therefore, skywave contamination is no problem.
- e. Propagation anomalies and multi-path effects due to the nature of the path between transmitter and receiver. These, of course, are of particular concern in a harbor environment where there may be many large buildings, etc.

The first two types of contamination, atmospheric noise and man-made noise, can be grouped together as random noise, since they are random in nature and unpredictable except in a purely statistical way. They afflict all radio systems to a similar extent, and usually represent the limiting factor in the performance that can be achieved. The LORAN system is able to reduce the effects of this noise on position determination. First, because of the pulse nature of the transmissions, and low duty cycle, it is possible

to transmit a much greater peak power in the pulse than the power transmitter input power, thus resulting in a better signal power to noise power ratio. Second, the Teledyne receiver uses correlation and signal averaging techniques, made possible by the precise repetition of the pulses, to cause noise effects to cancel out. In this way it is possible to operate satisfactorily with the noise as much as 20 times greater than the signal.

Additionally, the hard limiter used in the Teledyne receiver gives much better rejection of burst type noise than the older linear type of LORAN receiver. This burst type noise (with large amplitude spikes) is observed to be the type received at these lower radio frequencies, and is also particularly characteristic of man-made noise likely to be encountered in the restricted waterways and harbor environment.

The third type of contamination, interference from other radio transmissions, should not be much of a problem since the band from 90 - 110 kHz is reserved on a primary service basis for LORAN in ITU Region 2, which covers North and South America. However, high power transmissions on adjacent frequencies, such as a close by Decca transmitter or a high power naval transmitter can occasionally cause interference. The phase coding of the pulses provides discrimination against such interference, but in the rare cases where this is not enough, it is relatively easy to use a notch filter to remove the offending frequency. (In the Teledyne LORAN receivers designed for military use, where intentional jamming is likely, two tunable notch filters are installed). The wide spectrum of the transmitted pulses ensures that several notches can be used in the receiver passband, without affecting the pulse shape in the area of the sampling point, and hence with no effect on the accuracy.

The skywave contamination problem is one that has been paid particular attention in the design of the LORAN system navigation, since it very

much limits the accuracy and usefulness of other comparable systems, particularly continuous wave systems such as Decca and Omega, which have no way of discriminating against skywave. In the LORAN C system, however, skywave problems are eliminated completely by two factors. First, the sampling point on the pulse is chosen at the third cycle, or 30 microseconds after the start, which is before the earliest possible time at which skywave from the start of the pulse could be received. Secondly, the pulses are phase coded in such a way that in the rare event that multihop skywave is delayed sufficiently (i. e., nearly 800 microseconds) for the skywave from one pulse to affect the following pulse, the contributions from the skywave completely cancel out over 16 pulses, or two repetition intervals.

The fifth type of contamination, i. e., propagation anomalies, is of particular concern for the LORAN Precision Guidance System, where large structures may be encountered along waterways. Because LORAN C uses a low carrier frequency of 100 kHz, which has a wavelength of about 2 miles, it is likely to be much less affected than systems using higher carrier frequencies because reflection and refraction effects occur mainly where the size of the structure concerned is comparable with or greater than the wavelength concerned. Tests indicate that this is in general the case. Some structures, such as railway lines and high voltage transmission lines do have dimensions of wavelengths at 100 kHz and "warping" of the LORAN C grid is produced. This will not create any great problems in the Precision Guidance System, since such structures are rarely moved, and due allowance can be made in the calibration process to compensate for any propagation anomalies.

SECTION 3

SYSTEM CONFIGURATION AND DESCRIPTION

A Precision Guidance System employing LORAN-C as a position reference is described in this section. The system is designed to meet all of the U.S. Coast Guard's requirements for evaluating the feasibility of using LORAN-C to satisfy the navigation requirements of large vessels traversing the St. Marys River under conditions when low visibility and/or winter ice make conventional visual aids to navigation ineffective or unuseable.

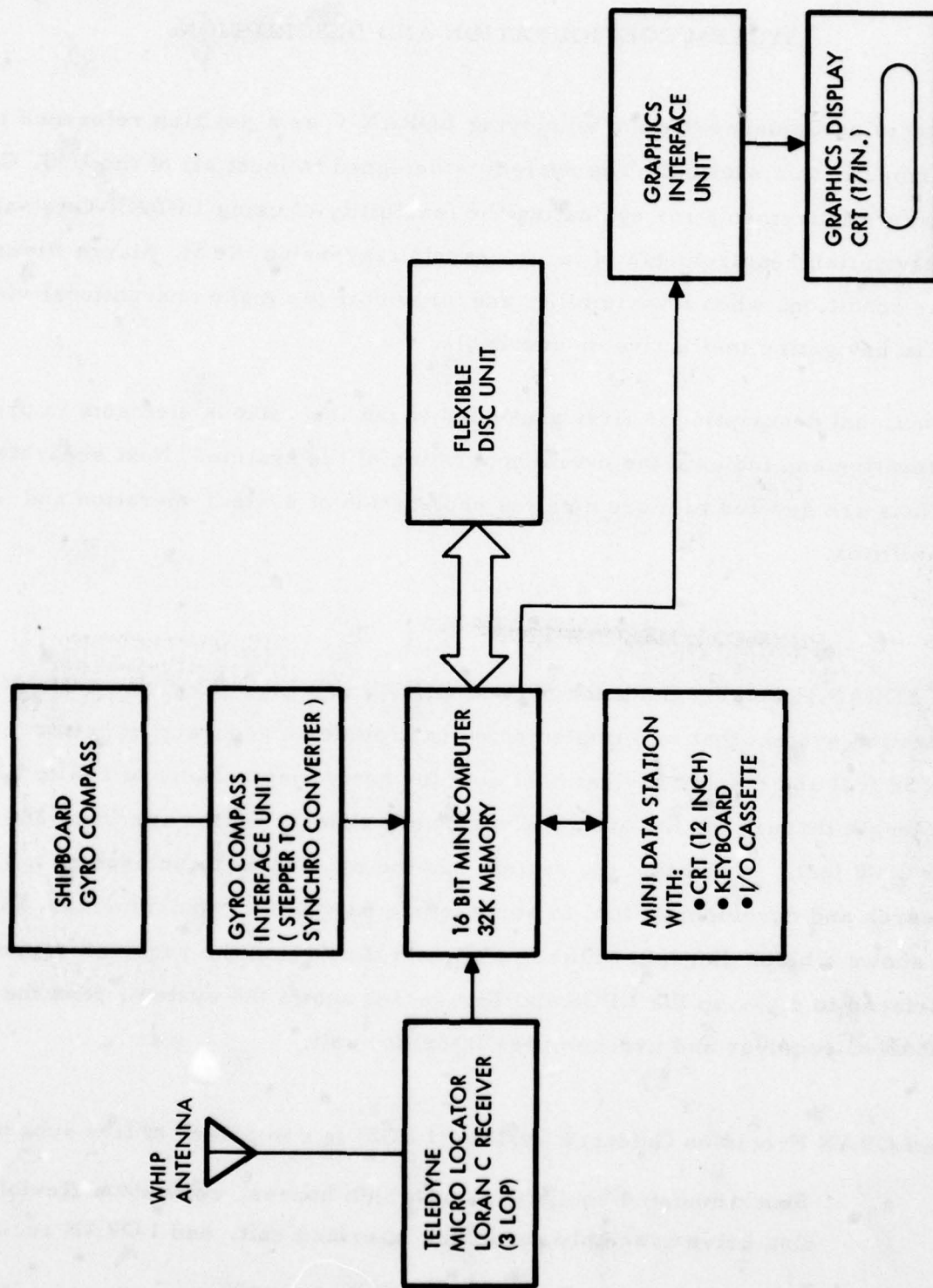
A functional description is first presented to put the various elements in proper perspective and indicate the overall operation of the system. Next separate sections are devoted to more detailed explanation of system operation and capabilities.

3.1 PHYSICAL DESCRIPTION

The LORAN Precision Guidance System (LPGS) is a high-precision LORAN navigation system that was implemented to provide an accuracy of better than 50 feet and display navigational data for navigating vessels of 150 to 1000 foot length through the St. Marys River where channel widths are from 300 to over 2000 feet. In addition the system has the provisions to be used as a research and development tool to study future navigation requirements. Figure 3-1 shows a block diagram of the system and illustrates the required equipments interfaced to make up the LPGS and Figure 3-2 shows the system, less the LORAN-C receiver and gyrocompass interface unit.

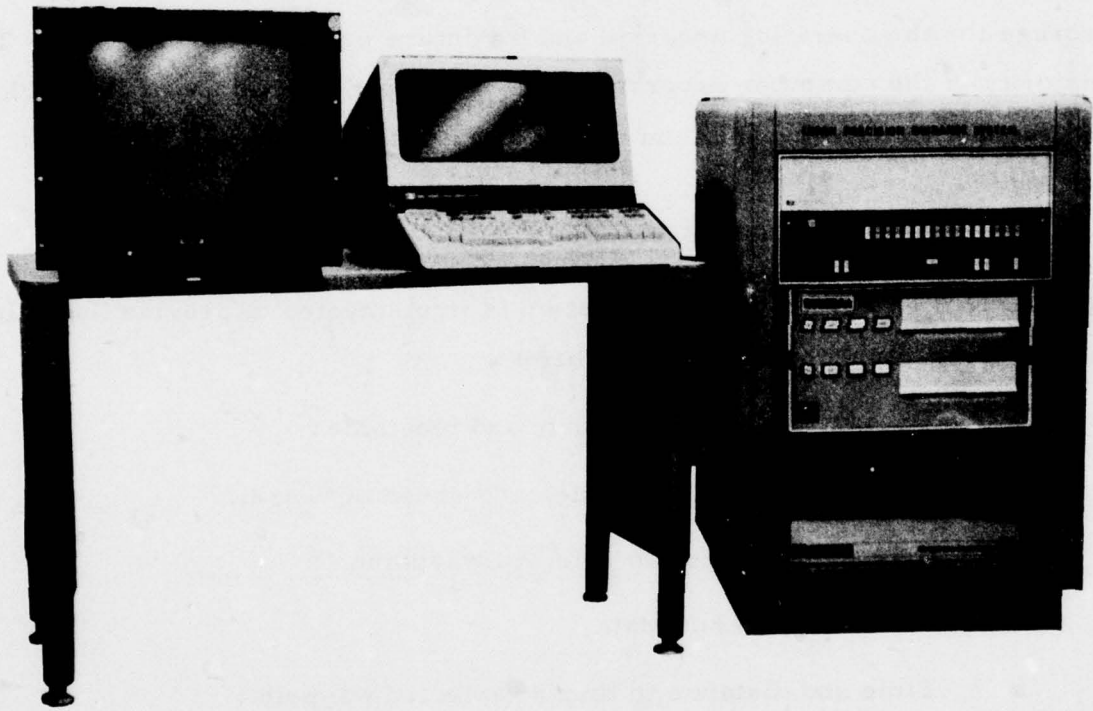
The LORAN Precision Guidance System (LPGS) is comprised of five subassemblies:

- a. Shock mounted equipment bay which houses, computer, flexible disk drive assembly, graphics interface unit, and LORAN receiver,
- b. A Graphics display unit with 17-inch screen.



T105191B

Figure 3-1. LORAN Precision Guidance System Block Diagram



P104259

Figure 3-2. LORAN Precision Guidance System

- c. A Mini Data Station with keyboard assembly and 12 inch display unit.
- d. An antenna assembly with 150 feet of RG-58/U cable.
- e. MK-14 Gyrocompass and interface unit with 125 feet of cable.

The only new equipment design was a Gyrocompass Interface Unit and a LORAN/Gyrocompass interface board. All the other equipment is off-the-shelf hardware thereby simplifying hardware maintenance logistics.

The LPGS is a disc operating system controlled by Hewlett-Packard's DOS III software routines. A disc unit accommodates two IBM compatible diskettes with 128K (16 bit word) capacity per disk. This provides sufficient storage for the operating program and for future program development. The majority of the computer programs were developed in FORTRAN IV which allows for rapid software checkout and program changes.

3.2 SYSTEM CAPABILITIES

The LORAN Precision Guidance System is implemented to provide the following navigational information and capabilities:

- Present position in latitude and longitude.
- Course, heading, attitude, and speed of vessel.
- Range and bearing to selected waypoint.
- Off-track steering data.
- Time and distance to turn at selected waypoint.
- Thirty-five prestored waypoints.
- Status and quality of LORAN data.
- Look-ahead vector in distance or time.

- Alphanumeric display of navigational data and an analog (graphical) display showing vessel's relationship to the trackline on a 12-inch screen.
- Graphics display of St. Marys River on a 17-inch screen showing vessel, trackline, channels, shore line, and channel markers.
- Remote operation of graphics display.
- Capability to compensate for receiver bias.
- Capability to calibrate graphics to compensate for chart errors, and LORAN grid distortion by entering waypoint offsets in Latitude and Longitude.
- Operates on any LORAN chain.
- Operates input commands (see Section 3.5) allow control of system, and change of numerous parameters.
- Data recording for post-mission analysis.
- Entry of new waypoints and chart data stored on tape cassettes for navigating in any area in the world.

Table 3-1 outlines the navigational parameters which can be entered or displayed.

Present latitude and longitude of the LPGS is determined by optimal processing of the LORAN C measurements from the LORAN receiver. The measurements are gathered approximately three times per second (about every seventh GRI) and process by a four state Kalman filter algorithm. The Kalman filter reduces the random errors in the signals which in turn produces a relatively stable position determination.

Course and speed of the vessel is derived by the Kalman filter which takes advantage of the correlation of the systems velocity and position errors. The improved position error reduction allows for a more accurate estimation of the vessel's velocity components. The Kalman filter processes the gyrocompass data to further refine the course and speed estimates. Course data is displayed on a CRT in degrees and tenths and speed is displayed in statute miles per hour and tenths.

Table 3-1. Navigational Parameters

Data	Input	Range	Displayed Resolution
Julian Calendar Day	Operator	1 to 366	1 Day
Greenwich Mean Time	Operator	0 to 23:59:59	1 Sec
Present Position: L/L Latitude/Longitude	Operator	-89, 59. 999 to +89, 59. 999 Deg. -180, 0. 0 to 179, 59. 999 Deg.	. 001 Minute
Time Diferrences	LORAN Rec.	All Values	10 NSec
Course		0 to 359. 9 Degrees	0. 1 Deg.
Heading	Gyrocompass and Operator	0 to 359. 59 Deg.	1/6 Deg.
Speed		-	0. 1 MPH
Crosstrack Speed		-	0. 1 Foot/Sec
Present Track		0 to 359. 9 Deg.	0. 1 Deg
Next Track		0 to 359. 9 Deg.	0. 1 Deg
Attitude		0 to 359. 9 Deg.	0. 1 Deg
Off Track		-	0. 1 Foot
Time to Turn		0 to 23:59:59	1 Sec
Miles to Turn		-	0. 001 Statute Mile
Lead	Operator	-	1 Foot
Quality Factor		0 to 100%	N/A
Waypoint	Operator	Up to 35 waypoints can be entered	-
Look-Ahead	Operator	Entry in time or Dist.	-
Receiver TD Offset	Operator	1 Nsec - 1 Mil Sec	+
Graphics Position Offset	Operator	1 degree L/L	. 001 Minute
Graphics Scale Factor	Operator	1 to 20 inches/mile	Integer

Range and bearing from the vessel's present position to a preselected waypoint is computed by the Andoyer-Lambert geodetic range routine and a great circle bearing routine.

Steering data consists of the off-track distance, miles to turn, and time to turn of the vessel from a predetermined great circle track line. When the vessel is on the desired great circle path, the off-track distance is zero. A video type steering indicator on a 12-inch CRT displays off-track error relative to trackline along with off-track parameters. Refer to Figure 5-1 which shows the displayed data and steering indication for on-track course.

The graphics capability of the system is a great asset for navigating in the St. Marys River area or any other restricted waterway by displaying a replica of the channel area being traversed and a vessel symbol to show precisely where you are relative to channel edge or danger areas. This includes shore lines, channel boundaries, buoys, lights, and any other prominent geographic objects. Presently, the LPGS has St. Marys River chart and waypoint data from Whitefish Bay to Detour Passage stored on diskettes for navigating in the St. Marys River area.

The vessel's position is updated every five seconds. When the vessel image reaches within 15% of the edge of the screen, the next sector of the channel is paged for display.

A 17-inch cathode-ray tube (CRT) is used to display the graphics. The CRT is equipped with a green contract filter with an anti-glare surface to enhance viewing in bright daylight situations. Brightness and focus are manually adjustable from the front panel.

The operator has the capability to change the scale factor of display (1 to 20 inches/mile) or to change the orientation angle (Northup or trackup). Also the operator can calibrate the graphics by entering a position-offset to the waypoints.

This provides compensation for errors found on Navigation charts, or errors caused by LORAN grid distortion. In addition, vessel's size is entered by operator during system initialization, therefore the size of vessel displayed is proportional to channel width.

The data points in latitude and longitude required to display a replica of the St. Marys River on the graphics display, were extracted from U. S. Lake Survey Charts No. 61, 62 and 63 and stored on diskettes. Changes to the display such as adding or deleting lights or buoys may be accomplished by editing this chart data. Provisions are also provided for recording system navigational data on optional line printer or paper tape devices for post-mission analysis. Recording can be done manually or automatically at any rate.

3.3. SYSTEM SPECIFICATIONS

The specifications for the LPGS are given in Table 3-2.

Table 3-2

Performance

Sensitivity	10 μ volts
Dynamic Range	90 dB
Signal Unbalance	60 dB
Envelope Discrepancy	+ 4 μ sec
Minimum SNR	- 14 dB
Number of Stations Tracked	5 (Master and 4 Secondaries)
LORAN Acquisition Time	50 seconds
Avg. Time to Initialize System (Power-on to Nav. mode)	3 minutes
Waypoint Entries	35 waypoints
Graphics Scale Factor	1 to 20 inches/mile

Table 3-2 (Cont.)

Physical

Size:

Equipment Cabinet	25"W x 36"H x 27"D
Mini Data Station	
Display	17.5"W x 18"D x 13.5"H
Keyboard	17.5"W x 8.5"D x 3.5"H
Graphics Display	16.5"W x 22.5"D x 16.2"H
Antenna Coupler Assembly	3.5"W x 3"D x 7.5"H
Antenna (Mounted on Coupler Assembly)	2 meters (7 feet)
Gyrocompass Interface	12.75"W x 11"D x 8.25"H
LORAN Receiver	9.62"W x 11.75"D x 6.75"H

Weight:

Equipment Cabinet (loaded)	315.0 lbs.
Mini Data Station	54.0 lbs.
Graphics Display	58.0 lbs.
Antenna Assembly	4.5 lbs.
Gyrocompass Interface	35.0 lbs.
LORAN Receiver	<u>8.25 lbs</u>
Total	474.75 lbs

Environmental Conditions

Temperature	
Non-operating	-15 to +65°C
Operating	0 to +40°C
Humidity	20 to 80% (non-condensing)

Power Requirements

Input Voltage:	115 ± 10% single phase at 60 ± 1 Hz
Power Consumption:	875 watts

FUNCTIONAL DESCRIPTION

The Marine Microlocator LORAN receiver provides positional data received from a LORAN C transmitter chain for hyperbolic navigation. The basic measurements derived from the 100 KHz LORAN C signals are time difference information. The time difference information is the result of taking the difference between the pulse groups from the Master and secondary station's transmitters. The time difference information corresponds to a unique hyperbolic line where each of a particular pair of LORAN C transmitters serves as the foci.

A LORAN C position is derived from the intersections of two hyperbolic time-difference lines as illustrated in Figure 3-3.

The hyperbolic time difference lines are known as line-of-position (LOP). The intersection of LOP 12 and LOP 13 determines the position of a LORAN C receiver with respect to transmitter 1, 2 and 3. The geographic position of each transmitter is maintained in the Mercury 1960 datum. Thus, the geographic position of the intersection of LOP 12 and LOP 13 can be computed. The information content of the LORAN C signal is a function of the random noise corrupting the measurements

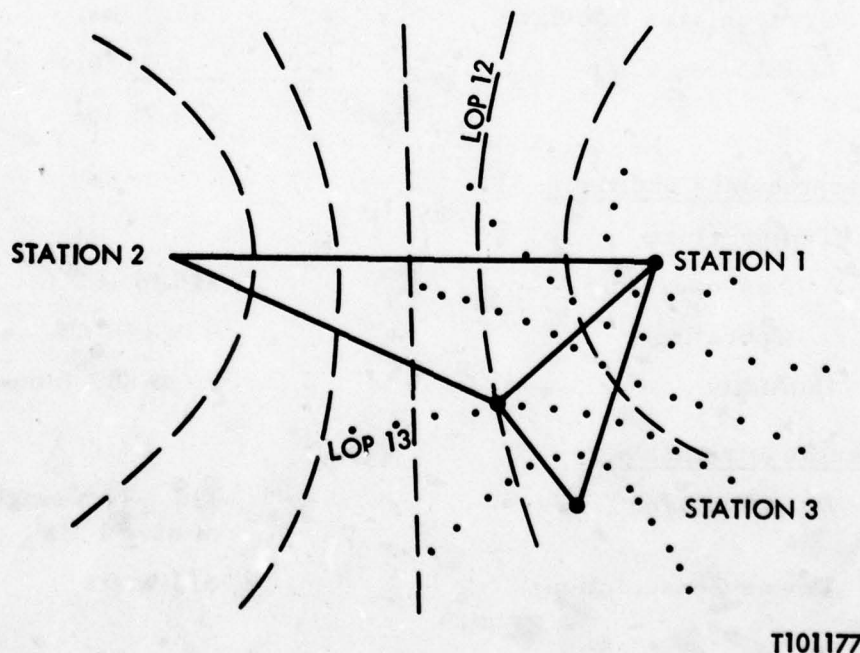


Figure 3-3. Three-Station LORAN C Geometry

and the geometry of the intersecting LOPs. The effects of random noise on the Loran-C signals can be reduced by employing an algorithm that will sequentially process the measurements. The net result is an averaging or smoothing effect which reduces the noise. The geometry of the LOP crossing angles determines how well the position can be measured.

KALMAN FILTER IMPLEMENTATION

When the receiver is in motion, then a moving sequence of intersecting LOPs are obtained. Thus, the receiver measurements are given by

$LOP_a(t_1)$,	$LOP_b(t_1)$,	$LOP_c(t_1)$	for time t_1
$LOP_a(t_2)$,	$LOP_b(t_2)$,	$LOP_c(t_2)$	for time t_2
$LOP_a(t_3)$,	$LOP_b(t_3)$,	$LOP_c(t_3)$	for time t_3
⋮	⋮	⋮	⋮
⋮	⋮	⋮	⋮
⋮	⋮	⋮	⋮
$LOP_a(t_n)$,	$LOP_b(t_n)$,	$LOP_c(t_n)$	for time t_n

The Loran-C receiver basically provides position data. By properly modeling the dynamics of the vessel and employing a Kalman filter estimation algorithm, both the position and velocity of the vessel can be obtained. The Kalman filter algorithm estimates the velocity components of the vessel by taking into account the derived correlation of velocity with the position errors. The dynamics of the vessel (at time t_k) are described by the 4x1 state vector:

$$x_k = \begin{bmatrix} LT \\ LN \\ Ve \\ Vn \end{bmatrix}_{t_k} \begin{array}{ll} \text{Latitude} & (\text{radians}) \\ \text{Longitude} & (\text{radians}) \\ \text{Velocity east} & (\text{meters/sec}) \\ \text{Velocity north} & (\text{meters/sec}) \end{array}$$

The purpose of the Kalman filter is to minimize errors in the system dynamics X by computing a correction vector \bar{X} and employing this to calibrate X . The 4x1 correction vector \bar{X} is defined by:

$$\bar{X} = \begin{bmatrix} \delta LT \\ \delta LN \\ \delta Ve \\ \delta Vn \end{bmatrix} \begin{array}{ll} \text{Latitude error} & (\text{meters}) \\ \text{Longitude error} & (\text{meters}) \\ \text{Velocity error, east} & (\text{m/sec}) \\ \text{Velocity error, north} & (\text{m/sec}) \end{array}$$

The filter sequentially processes the Loran-C measurements in order to provide the best estimate of the vessel's position. The gyro-compass input is used as an aid to further refine the navigation accuracy.

Up to three Loran-C time differences from the receiver are processed sequentially by a software subprogram called LORAN, as shown in Figure 3-4. This program computes the Kalman filter input parameters Z (observation error in meters), H (1x4 measurement matrix) and R (observation noise covariance of Z).

The Kalman filter observation error Z is defined as the difference between the measured and predicted time differences, converted to units of distance:

$$Z = (TD - TD^p)C$$

where

TD = measured time difference (seconds)

TD^p = predicted time difference (seconds)

C = propagation velocity of Loran-C signal (m/sec)

Z is computed for each station pair by the formula:

$$Z_{sm} = [TD_{sm} - (CD_s - CD_m) - (\sigma_s - \sigma_m) - (R_s^p - R_m^p)/C]C \quad (1)$$

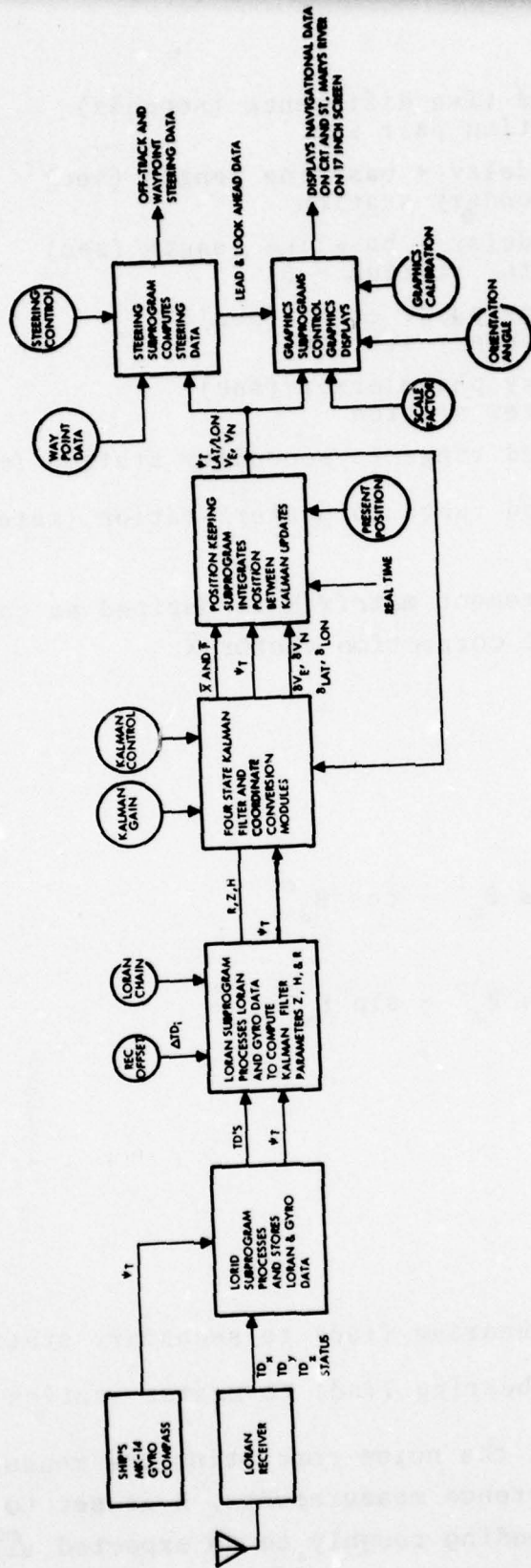


Figure 3-4. Simplified Block Diagram of System Operation

where

- TD_{sm} = measured time difference (seconds)
for station pair s,m
- CD_s = coding delay + baseline length (sec)
for secondary station
- CD_m = coding delay + baseline length (sec)
for master station = 0
- σ_s = secondary phase error (sec)
for secondary station
- σ_m = secondary phase error (sec)
for master station
- R_s^ρ = predicted range to secondary station (meters)
- R_m^ρ = predicted range to master station (meters)

The 1x4 Kalman measurement matrix H is defined as the sensitivity of Z with respect to the correction vector \bar{X} :

$$H = \frac{\partial Z}{\partial \bar{X}} \quad (2)$$

and is computed by:

$$H(1) = \frac{\partial Z}{\partial LT} = \cos B_m^\rho - \cos B_s^\rho$$

$$H(2) = \frac{\partial Z}{\partial LN} = \sin B_m^\rho - \sin B_s^\rho$$

$$H(3) = \frac{\partial Z}{\partial Ve} = 0$$

$$H(4) = \frac{\partial Z}{\partial Vn} = 0$$

where

B_s^ρ = predicted bearing (rad) to secondary station

B_m^ρ = predicted bearing (rad) to master station

R is the covariance of the noise corrupting the measurements. For the Loran-C time difference measurements, R is set to a constant of 1300 meters², corresponding roughly to an expected $\sqrt{1300} = 36$ meters of positional jitter.

The predicted ranges and bearing angles are computed from the Kalman-derived position of the vessel (state vector), dead reckoned to the time of the present measurement by the position keeping subprogram POSKP according to the formulas:

$$X_{k+1}^{\rho} = \begin{bmatrix} LT \\ LN \\ Ve \\ Vn \end{bmatrix}_{t_{k+1}}^{\rho} = \begin{bmatrix} LT_k + \Delta t Vn_{k+1}/Re \\ LN_k + \Delta t Ve_{k+1}/[Re \cos LT_{k+1}] \\ Ve_k \\ Vn_k \end{bmatrix} \quad (3)$$

where

X_{k+1}^{ρ} = predicted value of state at time k+1 based on information available at time k

t_{k+1} = time of present measurement

t_k = time of last measurement

Δt = $t_{k+1} - t_k$

Re = equatorial radius of earth

The Z, H and R values for a given time difference measurement are passed to the Kalman filter subprogram CORCN, which computes the correction vector \bar{X} per the following process.

The correction vector \bar{X} has an associated error covariance matrix P given by:

$$P = E(\bar{X} \bar{X}^T)$$

When the Kalman filter routine is started, the error covariance matrix is assigned an initial value P_0 :

$$P_0 = \begin{bmatrix} 10^8 & 0 & 0 & 0 \\ 0 & 10^8 & 0 & 0 \\ 0 & 0 & 2500 & 0 \\ 0 & 0 & 0 & 2500 \end{bmatrix} \begin{matrix} \text{meters} \\ \text{meters} \\ (\text{m/sec})^2 \\ (\text{m/sec})^2 \end{matrix}$$

The error covariance is extrapolated between measurements by:

$$P_e = \Phi P_k \Phi^T + Q \quad (4)$$

where the state transition matrix for any time interval is given by:

$$\Phi = \begin{bmatrix} 1 & 0 & 0 & \Delta t \\ 0 & 1 & \Delta t & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Q is the state noise matrix given by:

$$Q = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & .001 & 0 \\ 0 & 0 & 0 & .001 \end{bmatrix} \begin{array}{l} \text{meters} \\ \text{meters} \\ (\text{m/sec})^2 \\ (\text{m/sec})^2 \end{array}$$

P_k = error covariance matrix at time t_k

$\Delta t = t_{k+1} - t_k$

The values used in the noise matrix affect the response of the filter to changes in the speed and heading of the vessel, and are adjusted experimentally. The extrapolated error covariance is used to compute the 4x1 Kalman gain matrix:

$$K = P_e H^T [H P_e H^T + R]^{-1} \quad (5)$$

Finally, the gain is used to compute the correction vector by:

$$\bar{X} = KZ \quad (6)$$

The gain K performs two functions. It transforms the measurement error Z into the proper units of the correction vector \bar{X} , and it weights the measurement error to determine what percentage should incorporate into \bar{X} .

Having processed this one time difference measurement, the error covariance is updated to its optimum value by:

$$P_n = [I - KH]P_e \quad (7)$$

where

I = Identity matrix

To complete the Kalman filter process for this one time difference measurement at time t_{k+1} , we add the computed correction vector to the predicted state vector to get the new state vector:

$$X_{k+1} = X_{k+1}^p + \bar{X} \quad (8)$$

This process (equations 1,2,3,5,6,7,8) is now repeated for the next available time difference measurement at time t_{k+1} . (NOTE: The covariance extrapolation of equation 4 is done only once per measurement time, and is not repeated for each individual measurement.) We compute a new Z and H, using predictions based on the Kalman present position from equation (8), corrected for the first time difference. The gain K is computed from the updated error covariance, P_n , from equation (7).

After all available time differences are processed at time t_{k+1} , we then go through an identical iteration for the gyrocompass measurement. We have:

$$Z = G - G^p \quad (9)$$

where

G = measured ship's heading from gyrocompass (rad)

G^p = predicted ship's heading

$$= \tan^{-1}(V_e/V_n)$$

The measurement matrix H is computed by:

$$\begin{aligned} H(1) &= \frac{\partial Z}{\partial LT} = 0 \\ H(2) &= \frac{\partial Z}{\partial LN} = 0 \\ H(3) &= \frac{\partial Z}{\partial Ve} = \frac{Vn}{Ve^2 + Vn^2} \\ H(4) &= \frac{\partial Z}{\partial Vn} = \frac{-Ve}{Ve^2 + Vn^2} \end{aligned} \tag{10}$$

For both Z and H, the values used for Ve and Vn are those resulting from the new state vector X (equation 8) after all time difference measurements have been processed.

The velocity terms in the denominator of (10) make the computation unstable at low velocities. To alleviate the problem, the gyrocompass measurement is not processed if vessel speed = $\sqrt{Ve^2 + Vn^2}$ drops below 2 miles per hour.

For the gyrocompass measurement, R is set to a constant of 0.0004 radians², representing an expected $\sqrt{0.0004} = .02$ radians = 1 degree of angular jitter.

As with the Loran-C data, the Z, H and R values are passed to the Kalman filter program CORCN which computes a correction vector X using (5) and (6), updates the error covariance matrix using (7), and gets the new state using (8).

The actual software implementation does not actually adjust the state vector per (8) after each measurement is processed. Rather, the individual contributions to the correction vector from each available time difference plus the gyrocompass are accumulated, and the net correction is made per (8) only once per measurement time. The following correction vector computation accomplishes this accumulation, and is used in place of (6):

$$\bar{X}' = \bar{X} + K(Z - H\bar{X}) \quad (11)$$

where

\bar{X} = accumulated correction vector
prior to measurement Z

\bar{X}' = net correction including measurement Z

After \bar{X} is computed from all measurements, it is added to the state vector per (8) and set to zero for use in equation (11) at the next measurement time. Thus the sequence at one measurement time is:

For time difference "a"

$$\begin{aligned} \bar{X}_a &= K_a(Z_a - H_a\bar{X}) \\ &= K_a Z_a \quad (\text{since } \bar{X} = 0 \text{ at start}) \end{aligned}$$

For time difference "b"

$$\bar{X}_b = \bar{X}_a + K_b(Z_b - H_b\bar{X}_a)$$

For time difference "c"

$$\bar{X}_c = \bar{X}_b + K_c(Z_c - H_c\bar{X}_b)$$

For gyrocompass

$$\bar{X}_g = \bar{X}_c + K_g(Z_g - H_g\bar{X}_c)$$

And finally

$$X_{k+1} = X_{k+1}^0 + \bar{X}_g$$

3.4.1 MICROLOCATOR LORAN RECEIVER

GENERAL

The LORAN receiver assembly consists of three units: Teledyne Marine Microlocator receiver (Model TDL-708), antenna assembly, and a LORAN/computer interface board. See Figure 3.4-1. Digital data from the receiver is applied to the Microprogrammable Computer via the interface board. The receiver is completely automatic; no operator intervention is required after turn-on.

The antenna is a seven foot whip with an integral antenna coupler housing which weighs approximately 4.5 pounds. This antenna is specifically designed for use in the severe marine environment. It has ruggedized construction, static discharge ball on end, and wall mount on vertical surfaces or masts. Antenna assembly is supplied with 150 feet of RG-58 cable.

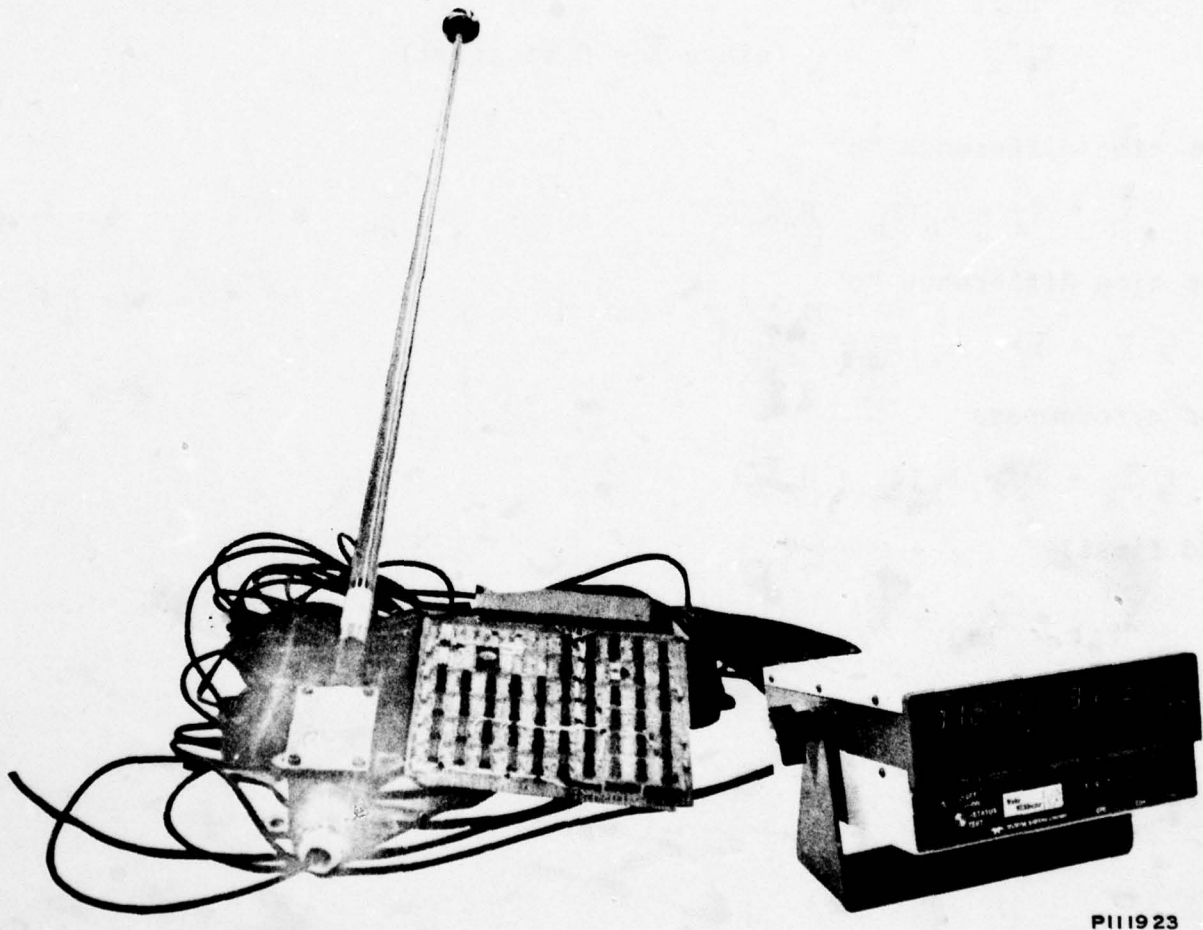


Figure 3.4-1. LORAN Receiver Assembly

The receiver is 9.6 inches wide, 6.75 inches high, 11.75 inches long and weighs approximately 8.25 pounds. A power control/status switch on the front panel allows the operator to monitor status anytime.

SPECIFICATIONS

Sensitivity (Acquisition & Track at minimum SNR conditions)	10 μ v RMS at 3rd cycle	
Input Dynamic Range	90 dB, 10 μ v to 300 mv	
Signal Unbalance	60 dB, at 0.1 μ sec max TD error	
Envelope/Cycle Discrepancy	+4 μ sec at -10 dB SNR	
Velocity Envelope	0 to 1200 feet/sec at -10 dB SNR	
Minimum SNR (Acquisition) (Tracking)	-14 dB -25 dB	
Number of Stations Tracked	5 (Master and 4 Secondaries)	
Acquisition Time to Full Accuracy		
<u>Chain-Rates</u>	<u>Time</u>	<u>SNR</u>
Slowest (9999)	8 min.	-10 dB
Fastest (3930)	1 min.	+6 dB

RF Interference Rejection - 2 manually adjusted notch filters. Each filter has center frequency rejection > 30 dB. Bandwidth of each filter is 3 KHz at 3 dB rejection points, and each filter is tunable from 70 to 130 KHz.

POWER REQUIREMENTS

Input Power 115 + 10% VAC
 50 - 70 Hz

Power Consumption Less than 25 Watts

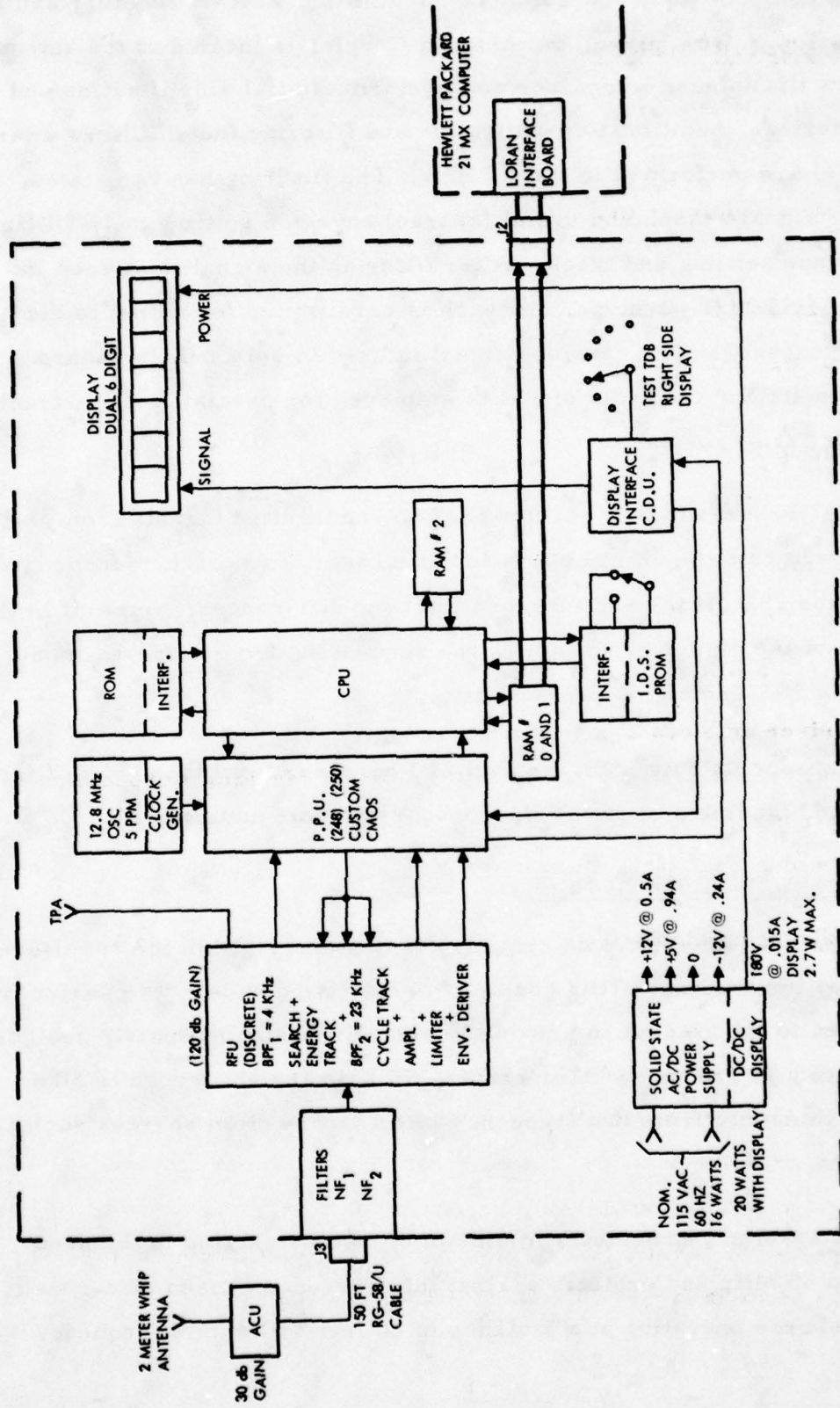
ENVIRONMENTAL RESTRAINTS

Operating Temperature	Receiver	0°C to +50°C
	ACU	-20°C to +60°C
Humidity	Receiver	95%
	ACU	Watertight
Vibration		10 - 30 Hz 0.03 inches double amplitude

GENERAL DESCRIPTION

The receiver employs a hardlimiting design, a technique whereby the statistical properties of noise and the transient (dynamic) properties of a non-linear phaselock loop complement one another to yield better performance than obtainable in a standard linear receiver.

The hardlimiting also enhances performance because it provides immunity to burst type noise. Burst noise in a linear receiver is weighted (amplitude integrated) over its life span, while only the duration corrupts the hardlimited receiver. The 1 db loss in signal strength (which is practically negligible) due to hardlimiting is derived from the assumption of Gaussian noise. In practice it is well known that true atmospheric noise is not Gaussian but has a considerably higher proportion of the power contained in the spikes (or burst). Thus, there is actually an increase in performance from 6 to 14 db in favor of the hardlimited approach.



T104923

Figure 3.4-2. Microlocator Block Diagram

The basic components of the Teledyne hardlimited LORAN receiver are shown in Figure 3.4-2. As shown, the Antenna Coupler is located at the antenna where it matches the antenna impedance and performs initial amplification and gross filtering. Additional amplification and filtering (notch filters where necessary) are performed in the RF unit. The filtering has two states, 4 KHz for signal search and initial (coarse) envelope settling and 23 KHz for fine envelope settling and track. After filtering the signal is divided into two channels, cycle and envelope, and each is hardlimited for output to the Digital Processor. The envelope signal is used to select the standard sampling point and the cycle signal is employed for precision phase tracking of the SSP zero-crossing.

The Digital Processor Unit accepts the two hardlimited signals from the RF unit and performs the digital operations necessary to search, synchronize, settle on the SSP, track and measure the time differences. Implicit in the operation of the digital processor is the sequencing from mode-to-mode based upon SNR and signal repeatability.

Time difference outputs from the Digital Processor are then provided for display and transmission to the microprogrammable computer.

FUNCTIONAL DESCRIPTION

The antenna coupler electronic circuitry is contained within the enclosure provided by the antenna. This coupler is an active device. Its passive front end is tuned to the antenna to provide bandpass filtering primarily designed to eliminate high frequency interference 375 KHz and above, while also providing immunity from low frequency interference from sources such as power lines.

This filter assembly provides a minimum of 60 db rejection in the band 375 KHz to 30 MHz and protects against interferences caused by a 1 kw radiating source operating at a distance of 20 feet within this frequency

band. Protection diodes in front of the active elements of the coupler prevent potentially damaging voltage transients from reaching the sensitive stages of Receiving Set. Power gain (i. e., impedance transformation from the high level of the antenna to the low impedance of the transmission cable) is provided in the active coupler circuitry. This signal (cycle) is used by the pulse processor to search for the master and secondary signals. For LORAN-C signals, this is accomplished by continuously comparing the cycle signal at eight points which are 1,000 microseconds apart to detect the phase code of the eight pulse master or secondary transmissions. This process will be described later during the discussion of the operation.

Two manual notch filters are adjustable externally to notch out (30 db min.) any interfering signals (in the 70 to 130 KHz frequency range) which may be present in the signal environment of the particular area of operations. The output of the notch filters is applied to the 4 KHz narrow band filter and the 23 KHz wide band filter.

During the search and coarse envelope 1 modes, when maximum sensitivity is required, the bandwidth is set to 4 KHz by the pulse processor. In the remaining modes of operation, the pulse processor selects the 23 KHz bandwidth. The wide band changes the shape of the rf pulses so that a more accurate tentative tracking point is achieved. The rf bandpass filter applies the signal to the envelope deriver and the wide band limiter amplifier.

The envelope deriver is used to generate a signal with a phase reversal at the adjusted reference cycle of each LORAN-C pulse. This phase reversal is required by the pulse processor to detect the tracking point within the LORAN pulse. The envelope deriver receives the LORAN signal output of the rf bandpass filter and sends this signal through a delayed and an undelayed signal path. The signal in the delayed path is delayed five microseconds (1/2 cycle at 100 KHz) amplified and applied to an adder circuit.

The signal in the undelayed path is applied directly to the adder circuit and added to the delayed signal. Since the two signal inputs to the adder are 180 degrees out of phase, they are cancelled (null) at the point where they are of equal amplitude. The reason for amplifying the delayed signal prior to the addition is to assure the delayed signal and undelayed signal are of equal amplitude only at the sampling point. (3rd cycle).

The envelope limited amplifier hard limits the output of the envelope deriver adder circuit to produce a squarewave output. The envelope signal is in phase with the cycle signal to the left of the null and out of phase with the cycle signal to the right of the null. This phase reversal is the result of the addition of the delayed and undelayed signals in the envelope deriver. That is, the in-phase portion of the envelope occurs while the amplitude of the undelayed signal is greater than the delayed signal. The out-of-phase portion of the envelope occurs while the amplitude of the delayed signal is greater than the undelayed signal. The envelope signal is used by the pulse processor to determine the sampling point within the LORAN pulse.

The Pulse Processor Unit (PPU) receives the hard limited LORAN signals from the limiter and processes these signals. Since some circuits of the PPU are time shared, the operation being performed at a given time depends upon the mode of operation. The Control Processor Unit (CPU) causes the PPU to operate in the four orderly modes.

1. Initial Search (Master only)
2. Search (Master or Secondary)
3. Coarse Envelope (Not in track or search)
4. Track

In track the CPU outputs a full message to the PPU after each pulse group. It is used to trigger a set of seven sample signals (6 cycle strobes and 1 envelope strobe). The cycle strobes are arranged in three pairs. Within a pair the strobes are 2.5 microseconds apart (except for the second pair which is 7.5 microseconds during Fine Envelope Track, and Dead Reckoning. The strobes derive the Guard, Phase Track, SNR, and Energy Track which are used to sample the envelope hard limited signals. An accumulation of these samples are constantly processed by the receiver's program to compute time differences of the received LORAN signals and stored in the Random Access Memory (RAM).

The Microlocator contains 6144 words of Read Only Memory (ROM) and 768 words of Random Access Memory (RAM).

The computed time differences, which are non-averaged, are stored in RAMS 0 and 1. This data is also sent to the LORAN/Gyro Interface Board where it is temporarily stored until the 21 MX computer is ready to accept the data.

The CPU outputs data to the I/O chip, and then the data is sent to the control panel's indicators. Six (6) segment displays are used to display time difference in increments of 100 nanoseconds from 0 to 99999.9 microseconds. The time differences are averaged over a 128 GRI time interval (6.3 seconds) by the CPU before they are displayed on the panel. In addition, the displays may be used to indicate status, secondary TDs, velocity, SNR, and envelope count by rotary switch selection. Also 10 nanosecond resolution is available by a slide switch selection.

The Initialization Data is used to provide application, or mission oriented data to the Central Processor unit. It is made of essentially two components, a Rockwell I/O chip and an Intel 1702A ultra-violet erasable PROM. The PROM is socket mounted so that it can be readily removed for reprogramming or replacement.

This module performs the function of providing the information required by the processor to designate and select the stations to be operated on or designates test parameters when operated in self-test mode. An ultra-violet erasable PROM is used to perform this function because of the relatively large number of bits required for the four secondary operation of this unit and the requirement for envelope data (pulse shape definition) for the extremely rapid acquisition operation of this receiver. A single PROM covers one entire LORAN C or D chain without modification. A different PROM would be inserted if the receiver were to be operated from the front panel thumbwheel switches or moved to another four or five station chain.

Two oscillators are used in the receiver. A 3.8 MHz crystal controlled oscillator controls the CPU timing, and a 12.8 MHz TCX0 oscillator is used to produce timing signals for the processing operations controlled by the PPU.

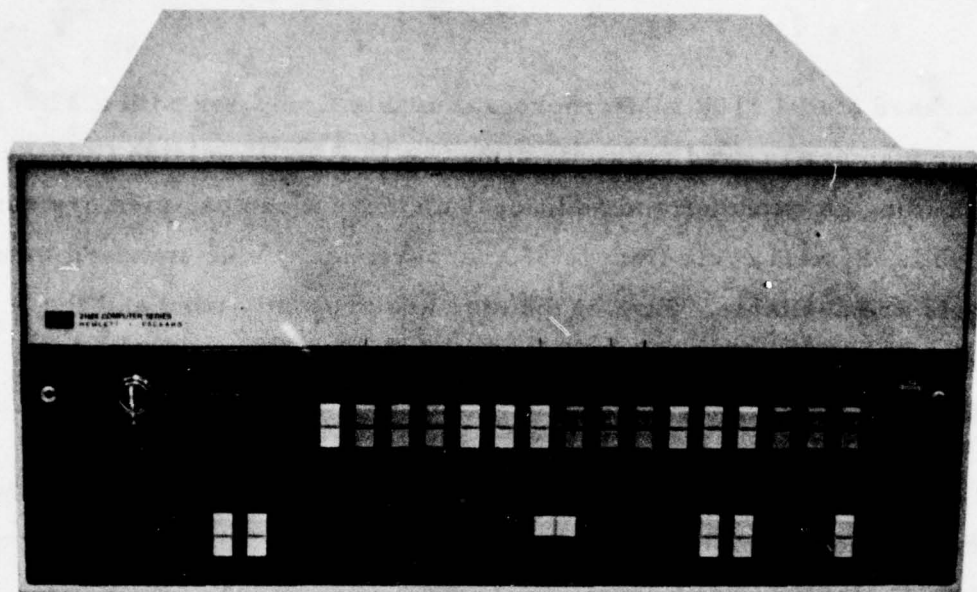
3.4.2 21 MX COMPUTER

GENERAL

A Hewlett Packard Model 2108 A Microprogrammable Computer with a 32K semiconductor memory is used for controlling the LORAN Precision Guidance System. By adding an extender and additional memory modules, memory can be expanded to 96K. System cycle time is 650 nanoseconds. Nine standard input/output channels are available. Five of the nine are presently used and the remaining four can be used for additional peripheral equipment.

Additional features include a fast FORTRAN processor which consists of 20 microcoded subroutines that provides 2 to 20-fold increase in program execution. Other features include memory parity check, and a vectored priority interrupt system.

The computer is supplied with a programmer's panel for monitoring and making program changes. The computer is a rack-mounted self-contained unit 19 inches wide, 8.75 inches high, 24.5 inches in depth. See Figure 3.4-3.



P107193

Figure 3.4-3. 21 MX Computer

COMPUTER SPECIFICATIONS

Processor

Control Store

Type: Bipolar LSI ROM Semiconductor

Size: Up to sixteen 256-word modules

Control Processor

Address Space: 4,096 words

Word Size: 24 bits

Word Formats: Four

Word Fields: Five

ROM Cycle: 325 Nanoseconds

Registers

Accumulators: Two (A and B), 16 bits each

Index: Two (X and Y), 16 bits each

Memory Control: Two (T and P), 16 bits each; and one (M)
15 bits

Supplementary: Two (overflow and extend) one bit each

Manual Data: One (display) 16 bits

Scratch Pads: Twelve, 16 bits each

Processor Timing 10.204-MHz crystal-controlled oscillator
provides 196 nanosecond pulses

Memory Parity Check Monitors all words read from memory.
Switch selectable to either halt or ignore
parity when detected. A parity indication
is displayed on panel.

Power Fail Interrupt Highest priority interrupt. Detects power
failure and generates an interrupt to trap
cell for user-written power-failure routine.
A minimum of 500 us is available for the
routine.

Memory

Density: Medium density: 32K words (four modules at 8K words per module)

Type: N-channel MOS/RAM semiconductor

Word Size: 16 bits plus parity bit

Page Size: 1,024 words

System Cycle Time: 650 nanoseconds

Execution Speed

1.96 μ sec. All instructions except IS2 and extended arithmetic

Input/Output

Priority Interrupt: Multilevel vectored priority interrupt determined by interface channel assignments.

I/O Channels: Nine internal channels

Power Requirements

Input Voltage: 110V \pm 20%, single phase 60 Hz

Power Consumption: 525W Maximum

Line Overvoltage

Protect: Input crowbar in series with line breaker.

Output Protect: All voltages protected against overvoltage and overcurrent.

Environmental Conditions

Temperature:

Non-Operating: -40 $^{\circ}$ to 75 $^{\circ}$ C

Operating: 0 $^{\circ}$ to 55 $^{\circ}$ C

Humidity: 20 to 95% at 20 $^{\circ}$ to 40 $^{\circ}$ C

Heat Dissipation: 1795 BTUs/Hour

Altitude:

Non-Operating: Sea level to 25,000 ft.

Operating: Sea level to 15,000 ft.

Vibration and Shock:

Vibration: 1g at 44 cycles per second

Shock: 30 G for 11 MS over a 1/2 sinewave
shape

FUNCTIONAL DESCRIPTION

The computer has eight 16-bit working registers which can be selected for display and modification by operator panel controls; two 1-bit registers; and one 16-bit display register. The functions of these registers are described in following paragraphs.

- a. A Register - The A-register is a 16-bit accumulator that holds the results of arithmetic and logical operations performed by programmed instructions. This register can be addressed directly by any memory reference instruction as location 000000 (octal), thus permitting interrelated operations with the B-register (e.g., "add B to A," "compare B with A," etc.) using a single-word instruction.
- b. B-Register - The B-register is a second 16-bit accumulator, which can hold the results of arithmetic and logic operations completely independent of the A-register. The B-register can be addressed directly by any memory reference instruction as location 000001 (octal) for interrelated operations with the A-register.
- c. M-Register - The M-register holds the address of the memory cell currently being read from or written into by the CPU.
- d. T-Register - All data transferred into or out of memory is routed through the T-register. When displayed, the T-register indicates the contents of the memory location currently pointed to by the M-register. The A- or B-register contents are displayed if the M-register contents are 000000 or 000001, respectively.

- e. P-Register - The P-register holds the address of the next instruction to be fetched from memory. Since this is a "lookahead" register, the P-register contents will frequently differ from the M-register contents.
- f. S-Register - The S-register is a 16-bit utility register. In the halt or run mode, the S-register can be loaded via the display register. In the run mode, the S-register can be addressed as an input/output device (select code 01) and can input and output data to and from the A- and B-registers.
- g. Extend Register - The one-bit extend register is used to link the A- and B-registers by rotate instructions or to indicate a carry from the most-significant bit (bit 15) of the A- or B-register by an add instruction (ADA, ADB) or an increment instruction (INA, INB, but not ISZ). This is of significance primarily for multiple-precision arithmetic operations. If already set (logic 1), the extend bit cannot be cleared by a carry. However, the extend bit can be selectively set, cleared, complemented, or tested by programmed instructions. When the operator panel EXTEND indicator is lighted, the extend bit is set.
- h. Overflow Register - The one-bit overflow register is used to indicate that an add instruction (ADA, ADB), divide instruction (DIV), or an increment instruction (INA, INB, but not ISZ) referencing the A- or B-register has caused (or will cause) the accumulators to exceed the maximum positive or negative number that can be contained in these registers. The overflow bit can be selectively set, cleared, or tested by programmed instructions. The operator panel OVERFLOW

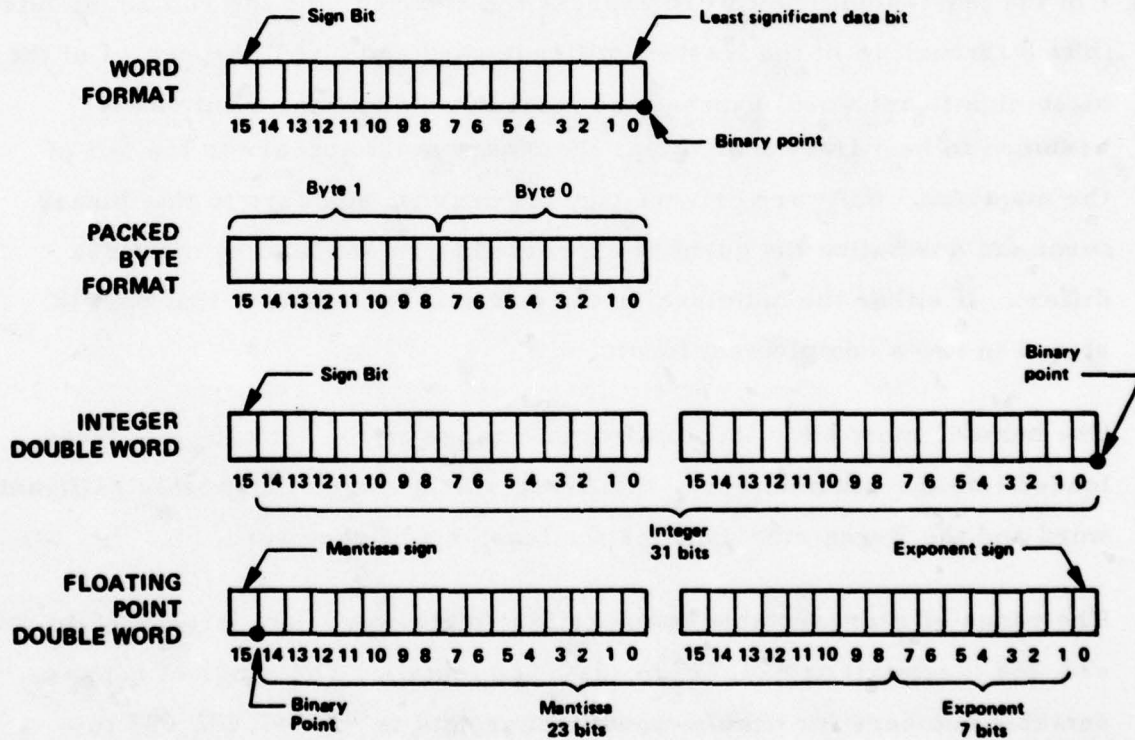
indicator will remain lighted until the overflow is cleared. The overflow bit cannot be set by any shift or rotate instruction except Arithmetic Shift Left (ASL).

- i. Display Register - The display register, which is included on the operator panel, provides a means of displaying and modifying the contents of the six 16-bit working registers when the computer is in the ahlt mode. An illuminating indicator is located directly above each of the 16 bit switches; a lighted indicator denotes a logic 1 and an unlighted indicator denotes a logic 0. When the computer is in the run mode, the contents of the S-register are displayed automatically.
- j. X- and Y-Registers - These two 16-bit registers, designated X and Y, are accessed through the use of 30 index register instructions and 2 jump instructions. These registers may also be accessed from the operator panel by entering the special register display mode.
- k. Special Register - A special register(s) display mode provides the capability of displaying and/or modifying the contents of the following X and Y registers, scratch pads S3 through S12, CPU counter, central interrupt register, overflow and extend registers.

DATA FORMATS

As shown in Figure 3.4-4, the basic data format is a 16-bit word in which bit positions are numbered from 0 through 15 in order of increasing significance. Bit position 15 of the data format is used for the sign bit; a logic 0 in this position indicates a positive number and a logic 1 in this position indicates a negative number. The data is assumed to be a whole number and the binary point is therefore assumed to be to the right of the number.

The basic word can also be divided into two 8-bit bytes or combined to form a 32-bit double word. The byte format is used for character-oriented input/output devices; packing two bytes of data into one 16-bit word is accomplished by software drivers. In I/O operations, the higher-order byte (byte 1) is the first to be transferred.



T107204

Figure 3.4-4. Data Formats

The integer double-word format is used for extended arithmetic in conjunction with the extended arithmetic instructions. Bit position 15 of the most-significant word is the sign bit and the binary point is assumed to be to the right of the least-significant word. The integer value is expressed by the remaining 31 bits. When addressing a double word in memory, the address refers to the least-significant word location; the next higher memory address contains the most-significant word. When loaded into the accumulators, the B-register contains the most-significant word and the A-register contains the least-significant word.

The floating-point double-word format is used with floating-point software. Bit position 15 of the most-significant word is the mantissa sign and bit position 0 of the least-significant word is the exponent sign. Bits 1 through 7 of the least-significant word express the exponent and the remaining bits (bits 8 through 15 of the least-significant word and bits 0 through 14 of the most-significant word) express the mantissa. Since the mantissa is assumed to be a fractional value, the binary point appears to the left of the mantissa. Software drivers convert decimal numbers to this binary form and normalize the quantity expressed (sign and leading mantissa differ). If either the mantissa or the exponent is negative, that part is stored in two's complement form.

The number must be in the approximate range of 10^{-38} to 10^{+38} . When loaded into the accumulators, the A-register contains the most-significant word and the B-register contains the least-significant word.

The range of representable numbers for single-word data is +32,767 to -32,768 (decimal) or +77,777 to -100,000 (octal). The range of representable numbers for double-word integer data is +2,147,483,647 to -2,147,483,648 (decimal) or +17,777,777,777 to 20,000,000,000 (octal).

MEMORY ADDRESSING

- a. Paging - The computer memory is logically divided into pages of 1,024 words each. A page is defined as the largest block of memory that can be directly addressed by the address bits of a single-length memory reference instruction. These memory reference instructions use 10 bits (bits 0 through 9) to specify a memory address; thus, the page size is 1,024 locations (2000 octal).
- b. Reserved Memory Location - The uppermost 64 locations of memory are reserved for the initial binary loader. The initial binary loader for the Sykes Disc Unit or tape reader is permanently resident in a read-only memory (ROM) and loaded into the uppermost 64 memory locations by a pushbutton switch (IBL) on the front panel. These 64 locations are not protected and therefore can be used for temporary storage of data, trap cells, buffers, etc.

INSTRUCTION FORMATS

The base set of instructions are classified according to format. There are five formats as follows:

- a. Memory Reference Instructions - The class of instructions, which combines an instruction code and a memory address into one 16-bit word, is used to execute functions involving data in a specific memory location. Examples are storing, retrieving, and combining memory data to and from the the accumulators (A- and B-registers) or causing the program to jump to a specified location in memory. Execution time for the various instructions runs from 1.94 to 2.92 μ s.

- b. Register Reference Instructions - These instructions manipulate bits in the A-, B-, and E-registers. Typical operations are clear and/or complement a register, conditional skips, and register increment. Execution time for typical instructions is 2.59 to 2.92 μ s.
- c. Input/Output Instructions - Input/output instructions use bits 6 through 11 for a variety of I/O instructions and bits 0 through 5 to apply the instructions to a specific I/O channel. This provides the means of controlling all peripherals connected to the I/O channels and for transferring data to and from these peripherals. Execution time is from 2.59 to 3.89 μ s.
- d. Extended Arithmetic Memory Reference Instructions - The extended arithmetic memory reference instructions include an instruction code and a memory address. The first word specifies the extended arithmetic class, and the second word specifies the memory address of the operand. Operations performed by the class of instructions are integer multiply and divide and double load and store. Execution time varies from 3.57 to 18.20 μ s, depending on instruction.
- e. Extended Arithmetic Register Reference Instructions - This class of instructions provides long shifts and rotates on the combined contents up the A- and B-registers, with execution times from 2.3 to 9 μ s.

FLOATING POINT INSTRUCTION

Six floating point instructions make it possible to add, subtract, multiply, and divide floating point numbers and to convert quantities from floating point format to integer format, or vice versa. Execution time for floating point instructions varies from 6.5 to 78.0 μ s.

INTERRUPT SYSTEM

The computer utilizes a vectored priority interrupt system which has distinct interrupt levels. Request for service is granted in a priority basis with lowest I/O channel 10_8 having highest priority.

Any device can be selectively enabled or disabled under program control, thus switching the device into or out of the interrupt structure. In addition, the entire interrupt system, except power fail and parity error interrupts, can be enabled or disabled under program control.

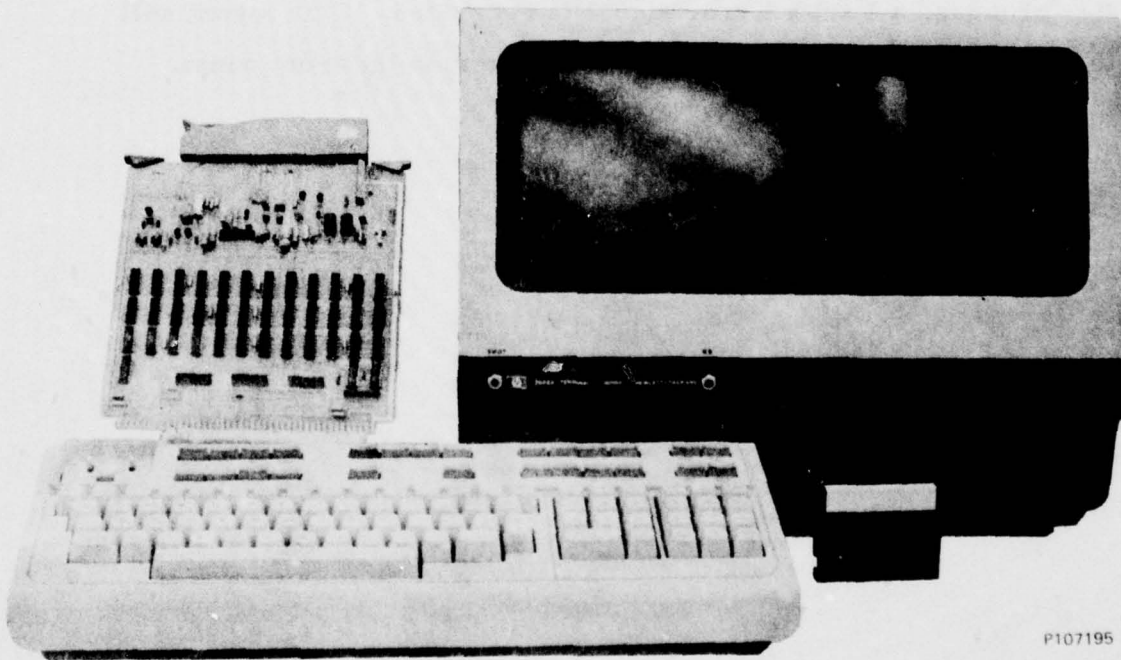
PARITY ERROR INTERRUPT

Parity checking of memory is done continuously. The parity logic generates correct parity for all words written into memory and monitors the parity of all words read out of memory. If a bit is either dropped or added in the transfer process, a Parity Error signal is generated. This signal will halt the computer and light the PARITY indicator on the front panel.

3.4.3 MINI DATA STATION

GENERAL

The Hewlett-Packard Model 2644A Mini Data Station consists of a detachable expanded typewriter keyboard and a 12 inch CRT display. The keyboard is used to control the operation of the LORAN Precision Guidance System, and for software development. While the 12 inch CRT displays navigational information during system operation. In addition, two tape transports that utilize mini cartridges for mass storage are located in the display unit.



P107195

HP-2644 Mini Data Station

MINIDATA STATION SPECIFICATIONS

Screen size:	5 inches x 10 inches
Screen capacity:	24 lines x 80 columns (1,920 characters)
Character size:	.097 inches x .125 inches
Refresh rate:	60 Hz
Memory:	
Control:	ROM - 12K bytes
User:	RAM - 6144 bytes
Cartridge tape:	Two mechanisms
Read/Write speed:	10 ips
Search/Rewind speed:	60 ips
Recording:	800 bytes/in
Mini cartridge:	110 kilobyte capacity
Keyboard:	Full ASCII Code Keyboard, 8 special function keys, and 16 additional control and editing keys; ten-key numeric pad; cursor pad; N-key roll-over, 4 foot cable.
Power requirements:	
Input voltage:	115 + 10% - 23%, 60 Hz \pm 1 Hz
Power consumption:	125 w max
Environmental:	
Non-operating	-10 to +65°C
Operating	5 to +40°C
Humidity	20 to 80% (non-condensing)
Vibration	.010 inches PP, 10 to 55 Hz, 3 axis
Shock	30G, 11 Ms, 1/2 sine

Size:

Display: 17.5"W x 18"D x 13.5"H

Keyboard: 17.5"W x 8.5"D x 3.5"H

Weight:

Display: 47 pounds

Keyboard: 7 pounds

FUNCTIONAL DESCRIPTION

Transfer of information between the Data Station and the Microprogrammable Computer is by an EIA RS 232 C interface with serial asynchronous operation and using ASCII Code. Data transfer rate is selectable by a BAUD RATE switch (110, 150, 300, 1200, or 2400 baud).

The Data Station has a 5-inch by 10-inch rectangular CRT providing a 1,920 character capacity in 24 lines of 80 characters per line. The characters are formed by a 7 X 9 dot matrix generated in a 9 X 15 dot character cell. Characters are refreshed at a 60 Hz rate.

Two tape transports which utilize mini cartridges for mass data storage and retrieval are located in the display unit. Each tape cartridge contains 140 feet of single-track 0.150 inch tape with a maximum formatted storage capacity of 110-K, eight-bit, data bytes. Read/Write speed is 10 inches/second.

Off-line operation allows operators to key-in and edit data such as graphics information software routine for storage on the mini cartridge.

The operating characteristics of the Data Station are controlled through firmware. The terminal's microprocessor manages memory allocation, data communications, keyboard scanning, and display control.

A 6K memory provides 6144 bytes of random access memory for storage. All Read/Write memory is accessed by the microprocessor.

Unit can be tested anytime by depressing a TEST button on the keyboard. A GO/NO-GO indication is displayed from results of an internal memory test, firmware test, tape transport test and display verification.

3. 4. 4 FLEXIBLE DISC SYSTEM

GENERAL

The Sykes Datatronics Model 7250 Dual Flexible Disc System, commonly referred to as a floppy disc system, interfaces with the microprogrammable computer. Two disk drives hold the diskettes that contain the operating and navigational programs.

Unit is in a rack mountable cabinet which is 11 inches high, 17 inches wide, and 26 inches in depth, and weighs approximately 55 pounds. The front panel contains two access doors through which the diskettes are inserted, a main POWER switch/indicator, and indicators to monitor the functions of each drive.

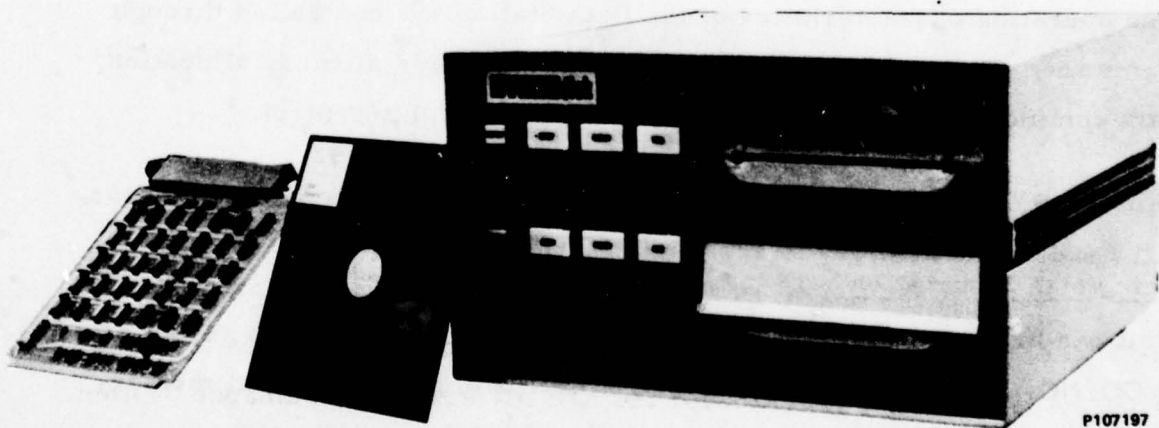


Figure 3. 4-5. Flexible Disc System

FLEXIBLE DISC SYSTEM SPECIFICATIONS

Data Transfer Rate	250,000 bits/sec
Recording Technique	Double Frequency
Drive Rotational Speed	360 RPM
Head	Read/Write with Tunnel Erase

Power Requirements:

Input Power	115 VAC \pm 10% @ 60 Hz \pm 0.5 Hz
Power Consumption	300 Watts

Environmental:

Non-Operating	-35°C to +60°C
Operating	+10°C to +38°C (7°C/hr maximum fluctuation)
Humidity	20 to 80% (non-condensing)

Vibration and Shock:

Vibration	1/2 G, 5 - 55 Hz
Shock	1/2 G \pm 10%, 1/2 Sine, 11 ms, 3 axis

Size: 11" H x 17" W x 26" D

Weight: 55 lbs

Functional Description

The Flexible Disc System controls the operation of two diskettes that contains the operating program for the LORAN Precision Guidance System. The disk located in drive 1 (bottom disk drive) is labeled the system disk.

This disk contains all the DOS III software routines (interrupt, input and output routines) which controls the operation of the system. The other diskette located in drive 2 (upper disk drive) is labeled the User disk. This diskette contains the operating programs associated with the navigation and graphics display.

Each diskette has a data capacity as follows:

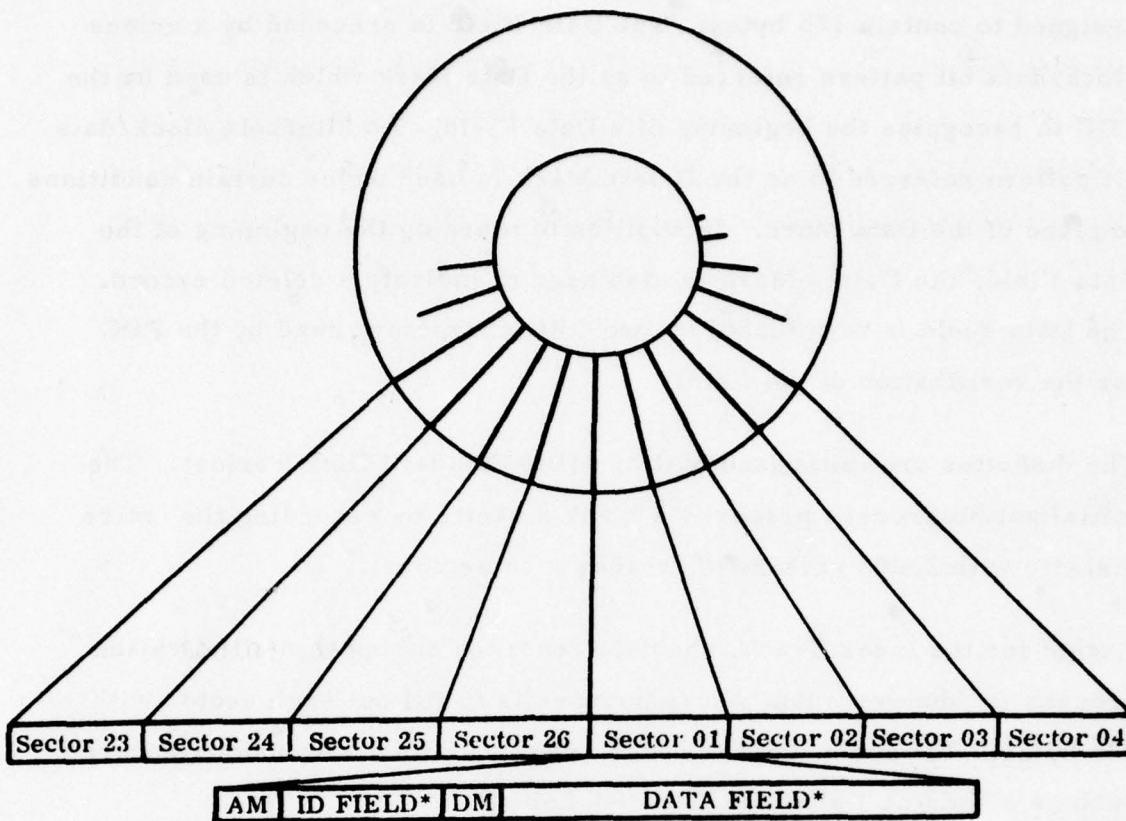
Number of tracks	77
Sectors per track	26
Bytes per sector	128
Bytes per track	3,328
Bytes contained on tracks 1 through 77	256,256 (2,050,048 bits)

DATA FORMAT

Information is arranged on a diskette in fixed length quantities of data called sectors which are magnetically written on tracks. A track is a circular band of area on a diskette which passes beneath the Read/Write head as the diskette revolves. Each diskette has 77 physical tracks numbered 00 through 76. Track 00, referred to as the Index Track, is the outermost track and Track 76 is the innermost tract.

Each track contains 26 sectors numbered 01 through 26. Each sector consists of an Identification (ID) Field and Data Field.

See Figure 3.4-6. The ID Field contains a track and sector value and is preceded by a unique clock/data bit pattern referred to as the Address Mark. The ID Field is terminated by two cyclic redundancy check (CRC) characters that are used by the Flexible Disk Controller (FDC) for verification of this field. The ID Field is followed by the Data Field which is



T107208

Address Mark (AM) - Identifies bytes between this address mark and the following Data or Delete mark as the ID field of the sector.

ID Field - Identifies the record contained in the Data Field by sector number and track number.

Data Mark or Delete Mark (DM) - A Data Mark indicates that the Data Field contains a good record; a Delete Mark indicates that the Data Field contains a deleted record.

Data Field - Contains a maximum of 128_{10} data bytes. If less than 128_{10} data bytes comprise the record, the Data Field is completed with fill bytes.

***NOTE:** The ID Field and the Data Field are each terminated by two Cyclic Redundancy Check (CRC) characters that are automatically generated and checked by the FDC.

Figure 3.4-6. Track Format

designed to contain 128 bytes. The Data Field is preceded by a unique clock/data bit pattern referred to as the Data Mark which is used by the FDC to recognize the beginning of a Data Field. An alternate clock/data bit pattern referred to as the Delete Mark is used under certain conditions in place of the Data Mark. In addition to marking the beginning of the Data Field, the Delete Mark is also used to indicate a deleted record. The Data Field is terminated by two CRC characters used by the FDC for the verification of the field.

The diskettes are initialized with the IBM Standard Disk Format. The initialization process prepares a blank diskette by recording the entire diskette with 2,002 sectors (77 tracks x 26 sectors).

Except for the Index Track, the data recorded during the initialization process is "dummy" data whose purpose is to fill out each sector with 128 bytes. The Index Track (Track 00) is recorded with unique records such as a Volume Label and Data Set Labels.

Data is transferred back-and-forth between the Microprogrammable Computer and Flexible Disc System (FDS) in an 8-byte format, plus status bits. Operation is completely asynchronous and the data output from the computer can be an even or odd number of bytes. The FDS will automatically block-a-data string into the necessary number of 128-byte records and record them as logically sequential sectors. Partial sectors are automatically filled with zeros.

Dual buffers are contained in the FDS which will hold two sectors of data (256 bytes).

Actual recording of data does not begin until the requested sector has been found on the disk and either one (or both) of the dual buffers is full

(128_{10} bytes). The dual buffer design permits data transfer and write/read overlap in that while the software program is outputting data to one of the dual buffers, the FDS is recording data onto the disk from the other buffer.

The FDS automatically performs the following operations when reading and writing data from or to, respectively, in the dual buffers which hold two sectors of data (256 bytes):

- a. Senses the IBM address "sync byte" preceding each sector;
- b. reads the sector address, calculates the CRC value and verifies it with the recorded IBM CRC bytes;
- c. if writing, then writes either a standard data sync byte on a "delete record" data sync byte (Programmer's option);
- d. calculates the CRC value while reading or writing the data;
- e. writes the data CRC bytes or reads and verifies the data CRC bytes;
- f. reads next sector as long as computer continues to transfer data.
- g. After a valid Write or Read Command is outputted by the computer, the disk drive will initiate a search for the requested track and sector.

The search process begins by determining the present track location of the Write/Read head. This is compared with the requested track and a differential and direction established. The head is stepped in or out to the requested track which is then read until the requested sector is found. The Write/Read head remains loaded during the entire search process unless the requested sector cannot be found within 7 to 8 revolutions

(approximately 1 second) resulting in a FAULT condition.
Every sector within a string of data is searched for by this algorithm.

STATUS

The status of the disk unit can be read at any time from the seven status lines to the computer interface as follows:

Data Service
Disk Ready
Busy
CRC Error
Disk Protect
Track 00
Fault

Data Service Status - Data Service status is set to a 1 when the unit is ready to accept a data byte from the Computer if in a Write mode or to transfer a data byte to the computer if in the Read mode. The Data Service status is reset to zero by performing the appropriate data transfer, or issuing a Terminate or Reset command.

Disk Ready Status - Disk Ready status is set to a 1 when the selected unit contains a diskette that is up to speed and the Power On delay is complete.

Busy Status - Busy Status is set to a 1 (and the BUSY indicator on the front panel is lighted) when the unit is in a Read or Write mode, during which it may be searching, reading, writing or waiting for data to be transferred. Busy Status is reset to zero when the operation has been terminated or a Reset command is output.

CRC Error Status - CRC Error Status is set to a 1 when the CRC bytes recorded at the end of a sector do not correlate with the data of that sector. This condition indicates a data error within that sector. CRC status is reset to zero by reading status or outputting a Reset command. Note that a Terminate command will not reset CRC status. CRC status for a buffered unit is available when Data Service status is set for transfer of a sector of data.

Disk Protect Status - Disk Protect Status is set to a 1 when the Disk Protect Indicator Switch on the front panel is enabled (light is on). Enabling of the Disk Protect Switch will inhibit writing of data on the disk.

Track 00 Status - Track 00 Status is set to a 1 when the Read/Write head is positioned at Track 00. The status line is reset to zero when the head is positioned at Tracks 1 through 76.

Fault Status - Fault Status is set to a 1.

3.4.5 GRAPHICS INTERFACE UNIT

GENERAL

The Megatek Model BP-742D-10 Graphics Interface Unit interfaces with the Microprogrammable Computer. It converts parallel data into analog signals for plotting in X and Y coordinates on a 17 inch graphics display. The analog information appears on the graphics screen as a collection of points, vectors or both. These points and vectors (lines) along with an intensity signal construct a representation of the St. Marys River shore line, channel banks, buoys, and other prominent geographical points. The Graphics Interface is a rack mountable self-contained unit measuring 19 inches wide, 3.5 inches high, 17 inches in depth, and weights approximately 26 pounds. The front panel contains a main POWER switch/indicator. See Figure 3.4-7.

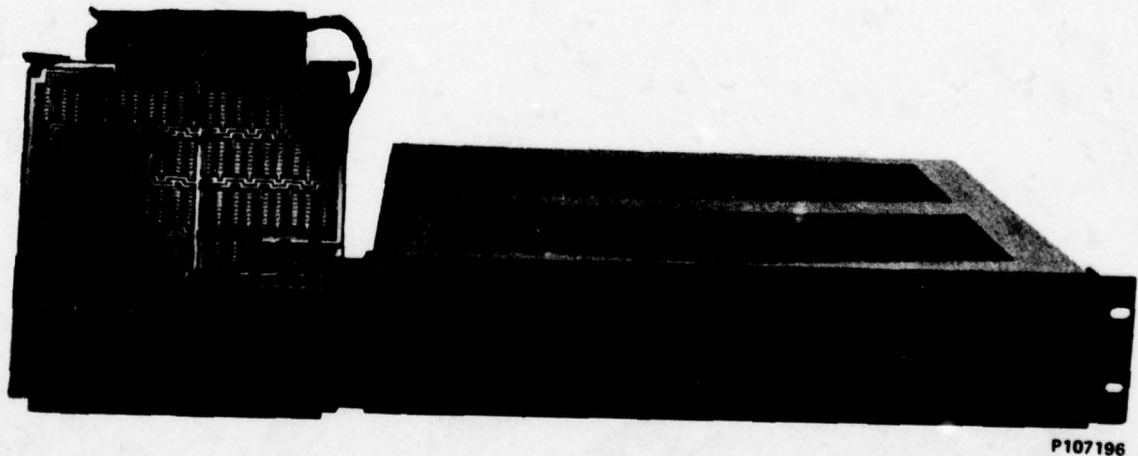


Figure 3.4-7. Graphics Interface Unit

GRAPHICS INTERFACE SPECIFICATION

Memory Capacity:	1024 points or vectors
Intensity:	4 levels line intensity 4 levels point intensity
Refresh Rate:	50 Hz (nominal)
X-Y Output Range:	- .05 to + 9.5V (10K min, 1000 pF max)
Z Output Range:	0 to \pm 10V (adjustable)
Resolution (X - Y):	\pm .05% Full Scale
Power:	
Input	115 \pm 10%, 60 Hz \pm 1 Hz
Consumption	56 watts
Environment:	
Non-operating	-25°C to +65°C
Operating	0°C to +50°C
Humidity	20 to 80% (non-condensing)

FUNCTIONAL DESCRIPTION

The Graphics Interface Unit is divided into five functional blocks:

- Three input buffers
- A 1024 semiconductor memory
- Internal clock
- Control logic
- Three digital to analog converters

The input buffers receive serial information from the computer.

Buffer A accepts X-axis information, Buffer B accepts Y-axis information and Buffer C the point and line intensity information in addition to the point number.

The data from the computer consists of three 16-bit words with a resolution of 10 bits which results into an X-Y resolution of $\pm .05\%$ full scale. After each of the input buffers have been loaded with suitable information a start command is issued. The start command immediately sets a Busy Flag and causes the unit to search for the point number specified by the C buffer. When the specified point has been found the contents of the A, B, and C Buffers are shifted into memory.

Word one and two are used to transmit X and Y displacement information respectively. Word three is used to transmit point number and point and line intensity information. There are four levels of intensity that can be selected for each point and line.

After the Buffer contents have been transferred into memory, a Busy Flag is cleared and a Done Flag set. If the interrupts have been enabled a program interrupt will be generated. The unit is ready to accept another command.

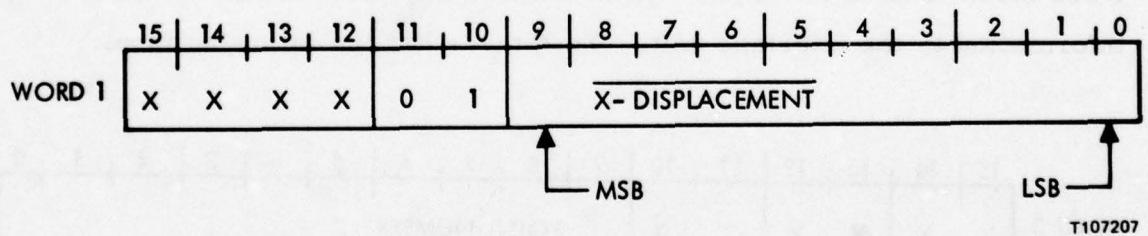
The 1024 semi-conductor memory is continuously cycled through all locations. This continuous shifting generates a 50 Hz refresh rate for refreshing the 17 inch Graphics Display.

The digital-to-analog converters convert the binary information from memory into an analog signal that varies between -0.5 and 9.5 volts DC.

The X and Y-axis information displayed on the 17 inch graphics display is broken up into discrete divisions. Each axis is divided into 1024 points. To generate a display, the points are connected to form lines. There are 1,048,576 possible positions a point can be located at (1024 x 1024). The intensity of the line is controlled by a horizontal signal (Z).

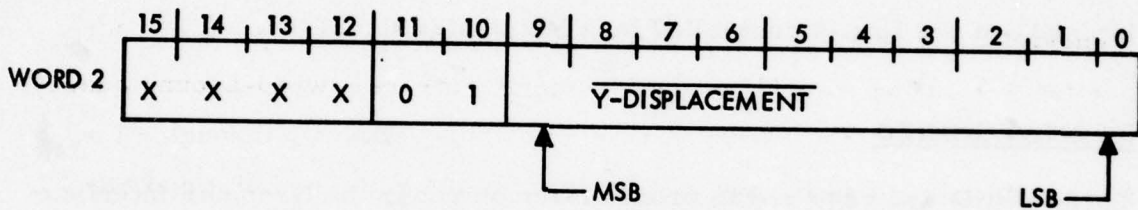
FORMAT WORDS

Three words are required to program the output to the Graphics Interface Unit. Word one is used to transmit X displacement information. It has the following arrangement:



The displacement in binary counts is placed in bit positions 0 through 9. It is necessary to complement the binary value of the displacement. That is, full scale displacement would be represented by all zeroes and no displacement would be represented by all ones. Bits 10 and 11 specify which register receives data. Other one set to zero and bits 12 through 15 are ignored.

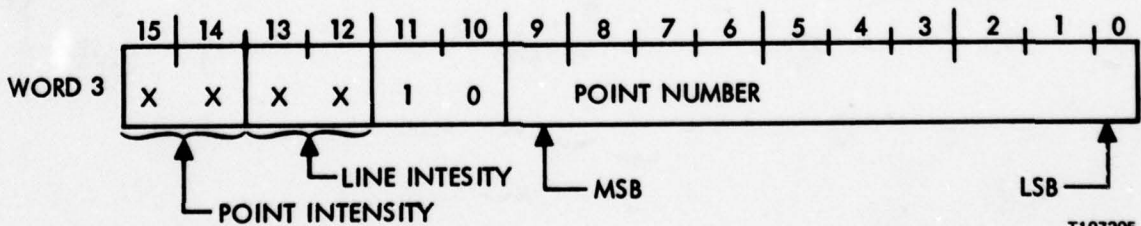
Word two is used to transmit Y displacement. It has the following arrangement:



T107206

Arrangement of word two is identical to word format one except for bit 10 which is a 1 instead of 0 to specify that Y register receives the data.

Word three is used to transmit point number and point and line intensity information to the interface unit. Word three has the following form:



T107206

Bits 14 and 15 contain point intensity information for the point number specified by bits 0 through 9. There are four levels of point intensity. 0 0 is the least intense and 1 1 the most intense. Bit 15 is the MSB.

Bits 12 and 13 contain the line intensity information for the line between the point number specified by bits 0 through 9 and the point specified by bits 0 through 9 minus 1. There are four levels of line intensity: 0 0 is the least intense (no line) and 1 1 the most intense (heaviest). Bit 13 is the MSB of this group.

Bits 0 through 9 are the point field and specify the point number. For 1024 points, all ten bits of the point field are utilized. In this case the highest numbered point (1024) would be specified by placing ones in bit positions 0 through 9. This gives the point address a wrap-around quality: i. e., if the binary equivalent of 1034 was placed in bits 0 through 9 the 1024 point unit would interpret it as $1034 - 1024 = 10$, or point number 10.

3.4.6 GRAPHICS DISPLAY

GENERAL

A Hewlett Packard Model 1317A high-speed graphics display is used for displaying navigational data, vessel's position relative to shore lines, channel banks, markers, and other prominent geographic objects on a 17 inch, cathode-ray tube. Three analog signals from the Graphics Interface Unit control the presentation and brightness. By use of a neutral contrast filter over the screen, the green-colored display can be viewed in daylight but not direct sunlight.

Size of Graphics Display is 16.5 inches wide, 16.2 inches high, 22.5 inches in depth, and weights approximately 58 pounds. The unit has rubber feet for mounting on a table, or it can be rack-mounted. The front panel contains controls to adjust display, and back panel contains power switch and inputs. Three 50-ft RG-58/ μ cables connect between the Interface Unit and Graphics Display allowing the display to be located away from the system.



Figure 3.4-8. Graphics Display Unit

GRAPHICS DISPLAY SPECIFICATIONS

Linear writing speed:	>10 in/ μ s
Diagonal setting time:	Within one spot diameter of final value is <1 μ s
Repeatability:	<0.15% error (full screen) for re-addressing a point from any on or off screen direction
Point plotting time:	Signal settles to within 0.010 in of final value in <200 ns for any 0.10 in step
Drift:	<0.10 inches in 24 hr
Spot jitter and motion:	<0.010 inches
Light output:	Line brightness is approximately 50 fL at a writing speed of 0.10 in/ μ s
Linearity:	<3% of full scale along major axis
Phosphor Protection:	Automatically detects absence of beam deflection and limits beam current to a safe but viewable level
Dynamic focus:	Automatically corrects spot geometry for position on screen and beam intensity

Safety Protection:

Implosion:

Meets safety requirements of U. L.
478 for EDP units and systems

High voltage:

Anode lead is permanently bonded to
CRT

X-Ray emission:

<0.1 mr/hr measured with Vectoreen
Model 440 RF/C

Power requirements:

Input power:

Selectable 100, 120, 220, or 240 Vac,
+5% or -10%, 48 Hz to 440 Hz

Power consumption:

100 watts

Environmental:

Operating:

0 to +55°C

Non-operating

-40°C to +70°C

Humidity:

Up to 95% relative humidity to
+40°C

Vibration:

Vibrated in three planes for 15
minutes each with 0.010 inches
excursion, 10 to 55 Hz

FUNCTIONAL DESCRIPTION

Three analog input signals from the Graphics Interface unit which range from 0 to +10 volts are amplified and used to control the cathode-ray tube's electron beam placement and intensity.

Electrostatic deflection system is used to control the beam. This consumes much less power than the multi-winding coils of magnetic deflection systems, thus making it more reliable. Additionally, the much faster response of electrostatic deflection permits more information to be displayed without flicker.

The cathode-ray tube has an aluminized P31 phosphor and a usable viewing area of approximately 13.5 inches x 10.25 inches. A 28-kilovolt accelerating potential produces a bright green display without harmful X-rays.

Some of the display's special features are:

- a. The input termination resistance and the input attenuation ratio for the X, Y, and Z amplifiers can be changed to compensate for various RG-58 cable lengths between the Graphics Interface and Display Unit.
- b. Dynamics Focus - Astigmatism - Voltages proportional to the position of the CRT beam are applied to the focus and astigmatism elements of the CRT. This causes spot size and shape to remain constant over the CRT viewing area. Focus is also corrected for changes in intensity level.
- c. Phosphor Protection - A protection circuit senses slow or static deflection signals and limits beam intensity to prevent burning of the CRT phosphor and mesh.

3.4.7 Gyrocompass Interface Unit

General

The Gyrocompass Interface Unit, which interfaces with MK-14, MK-27, or MK-37 Shipboard Gyrocompass Systems, is used to convert the gyro's +70 VDC stepper output to 90 VAC synchro output for providing ship's true heading to the LORAN Precision Guidance System. The analog signals are converted to digital signals and then send to the 21 MX computer for use in the St. Marys software program.

The unit consists of a DC stepper motor and a 115 VAC synchro torque transmitter which is mechanically coupled to the motor. These components are mounted in a ruggedized cast aluminum housing with four mounting flanges. Size of housing is 12.75 inches wide by 11 inches long by 8.25 inches in height and it weighs approximately 35 pounds.



Figure 3.4-9. Gyrocompass Interface Unit

A compass dial attached to the stepper motor, which displays the ship's heading, can be viewed through a plexiglass cover. Under the cover is a stepper control switch which allows the operator to pre-set the dial to display the same heading as ship's gyro displays by manually moving dial.

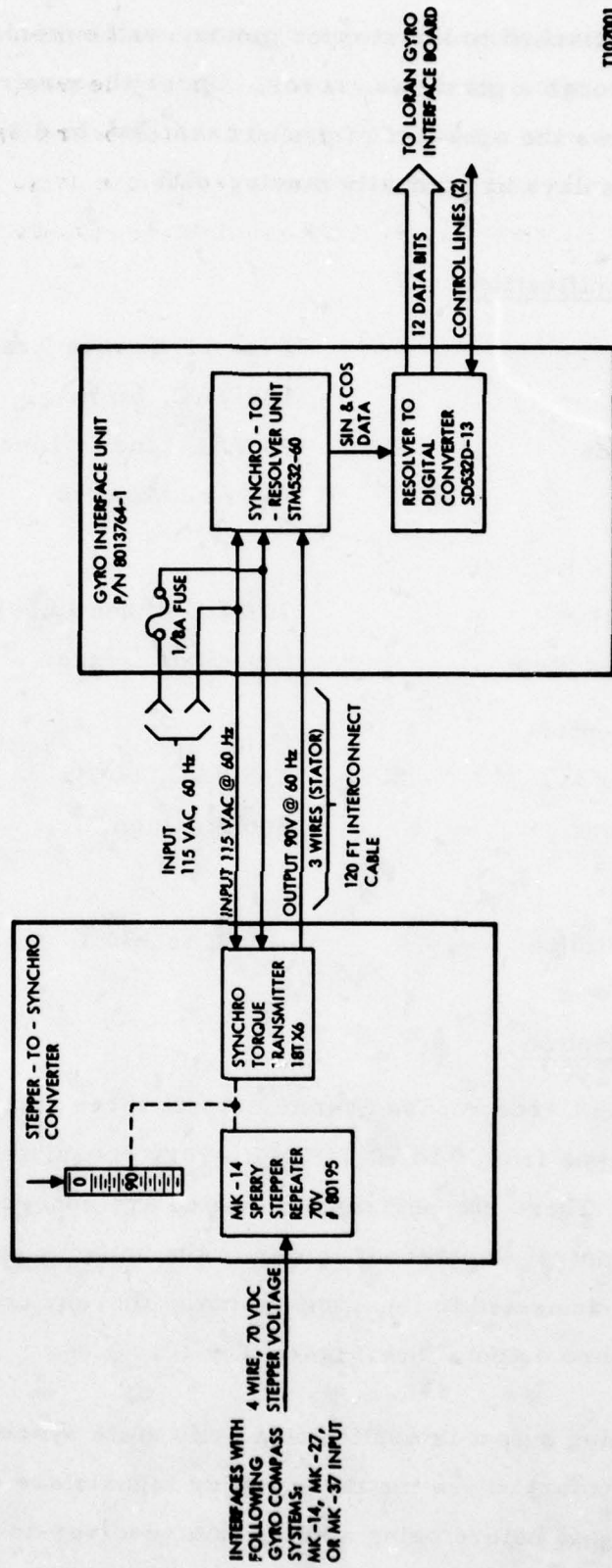
Gyrocompass Specifications

Synchro:	Type 1F Torque Transmitter
Rotor Input	115 VAC, 60 Hz
Stator Output	90 VAC Line to Line (three lines)
Accuracy	±10 Arc Minutes
Stepper Motor:	
Input (three)	70 VDC (three lines)
Degrees Per Step	One-Sixth Degree
Power Requirements:	
Input Power	115 VAC, 60 Hz
Input Current	300 mA (nom.)
Environmental:	
Operating Range	-40°C to +55°C

Functional Description

The ship's MK-14 Gyrocompass System outputs three stepper signals that alternately switches from 0 to 70 VDC for every one-sixth degree of ship's heading change. These stepper signals, which are connected to the Gyrocompass Unit, control the stepper motor in the unit. A synchro transmitter is mechanically connected to the stepper motor thereby converting the stepper input to the synchro output. See Figure 3.4-10.

The synchro analog output is applied to a solid state synchro-to-resolver module (Scott-T transformer) where the three analog signals are converted to a sine and cosine analog signal before being applied to a resolver-to-digital converter module.



T107001

Figure 3.4-10. Block Diagram of Gyrocompass Interface Unit

The resolver-to-digital module converts the sine and cosine signal into 12 digital data bits. Least significant bit equals 0.175 degree. These data bits are applied in parallel to a LORAN/GYRO interface board in the 21 MX computer and temporarily stored until the computer accepts the data. Two signals from the interface board control the resolver-to-digital converter processing time.

Operator commands are provided for initialization and control of the LORAN Precision Guidance System. All operator commands are originated and displayed within the Mini Data Station. The following data can be entered or displayed by keyboard control.

- Data (DA): This command enters the Julian Calendar day (1 - 366).
- Dump (DU): This command allows the operator to dump navigational data (shot) at any time.
- Display Waypoints (DW): This command allows the operator to display the entries in the waypoint table on the CRT.
- Gyrocompass (GC): Allows operator to enter a gyrocompass heading to compensate for error in vessel's gyrocompass system.
- Kalman Initialize (KI): This command initializes the coordinate conversion routine (Kalman filter) to allow LORAN data to optionally calibrate the position keeping software module.
- Kalman Off (KO): This command turns off Kalman processing.
- Look-Ahead (LA): Operator can enter parameters in feet or seconds to provide a look-ahead vector emanating from the reference point on the vessel symbol displayed on the 17-inch graphics display unit.
- Lead (LE): This allows entry of a lead value in feet for any waypoint table entry thereby operator can select a turning point prior to waypoint arrival.

LORAN Station (LS): This command allows the operator to select the LORAN stations to be used by the Kalman filter.

LORAN Transmitters (LT): This command allows the operator to enter LORAN Transmitter locations and coding delays for any chain. The St. Marys River chain (S7) data is stored without these entries.

Graphics Orientation Angle (OA): Operator can select a Northup or Trackup display on the 17-inch Graphics Unit.

Compute Speed and Course between two positions (P1 and P2): P1 command stores current time and position. On arrival at second position, operator initiates a P2 command. This computes the mean speed and course from P1 to P2.

Receiver Offset Corrections (PF): This entry allows the operator to calibrate the LORAN receiver by correcting for each time difference (TD) offset caused by receiver bias. Offset is added to processed TDs in LORAN subprogram.

Position Keeping Initialization (PI): This initializes the position keeping software module for dead reckoning between LORAN updates.

Position Offset Display (PO): This offsets the vessel symbol on the 17-inch graphics display, thereby correcting for a constant graphics bias.

Present Position (PP): Operator can change or enter the vessel's position, either for test purposes or to give a starting location for the Kalman filter's coordinate conversion algorithm.

Kalman Filter Gain Control (QP and QV): The operator can change the Kalman filter Q matrix, position and velocity elements, when required to obtain maximum system accuracy.

System Data Printout (SD and SH): Allows the operator to record the following navigational data automatically or manually on line printer, paper tape, or CRT for post mission analysis and evaluation.

Record Number	XXX
Julian Day	XXX
Greenwich Time	XX:XX:XX
Latitude	SXXX XX.XXX
Longitude	SXXX XX.XXX
Speed	XX.X
Crosstrack Speed	XX.X
Crosstrack Distance	XXXXX
Segment Number	XXX
Dist to Waypoint	XXX.XXX
Gyrocompass Heading	XXX.X
TDA	XXXXXXXXXX.XX
TDB	XXXXXXXXXX.XX
TDC	XXXXXXXXXX.XX

Graphics Scale Factor (SF): Allows operator to change the scale factor of the display on the 17-inch graphics display unit. Range of scale factor is one inch = one mile to 20 inches = one mile (Integer only).

Steering Control (SI or SO): Steering software routines can be initialized or turned-off by operator control. When initializing the operator selects one of the following routes the vessel will be traversing on the St. Marys River:

Channel 1	Summer and Winter Upbound
Channel 2	Summer Downbound

Steering Control (SI or SO): (Cont.) Channel 3 Winter Downbound
Channel 4 Operator Input

Greenwich Mean Time (TI): This command allows the operator to enter the correct time in hr. min. and sec.

Waypoint Entry and Graphics Calibration (WP): This command allows the operator to enter data for a selected waypoint, and enter data for calibrating the graphics vessel symbol relative to the trackline, to compensate for chart errors and/or LORAN C - grid distortion.

Screen Select (S1 or S2): Normally ("S1" command) all the required alphanumeric navigational data is displayed on the 12-inch screen. Clutter on the screen can be reduced to show only speed, off-track, time and distance to turn by operator command S2.

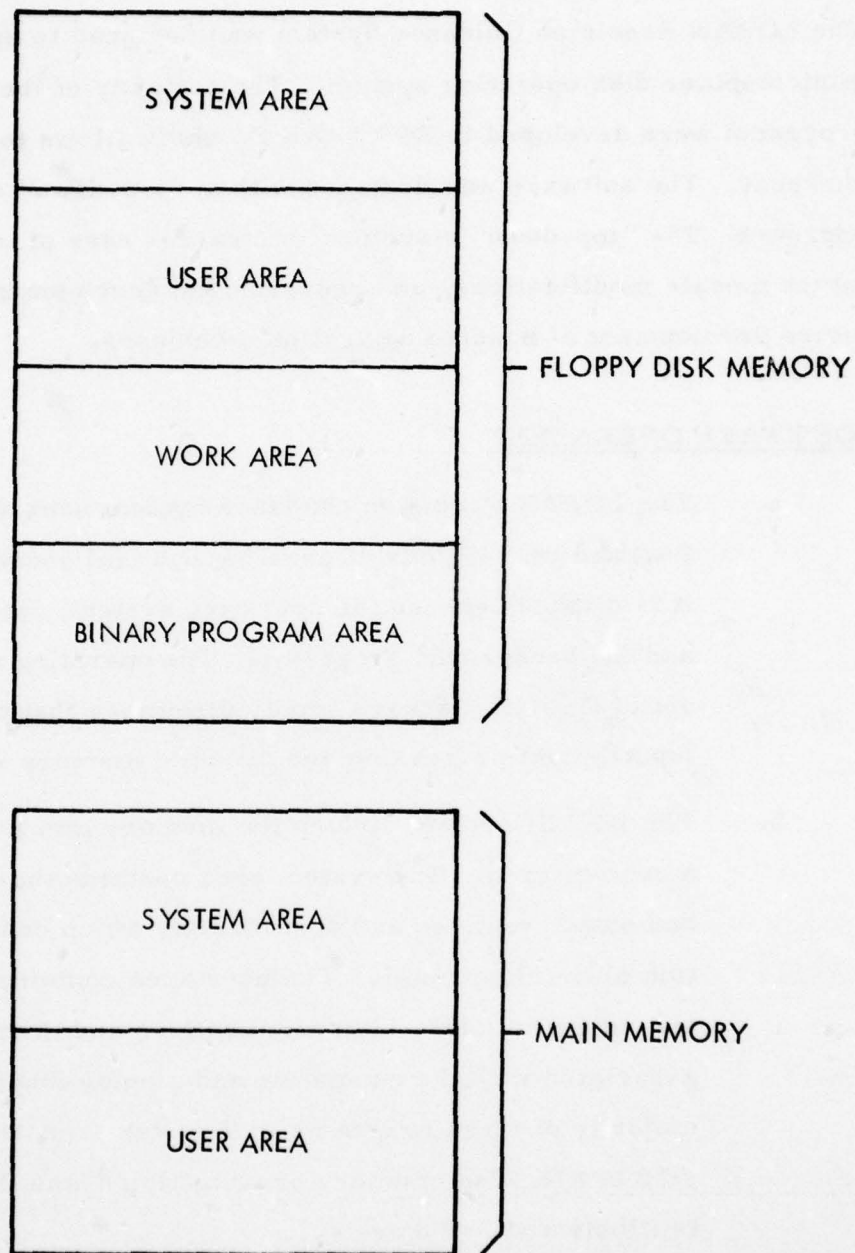
SECTION 4

SOFTWARE CONFIGURATION

The LORAN Precision Guidance System was designed to operate on a minicomputer disk operating system. The majority of the computer programs were developed in FORTRAN IV which allows for rapid software checkout. The software was designed with a "top-down" structured approach. The "top-down" structure is ideal for ease of integration, future module modifications, and research and development tool for future development of precise navigation techniques.

4.1 SOFTWARE OPERATION

- a. The LORAN Precision Guidance System uses the Hewlett-Packard DOS III (Disk Operating System) software program. It is divided between the operating system, interrupt routine, and the background programs. The operating system is a set of Hewlett-Packard supplied routines that control the input/output processing and dynamic memory allocation.
- b. The DOS III system divides the memory into a user area and a system area. The system area contains the system input and output routines and disc monitor which controls the operation of the floppy disk. The user area contains the LORAN and real time clock interrupt routines and the programs associated with the navigation and display functions. The majority of these programs in the user area are written in FORTRAN. The memory organization of the DOS III system is illustrated in Figure 4-1.



T105190

Figure 4-1. DOS III Functional Diagram

System Area Routines

The system area routines contain the DOS III operating modules

JOB PROCESSOR
EXECUTIVE

User Area Routines

The user area routines consist of special interrupt modules, background programs, and FORTRAN utility routines. The interrupt modules are hardware device communication software routines. The background programs are routines that perform the majority of the navigation and display functions. The FORTRAN utility routines are special software functions that are supplied by Hewlett-Packard.

Software Structure

The LORAN Precision Guidance System's software employs a "top-down" design structure. The majority of the background programs are called by a single round-robin executive called "MARY." All the routines operate independently and communicate through COMMON data storage. During checkout phase, the subroutine CALLS in MARY can freely be put in or taken out without fear of adversely affecting the operation of the main program. Each of the routines called by MARY in turn calls a sequence of special modules that can be checked out on an individual basis.

Operational Program Description

The operational programs for the LPGS are divided into three categories:

- Interrupt Routines
- Background Routines
- Utility Routines

Interrupt Routines - The interrupt routines are the software modules that are activated by a peripheral hardware device. The following lists the interrupt routines and their order of priority:

1. Real Time Interrupt RTCIN - RTCIN is the real time clock interrupt and is the highest priority. The interrupt is generated by a Time Base Generator Module in the computer. RTCIN is interrupted once every 100 miliseconds and updates the time counter "T" in COMMON which is accumulated in seconds.

2. LORAN Interrupt: LORI3 - The LORI3 module is activated by the LORAN interrupt which is generated in the LORAN/Gyro interface board and controlled by the GRI interrupts from the Microlocator. The LORAN interrupt occurs approximately every 100 milsecs and is the next highest priority interrupt. When LORI3 module is activated 65 sixteen-bit words are transferred into the computer memory and processed. The final word contains 12 bits of gyro-compass data, operator console input and data recording flags which are manually controlled interrupts activated by KB and SHOT pusbutton^s on the keyboard/display terminal.

The next 64 sixteen bit words contain the Microlocator receiver data which consists of time differences, status, SNR, velocity, and blink codes.

3. Flexible Disc Interrupt - The interrupt occurs to acknowledge a data transfer is complete and the device is available.

4. Mini Data Station Interrupt - The interrupt occurs to acknowledge that an input or output data transfer is complete and the device is available.

AD-A062 141

TELEDYNE SYSTEMS CO NORTHRIDGE CALIF

F/G 17/7

SAINT MARYS RIVER LORAN-C. PRECISION GUIDANCE SYSTEM. VOLUME I.--ETC(U)

DOT-CG-61419-A

UNCLASSIFIED

TSC-60133

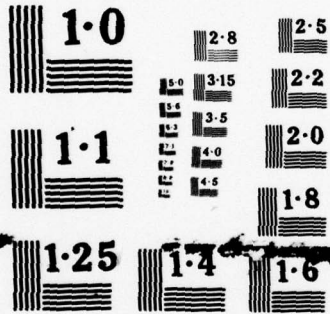
USCG-D-57-77-VOL-1

NL

2 OF 2
AD
A062 141



END
DATE
FILMED
3 -79
DDC



NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

5. System Interrupt - The DOS III software handles the interrupts for hardware parity and power fail/recovery.

Background Routines - The background routines perform most of the navigation and display functions for the LPGS. The overall flow of the program is illustrated in Figure 4-2. The background routines are called from an executive in an established order which is continuously repeated. A called routine must complete execution and return program control to the executive program before the next sequential routine is executed. Thus, the call sequence is continuously repeated.

Each of the following subroutines are briefly described in the following subsections:

1. BEXEC (Background Executive Routine) - The processing of the background routines is controlled by a round-robin scheduler called BEXEC.
2. SINIT - The SINIT routine initializes the interrupt system for processing LORAN and real-time clock data.
3. FINIT - The FINIT routine serves the same function as BLOCK DATA functions in ANSI FORTRAN IV. FINIT clears the COMMON area and then stores predetermined program constants.
4. OCINP (Operator Console Input) - The OCINP routine allows the operator to communicate to the computer via the Mini Data Station.
5. BPSNK - BPSNK is the background position routine and is entered only once per 1/2 hour. BPSNK computes data necessary to operate POSKP. No subroutine calls are made.

6. POSKP - POSKP is the position keeping or dead reckoning routine. POSKP integrates the ship position between LORAN C Kalman updates. No subroutine calls are made.
7. SYSR - SYSR prints the ship's navigation data on the Mini Data Station's CRT. SYSR prints both numerical data such as time, position, speed, quality, and steering data. In addition, it prints a graphical representation of the ship's attitude in relation to trackline. Data can be recorded on cassette, CRT, printer, or paper tape device.
8. LORID - LORID processes the LORAN C interrupt buffer and reformats the data on the following:

Time difference

Velocity

SNR

State

Blink

Data is accessed from the buffer and formatted and/or scaled as necessary. It is then stored into the data base or common area for use by LORAN.

9. LORAN - LORAN processes the data from LORID and computes the input variables Z, H and R for the Kalman Routine.
10. STEER - STEER computes cross track steering error based on present position and waypoint and lead information. A table containing 35 waypoints can be stored internally in the computer to provide the course description.
11. SHOT - SHOT performs the data record function. SHOT can record the ship's navigation and LORAN C measurement data

by either a manual request, time, or distance travelled. The manual request is made by pressing the SHOT pushbutton on the Mini Data Station. The time or distance record is selected by entering the appropriate command via the KB pushbutton on the station.

12. LDATA - LDATA is a diagnostic tool that computes statistics associated with the Microlocator receiver. The data is either displayed on the station's CRT or printer.
13. GINIT - GINIT initializes the interrupt system for processing Extended Graphics data.
14. GMAPU - GMAPU is the real time graphics update routine. GMAPU updates the map data for a given scale factor, for off the screen change in the ship position, or for orientation change angle. Additionally, GMAPU moves the ship's image across the screen as a function of the ship's motion and also updates the screen data display.

Utility Routines - The utility routines are the support modules for the background routines. A brief description will be given of each utility subroutine.

1. OCNP1 - OCNP1 is a segment program called by OCNP and performs some of the operator command functions.
2. OCNP2 - OCNP2 is a segment program called by OCNP and performs some of the operator command functions.
3. OCNP3 - OCNP3 is a segment program called by OCNP and performs some of the operator command functions.

4. PRINT - PRINT is called by OCNP1 and SHOT. The routine prints the navigation data on either the cassette, the CRT, or the printer.
5. DEGOT - DEGOT is called by PRINT, OCNP1, and OCNP2. The routine converts data from radians to degrees and minutes.
6. DEGIN - DEGIN reads in angle data in degrees and minutes for input and converts it to radians. DEGIN is called by OCNP1 and OCNP2. Program control is retained by DEGIN until the input function is complete.
7. WPGET - WPGET reads in navigation waypoint data from cassette for up to 35 waypoints and stores the data in common. WPGET is called by OCNP2 and OCNP3.
8. UNTDN - UNTDN turns off the time base generator and LORAN C interrupts. This routine provides an orderly escape from the St. Marys program and returns control to DOS III operating system. UNTDN is called by OCNP2.
9. SMOTH - SMOTH will put a sliding average on the display output data if sense switch 8 is on. Sense switch 8 is located on the computer. SMOTH is called by SYSPR.
10. SHMSC - SHMSC converts floating point seconds to integer hours, minutes, and seconds. Time increments in the interrupt module RTCIN. SHMSC is called by SYSPR and GBSTA.
11. SPCRT - SPCRT plots the ships off track distance and orientation angle on the station's CRT screen. SPCRT is called by SYSPR.
12. XPOS - XPOS converts single precision LAT/LON data into double precision LAT/LON. XPOS is called by LORAN and STEER.

13. CORCN - CORCN is a four state optimal Kalman filter. CORCN is called by LORAN.
14. SETCR - SETCR consists of the Hollerith format statements which contain the labels for the navigation data which is displayed on the CRT. SETCR is called SHOT.
15. AXIS - AXIS will draw an axis at either 0 or 90 degrees, add tic marks at intervals of 1 (1 = 1 inch on graphics display), label the axis, and add numbers at each tic mark .15 interval units in height.
16. IPLT - The subroutine IPLT is used to enter data into the data buffer in COMMON. The data is placed in the next available location and the point counter is incremented.
17. NOTE - NOTE is used to place characters in the data buffer. The characters may be input to the subroutine as storing data, real numbers, or integers.
18. MEGOT - This subroutine sends the current buffer contents to the MEGATEK. There are no arguments for this CALL and the entire contents of the buffer in COMMON are sent to the graphics interface. The interrupt is turned off since it only takes 80 ms to send out the entire buffer. This routine may be used once, or as often as desired to create a moving display.
19. PLOT - The subroutine PLOT is used to scale data from user units to the units used within the graphics interface system (0 - 10.0). The values supplied by the user are used for scaling purposes, the user origin is added, and the data is placed in the COMMON data buffer using IPLT.

20. SCALE - This subroutine is used to set scaling parameters or to move the user origin.
21. SET - The SET subroutine initializes the plotting subroutines, blanks the screen, resets the buffer pointer, or returns the present buffer point number.
22. CCONV - CCONV converts data to screen center coordinates, rotates to proper orientation angle and converts to the lower left corner of the screen.
23. MEGOT - MEGOT sends an internal 2048 word buffer to the graphics interface memory. The buffer contains X, Y coordinates information along with line and point intensity data.
24. GINTR - GINTR determines whether a line is within the graphics screen display.
25. DINTR - DINTR determines the intersection of two lines given 4 points.
26. XPLD - XPLD converts binary data to ASC II data for output.
27. BBYTE - BBYTE separates an input 16 bit data word containing 2 ASC II characters into two words each of which contains a character which is right adjusted.

Hewlett-Packard Library - The HP Library consists of support routines in the following areas:

Arithmetic
Trigonometric
Number Conversion

Input/Output Control

Double Precision

Floating Point

These routines are used by the executive programs in the background environment.

4.2 MEMORY ALLOCATION

- a. At the time of the initial deployment to the field, the LORAN Precision Guidance System's (LPGS) program memory allocation was divided between the following sections:

1.	Data Base	0 - 1777 ₍₈₎
2.	DOS III	2000 ₍₈₎ - 15777 ₍₈₎
3.	St. Marys	16000 ₍₈₎ - 65277 ₍₈₎
4.	Segments	65300 ₍₈₎ - 71334 ₍₈₎
5.	Available Core	71335 ₍₈₎ - 77700 ₍₈₎
6.	Boot	77700 ₍₈₎ - 77777 ₍₈₎

These sections comprise the LPGS program and are memory resident except for the segments. They are loaded into memory as required.

- b. The data base contains global variable constants, and interrupt slots used by DOS III and St. Marys. The St. Marys global constants and variables are generated into an area allocated by DOS III on the base page. Should more base page locations be required than allocated by DOS III, they must be generated on the current page. The interrupt slots are locations 10₍₈₎ - 20₍₈₎ and contain a JSB indirect to an address on the base page of the interrupt routine.

- c. The DOS III program resides in low core and controls segment management, I/O requests, and basic operating system capability. It controls the FORTRAN assembly and load module formation including diagnostic messages. When the St. Marys is operative, DOS III handles I/O requests to various devices and loads any segment structures as required.
- d. The St. Marys program occupies the next available core. It computes the ships navigational quantities including position updating, waypoint steering, operator input/output, and a graphics visual display.
- e. The segment portions reside on disc and are brought into main memory when requested by the St. Marys program thru DOS III executive calls. DOS III reserves enough memory to accommodate the largest segment. St. Marys segments are listed as follows:
 - 1. FINIT FORTRAN Initialize Program
 - 2. OCNP1 Operator Command Set 1
 - 3. OCNP2 Operator Command Set 2
 - 4. OCNP3 Operator Command Set 3
- f. The available core was set aside for future program growth, data retrieval, or data processing. Since the initial deployment, modifications and operational improvements have used up all of the available core.
- g. The boot program resides in the highest 100 words of memory. It is used to load DOS III from disc into memory.

SECTION 5

DISPLAY CONFIGURATION

The LORAN Precision Guidance System is supplied with two displays; one 12 inch screen for displaying navigational data, steering information, and software information, and one 17 inch screen for displaying symbol of vessel, shore line, channel banks, and other prominent geographic objects, such as buoys, rocks, trees, etc.

The 12 inch display is part of a Mini Data Station. This display is a 5 inch by 10 inch rectangular cathode-ray tube (CRT) providing a 1,920 character capacity in 24 lines of 80 characters per line. The characters .097 inches x .125 inches are formed by a 7 x 9 dot matrix generated in a 9 x 15 dot character cell. Characters are refreshed at a 60 Hz rate to maintain constant brilliance.

When the CRT is used for displaying navigational data, two different display formats are available for selection by operator. The normal display contains all the prominent navigational data while the alternate display shows the minimum required navigational data thereby reducing clutter. Figure 5-1 shows the normal display. The following alphanumeric navigational data is updated every 5 seconds along with a graphical display of the vessel's attitude and distance from the desired trackline:

DESCRIPTION OF THE DISPLAYED DATA

GMD	Julian Day (1-366)
GMT	Greenwich Mean Time (hours, minutes, seconds)

GMD	0
GMT	0:49: 7 QUAL - 100
LAT.	46 29.669
LON	-84 18.399
CDR	.0
ALONG TRACK SPD	.00
CROSS TRACK SPD	.00
PRESENT TRACK	.0
NEXT TRACK	.0
ATTITUDE	153.0
OFF TRACK	.0
TIME TO TURN	01 01:0
MILES TO TURN	.000
LEAD	.0

9 11 11 11

.....| | | |

Figure 5-1. Normal CRT Display

LAT	Latitude of vessel's position (North is positive and South is negative)
LON	Longitude of Vessel's position (East is positive and West is negative)
COR	Course of vessel in degrees from True North
HED	Gyro compass heading degrees True North
ALONG TRACK SPD	Speed in statute miles per hour in direction of desired track
CROSS TRACK SPD	Speed in feet per second in a direction perpendicular to, and toward the desired track
PRESENT TRACK	The present trackline course in degrees True North
NEXT TRACK	The next trackline course in degrees True North
ATTITUDE	Degrees right or left of trackline (Gyro compass heading minus desired trackline)
OFF TRACK	Distance in feet from vessel's present position to desired track (left is defined to be negative)
TIME TO TURN	Time to next turning point (Time to next waypoint if LEAD is zero for present waypoint)
MILES TO TURN	Distance in statute miles to next turning point (Distance to next waypoint if LEAD is zero for present waypoint)

LEAD Distance in feet along the desired track by which the turning point preceeds the waypoint (used to initiate turns prior to reaching a waypoint)

QUAL Scaled in percentage value (0 - 100) indicating quality of navigation based on received LORAN information

The bottom line of the display is for the LORAN status summary. The format on the CRT is as follows: where the first four Xs denote the state condition of the LORAN receiver and the following four denote Station state, the following X denotes a status condition or is blank.

RECEIVER AND STATION STATES	STATUS
X X X X X X X X	X

- 1st "X" denotes MASTER station's state
- 2nd "X" denotes SECONDARY A station's state
- 3rd "X" denotes SECONDARY B station's state
- 4th "X" denotes SECONDARY C station's state
- 5th "X" denotes BLINK ON MASTER
- 6th "X" denotes BLINK ON A
- 7th "X" denotes BLINK ON B
- 8th "X" denotes BLINK ON C
- 9th "X" denotes LORAN MEASUREMENT REJECTED because TD jitter or change was too high. This status is accumulated every five minute period.

Table 5-1 contains a summary of states.

<u>STATES</u>	<u>NO.</u>
SEARCH	BLANK 0, 1, 2, 3
COURSE ENVELOPE 1	4
COURSE ENVELOPE 2	5
COURSE ENVELOPE 3	6
FINE ENVELOPE 1	7
FINE ENVELOPE 2	8
FINE ENVELOPE 3	9
FINE ENVELOPE 4	10
TRACK	11
FLOAT	12
BLINK	15

Table 5-1. Summary of LORAN States

The string of asterisks and I's located on the right-hand side of the display are used for steering information. The I's remain stationary, representing the track line, while the asterisks move to represent the attitude, direction, and distance the vessel is off track. Figure 5-1 indicates vessel is on track. Display is scaled for ± 100 feet off-track. When vessel is off-track more than 100 feet, the asterisks will disappear.

An alternate display format can be selected by the operator any time if a less cluttered display with only pertinent navigation information is desired. When S2 screen is selected, the following alphanumeric data will be displayed (double spaced) along with steering indication and LORAN status numbers:

ALONG TRACK SPEED	XX.XX
OFF TRACK	XX.X
TIME TO TURN	XX.XX.XX
MILES TO TURN	XX.XXX
QUAL	XXX

Any desired format can be displayed by modifying some of the software routines.

5.1 GRAPHICS DISPLAY

The Graphics Display Unit which contains a 17 inch cathode-ray tube is used to provide an extended graphics capability. It displays a graphical picture of the area the vessel is located in by using prestored information which was extracted from navigation charts and stored on diskettes for system use. The scale factor of the picture can be selected by the operator to display from 1 inch to 20 inches per mile. The display is equipped with a contrast filter for viewing the screen without a viewing hood in daylight, but not direct sunlight. All information is displayed in a 10 x 10 inch section in the center of the screen. The display includes a representation of the vessel plus the center-

of-channel trackline, channel edges, aids to navigation and surrounding geography. Alphanumeric information, as tabulated below, is displayed in the upper-right portion of this 10 x 10 inch area.

Figure 5-2 shows the Sault Ste. Marie, Michigan, area near the Soo Locks. Scale factor is 4 inches = 1 mile. Vessel symbol represents a 1000 ft x 105 ft ore carrier. Figure 5-3 is displayed at a scale factor of 20 inches = 1 mile.

The following describes the displayed alphanumeric data:

OFF	Indicates how many feet and which side vessel is off from desired track line
COR	Course vessel is travelling in degrees from True North
ATS	Along track speed vessel is moving in statute miles per hour.
XTS	Cross track speed vessel is moving in feet per second
PTK	Present track; this indicates the desired track in degrees from True North that vessel is steering to between waypoints.
NTK	Next track in degrees that vessel will steer to after passing waypoint
ATT	Attitude of the vessel's heading in degrees relative to desired track line

Figure 2-5: Clabpica Diablsy (2c916 Eactor 4 pucpca\W116)

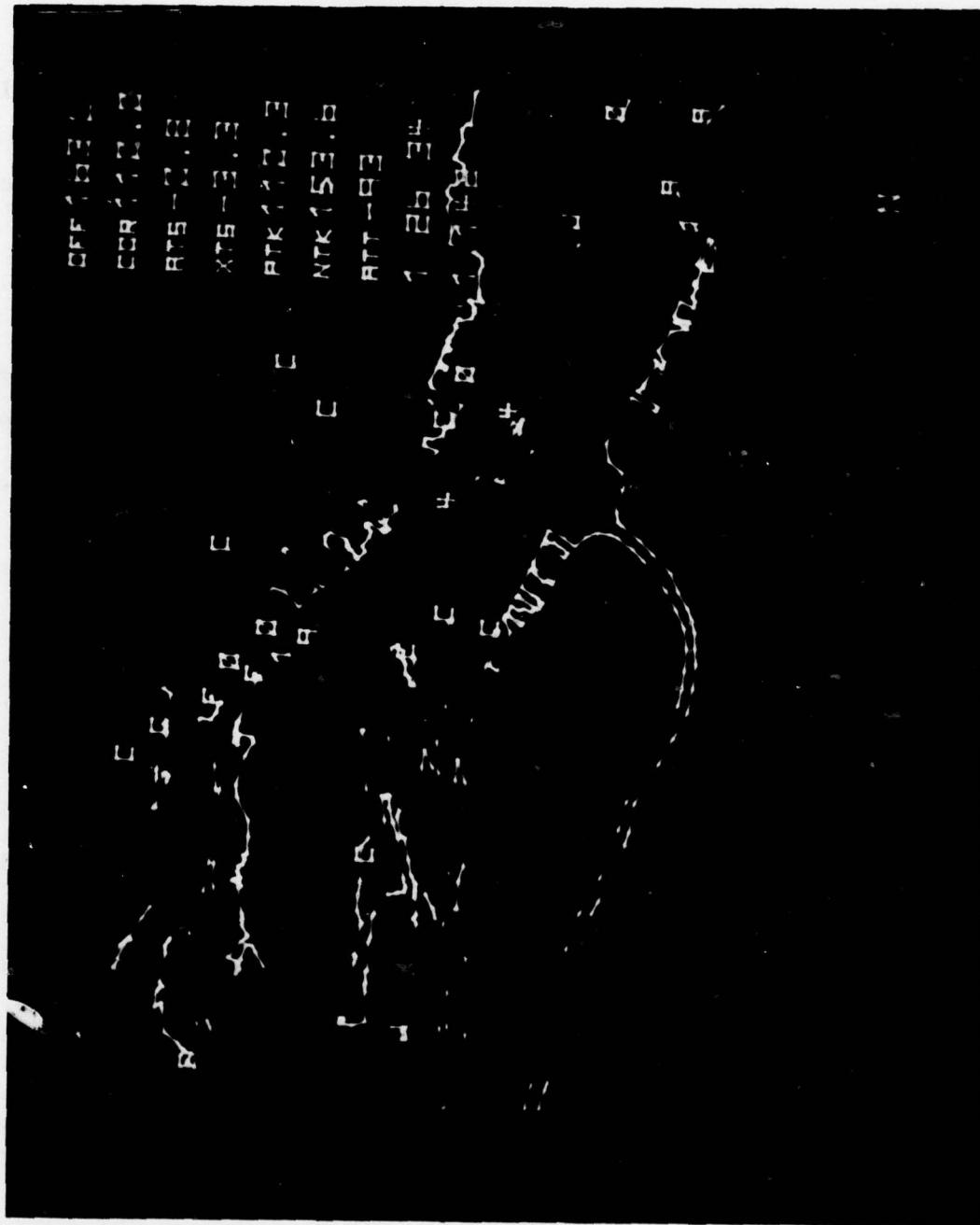


FIG 5-2

Figure 5-2. Graphics Display (Scale Factor 4 Inches/Mile)

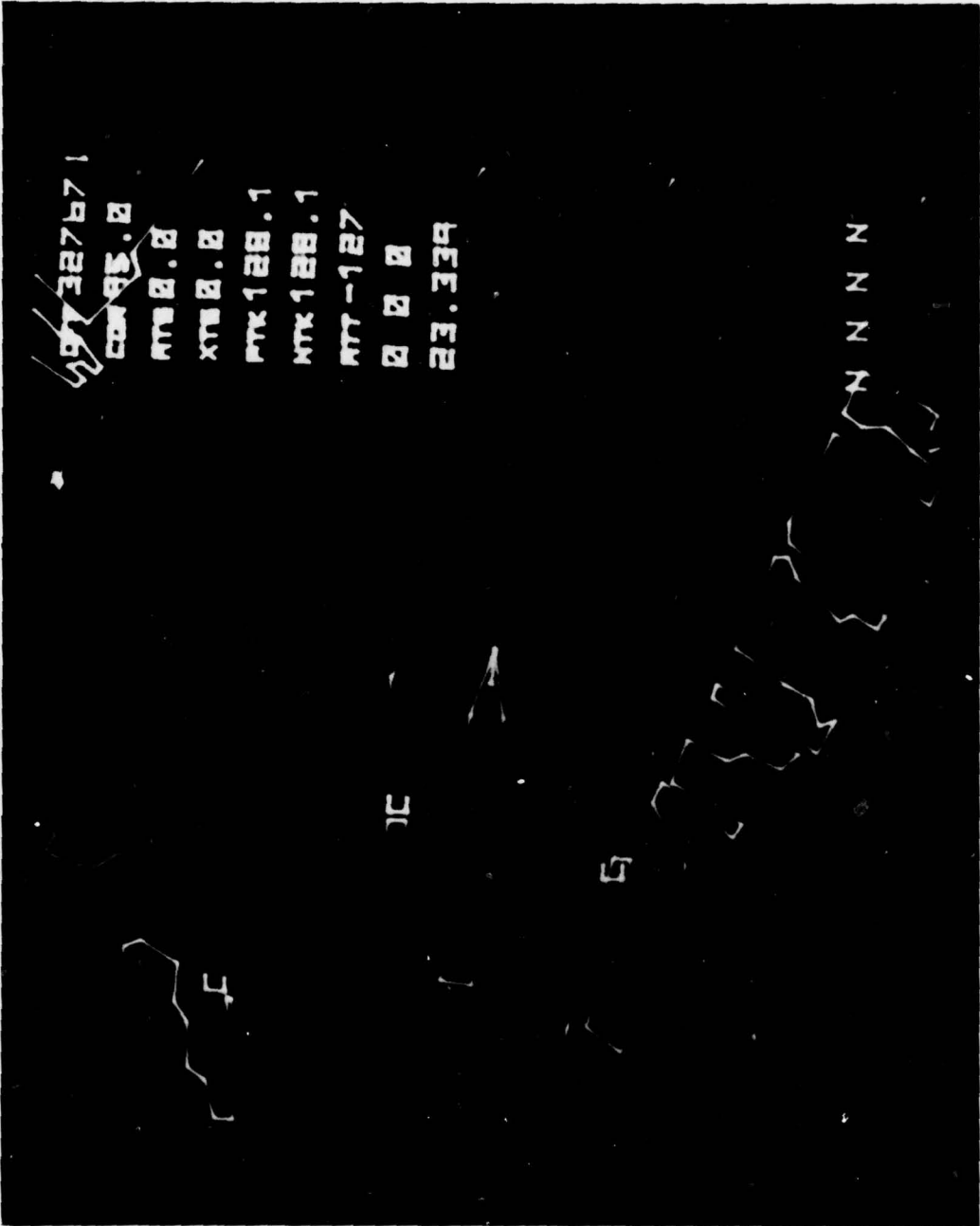


FIG 5-3

Figure 5-3. Graphics Display (Scale Factor 20 Inches/Mile)

X XX XX

X's denote numbers. This line displays time to make turn (waypoint-lead) in hours, minutes, and seconds.

X. XXX

This line displays distance to turn (waypoint-lead) in statute miles

Status of the LORAN receiver is displayed in the lower, right-hand corner of the screen. This informs and alerts the user when LORAN is unreliable for navigation by displaying the following letters:

N = Receiver is not tracking station

F = Receiver is in float mode due to loss of signal

No letter (blank) = Receiver is tracking station

Status of four LORAN stations master, and three secondaries, are displayed in the following order:

M, X, Y, and Z

The symbol size of the vessel is controlled by operator's input, thereby maintaining correct size relative to channel scale factor. The vessel's movement and position shows both distance from track line and attitude in the channel. The vessel's location, as well as the alphanumeric, are updated every five seconds. When the vessel moves to within 1% of the screen's edge, the next segment of channel is paged onto the screen.

The display can be oriented to a track-up angle by operator request. Figure 5-4 shows a track-up display. In this mode, the desired track line is always pointed up. When a turn is reached, the display is redrawn with the orientation of the next trackline. A time delay is incorporated (presently 15 seconds) to prevent redrawing the display in the midst of a turn.



P107190

Figure 5-4. Track-Up Display

SECTION 6

SYSTEM ERROR ANALYSIS

Error Analysis

The accuracy of the LORAN Precision Guidance System (LPGS) is limited by the errors inherent in the system and LORAN chain. The errors fall under two categories: bias errors and random errors. Some of these such as receiver bias and earth's ellipticity error, can be reduced substantially by their approximate evaluation. The rest of the errors will dictate the variance of the navigational data.

Table 6-1 contains a list of LORAN errors, and their classification (random or bias).

The navigation errors can be characterized as a Gaussian process. Thus, the navigation accuracy objective of 25 feet cross-track error (jitter) with a ninety-five percent probability can be translated to a standard deviation of 12.5 feet (1 σ). To obtain the best possible accuracy, a great deal of data processing is done. The LORAN-C measurements are obtained once every group within the LORAN receiver. The GRI rate is 49,300 microseconds.

The measurement process is autocorrelated in time such that

$$E(TD_i, TD_{i-1}) = \rho$$

where $E(-)$ is the statistical expected value operation. The autocorrelation of the measurements is caused by the phase-lock loop in the LORAN receiver's tracking filters. The measurement process can be characterized by an exponential autocorrelation function with a one lag normalized autocorrelation given by

$$\rho = e^{-\frac{\Delta t}{T_c}}$$

TABLE 1

Error Source	Error Type (random, bias)
TRANSMITTER ERRORS:	
1) Station location uncertainty	B
2) Coding delays	R
3) Equipment errors	R
PROPAGATION ERRORS:	
1) Seasonal lapse	B
2) Secondary phase	B
3) Sky waves	B
4) Warpage	B
GEOMETRY ERRORS:	
1) Earth's ellipticity	B
RECEIVER ERRORS:	
1) Phase deviation	R
2) Input signal least significant bit	R
3) Synchronization and differential gain	R
COMPUTATIONAL ERRORS	
(convergence)	R

where T_c = time constant
 Δt = sample interval

The measurement process is autocorrelated by the second order phase lock loops of the receiver's tracking filters. As a result a simple time average will not provide the required jitter reduction on the measurement noise. The optimal estimate of the average TD for a given presmoothing time is given by

$$\overline{TD} = \frac{\tilde{TD}_1 + (1-\rho) \sum_{i=1}^{N-1} \tilde{TD}_i + \tilde{TD}_N}{(1+\rho) + (N-1)(1-\rho)}$$

Notice that if there is no autocorrelation, i. e., $\rho = 0$, then

$$\overline{TD} = \frac{1}{N} \sum_{i=1}^N \tilde{TD}_i$$

which is a simple flat average. However, if

$\rho = 1$, then

$$\overline{TD} = \frac{\tilde{TD}_1 + \tilde{TD}_N}{2}$$

which is the best estimate for autocorrelated measurements.

The best navigation accuracy can be achieved by processing the LORAN time differences through a Kalman filter.

SECTION 7

SYSTEM CALIBRATION AND VERIFICATION TESTS

The LORAN Precision Guidance System (LPGS) was installed on the USCGC NAUGATUCK for the purpose of calibrating the system with measured waypoints and verify repeatability and accuracy by using the waypoints for navigating on the St. Marys River.

This section presents a brief summary of the results of the LPGS Calibration and Verification tests, followed by a description of test procedures. The final results of the tests are presented separately for static repeatability and accuracy tests, waypoint calibration tests, and dynamic performance tests.

The St. Marys River LORAN-C monitor station located near Sault Ste Marie, Michigan was continually recording local shifts in the LORAN grid and making grid-shift corrections during the tests for the purpose of maintaining stable LORAN coverage to an accuracy of ± 10 nanoseconds throughout the St. Marys River area.

7.1 SUMMARY OF RESULTS

The tests were classified into three categories as follows: (1) Static repeatability and accuracy tests (2) waypoint calibration tests, and (3) Dynamic performance tests.

The static repeatability and accuracy tests performed while the ship was tied to the U.S. Coast Guard dock at Sault Ste. Marie, Michigan indicates that the LPGS is capable of providing a repeatable accuracy of 20 to 30 feet (1σ) by changing some of the receivers parameters.

A total of 17 waypoints between Sault Ste. Marie and St. Joseph Island were selected for system waypoint calibration. Due to strong winds and excessive river traffic, collecting reliable data at every waypoint was very difficult. In fact some of the waypoints will require recalibration.

Several dynamic tests were performed between two waypoints to evaluate dynamic response of LPGS. Response was slower than desirable when the ship made a maneuver because the ship's gyrocompass wasn't aiding the Kalman filter gains. A gyrocompass interface problem which couldn't be fixed within time prevented use of ship's gyrocompass heading. However preliminary comparison of LPGS's performance with AUTOTAPE and COGLAD system (USER I) showed worst case positional differences to be less than 50 feet; mean average of approximately 10 to 20 feet.

7.2 INSTALLATION

The LPGS was installed on the USCGC NAUGATUCK at Sault Ste. Marie, Michigan for the initial testing, calibration and verification tests. The CGC NAUGATUCK is a 110-foot harbor tug. The two LPGS displays were installed in the bridge so they could be observed and evaluated while navigating. Remaining equipment was installed in the chart room.

The 7-foot antenna for the LORAN receiver was installed on top of the ship's main mast about 12 inches to the left of center-line. Several other antennae and obstructions were nearby but this didn't create any noticeable noise or grid distortion.

To reduce primary power fluctuations and have independent power control, the LPGS was powered by an external 3KW gasoline motor-generator.

The LPGS was connected to the ship's MK-14 Gyrocompass system for heading data, but due to excessive noise on the data lines, compass repeater relay contact bounce, and inconsistency of closure of the relay's contacts, gyrocompass data couldn't be used during the calibration and verification tests.

Without the gyrocompass aiding the LPGS, system response was slower when the ship's heading changed. Since the calibration and verification tests, a redesigned gyro interface unit has been incorporated and tested.

After installation, electromagnetic susceptibility and interference tests were performed to insure that the LPGS didn't interfere with ship's electronic equipment and ship's equipment didn't induce noise into the LPGS.

The electromagnetic susceptibility test was performed by monitoring the LORAN signal input and atmospheric noise at receiver's test point TP-A with an oscilloscope. Signal was measured with all the shipboard electronic equipments turned-off except the MK-14 Gyrocompass System. This measurement was recorded as a baseline reference.

While monitoring signal at TP-A, the radio equipment was turned-on and transmitters activated. Next the radar was turned-on and operated. No change in signal or noise level was detected when these equipments were operated.

The electromagnetic interference test was performed by observing the performance of the ship's gyrocompass repeaters, radar and radio receivers when the LPGS was switched on and off. No degradation in performance of the tested equipments was noticed.

LORAN signals received by the LPGS were good and no interfering signals were present at receiver's output. Received signal at antenna was:

Master Station	2.1 mv
X-Ray Station	1.8 mv
Yankee Station	1.1 mv
Zula Station	5.1 mv
Gaussian Noise	0.6 mv
Crossing Rate	1.8 mv
Interference (9930 Rate)	

7.3 DATA ANALYSIS

All the data for the calibration and verification were recorded on hard copies by the LPGS printer at intervals of 30 to 45 seconds. Statistical parameters for each of the static accuracy and waypoint calibration tests printed out by the computer were computed as follows:

- a. Mean error, \bar{X} :

$$\bar{X} = \frac{1}{N} \sum_{i=1}^N X_i$$

where N is the number of successful measurements and X_i is the individual measurement.

- b. Standard deviation, S

$$S = \sqrt{\frac{\sum (X_i^2 - N\bar{X})}{N}}$$

7.4 STATIC REPEATABILITY AND ACCURACY TESTS

A series of 19 tests were performed between 28 August and 8 October 1976 for the purpose of determining the repeatability and static accuracy of the LPGS by taking 19 separate measurements when the vessel was tied to the dock at U. S. Coast Guard Base in Sault Ste. Marie.

Four tests were performed with the basic LORAN receiver and six tests were performed with the receiver's 1st order phaselock loop gain set at 2 and operating without energy track strobe. Table 7-1 is a tabulation of the results. Figures 7-1 and 7-2 show the positional distribution about the mean. With phaselock loop gain at 2 and no energy track strobe less jitter was noted.

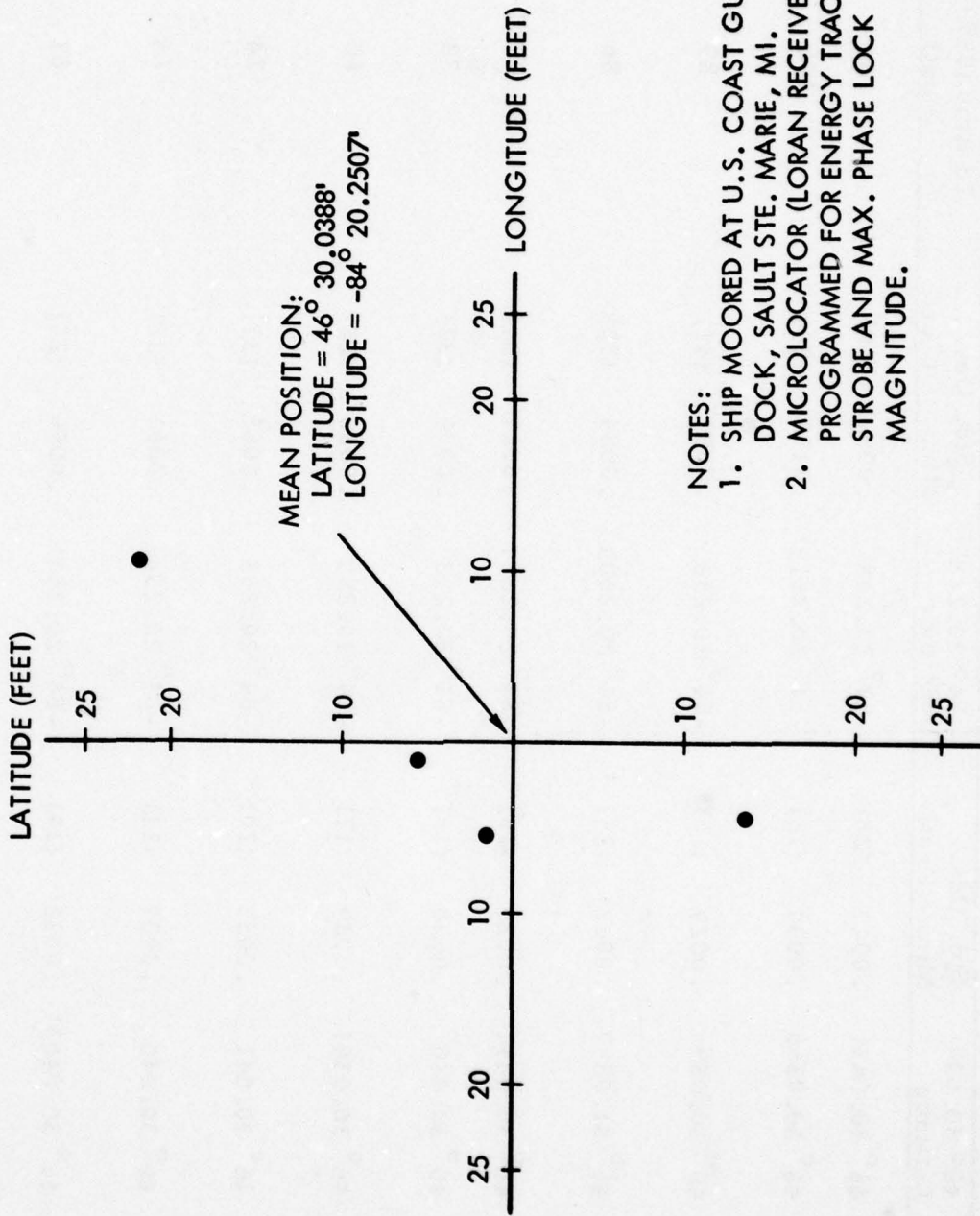
Nine tests were performed with a rubidium oscillator with an accuracy of of $<1 \times 10^{-12}$ controlling the receiver's oscillator to determine the effects of oscillator stability.

Table 7-1. Static Positional Data Taken At Dockside

Date	Measured Present Position					2d Rms (95%) Jitter (Feet)
	Latitude	Std. Dev. Min. (Feet)	Longitude	Std. Dev. Min. (Feet)	Std. Dev. (Feet)	
8/23/76	46° 30.039'	.0047 (28)	-84° 20.248'	.0069' (30)		82
8/30/76	46° 30.0366'	.0030 (18)	-84° 20.2519'	.0130 (55)		116
9/1/76	46° 30.039	.0029 (17)	-84° 20.252	.0099 (41)		89
9/2/76	46° 31.0397	.0042 (25)	-84° 20.2509	.0084 (35)		86
* 9/29/76	46° 30.0411	.0025 (15)	-84° 20.2537	.0057 (24)		57
* 9/30/76	46° 30.040	.0030 (18)	-84° 20.253	.0076 (32)		73
* 10/1/76	46° 30.0391	.0029 (17)	-84° 20.250	.0083 (25)		60
* 10/2/76	46° 30.041	.0033 (20)	-84° 20.253	.0088 (37)		84
* 10/4/76	46° 30.040	.0037 (22)	-84° 20.2546	.0061 (26)		68
* 10/5/76	46° 30.0402'	.0032' (19)	-84° 20.254'	.0056' (24)		61

Notes: Ship tied to Dock

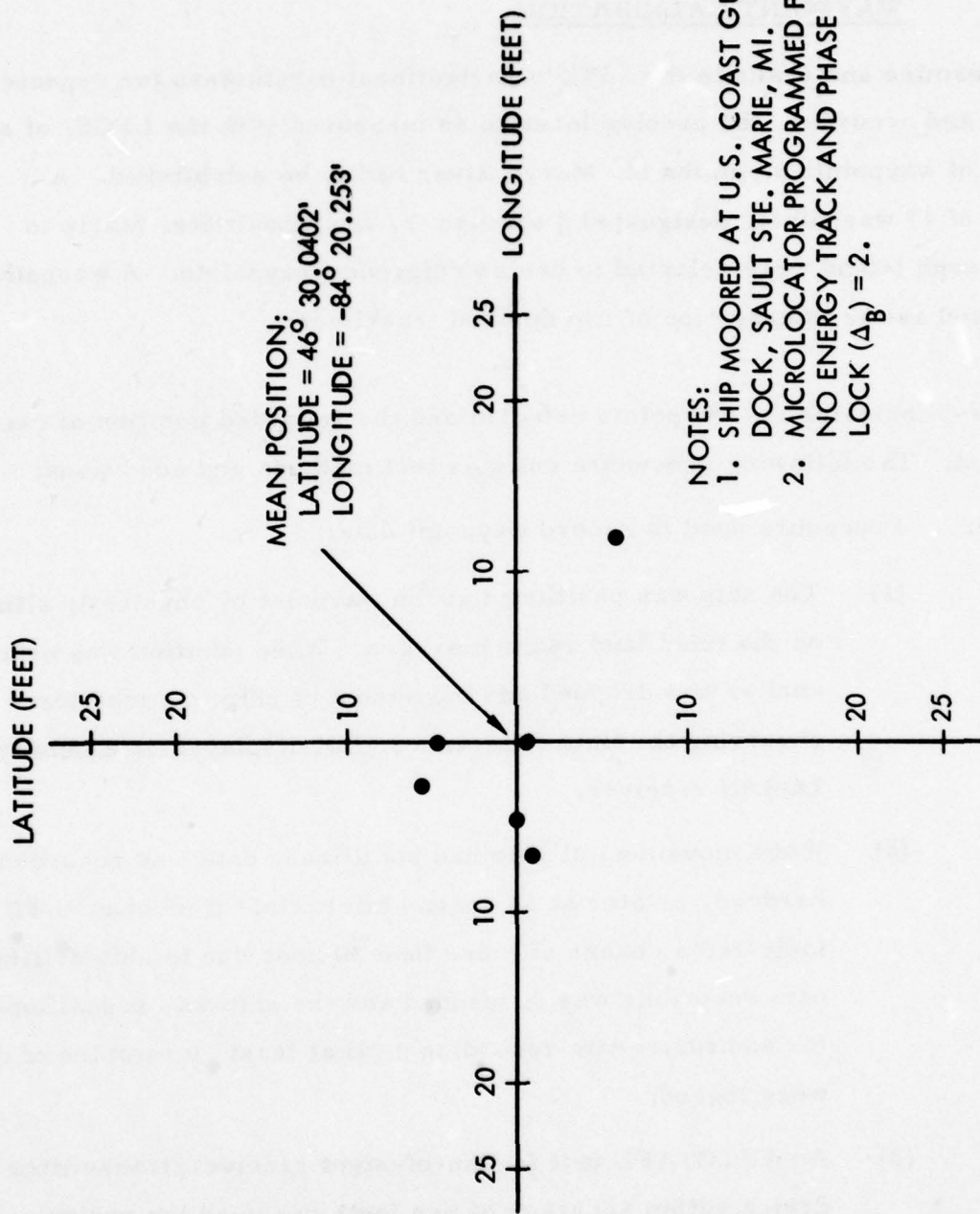
* Microlocator programmed for no energy track strobe and $\Delta_B = 2$.



- NOTES:
- SHIP MOORED AT U.S. COAST GUARD DOCK, SAULT STE. MARIE, MI.
 - MICROLOCATOR (LORAN RECEIVER) PROGRAMMED FOR ENERGY TRACK STROBE AND MAX. PHASE LOCK MAGNITUDE.

T111905

Figure 7-1. Present Position Distribution (Standard Configuration)



T111906

Figure 7-2. Present Position Distribution (Modified Configuration)

Table 7-2 indicates the test results with the rubidium and Figure 7-3 displays the positional distribution. No definite improvement was shown.

7.5 WAYPOINT CALIBRATION

To determine and evaluate the LPGS's navigational parameters for repeatability and accuracy, the precise location as measured with the LPGS, of a series of waypoints along the St. Marys River had to be established. A series of 17 waypoints, designated J through Y, from Sault Ste. Marie to St. Joseph Island were selected to use as reference waypoints. A waypoint is defined as the intersection of two desired tracklines.

Table 7-3 indicates the waypoints selected and the recorded position of each waypoint. The following procedure outlines test methods and conditions:

- a. Procedure used to record waypoint data:
 - (1) The ship was positioned at the waypoint by physically siting on the fixed land range markers. When position was established, anchor was dropped and movement of ship was monitored by observing the time differences (TD) displayed on a monitor LORAN receiver.
 - (2) When movement of ship had stabilized, data was recorded by hardcopy printer at 30 second intervals. If monitor's TD's indicated a change of more than 30 nsec due to ship drifting, data recording was suspended and the ship was repositioned for additional data recording until at least 10 samples of data were logged.
 - (3) An AUTOTAPE unit (a line-of-sight receiver/transmitter device within accuracy of two feet) was used for position fixing at waypoints M, N, and O.

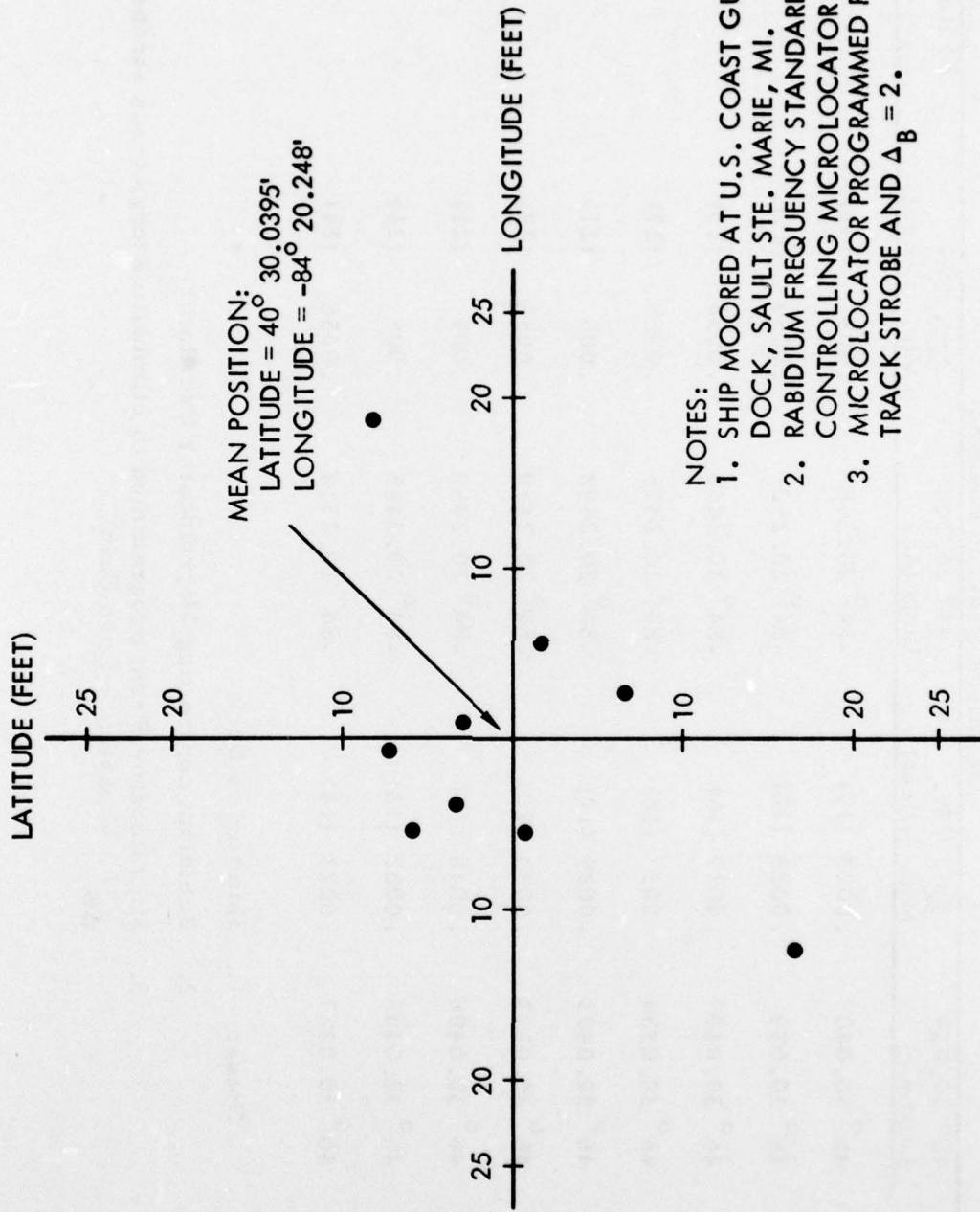
Table 7-2. Positional Data Taken At Dockside With Rubidium Oscillator

Date	Measured Present Position				2d Rms (95%) Jitter (Feet)
	46° 30.039' Latitude	Std. Dev. Min. (Feet)	-84° 20.248 Longitude	Std. Dev. Min. (Feet)	
10/1/76	46° 30.040	.0028 (17)	-84° 20.248	.008 (33)	74
10/2/76	46° 30.039	.0023 (14)	-84° 20.250	.0059 (25)	57
10/2/76	46° 30.0409	.0027 (16)	-84° 20.2436	.0056 (23)	56
10/4/76	46° 30.0384	.003 (18)	-84° 20.2475	.0065 (27)	65
10/4/76	46° 30.0401	.0029 (17)	-84° 20.2492	.005 (21)	54
10/5/76	46° 30.0393	.0033 (20)	-84° 20.2468	.0053 (22)	59
10/5/76	46° 30.0408	.0018 (11)	-84° 20.2483	.005 (21)	47
10/6/76	46° 30.0405	.0022 (13)	-84° 20.2495	.005 (21)	45
10/6/76	46° 30.0367	.0023 (14)	-84° 20.2514	.0058 (24)	45

Notes: 1. Ship tied to Dock

2. Rubidium controlling Microlocator Oscillator

3. Microlocator Prom programmed to eliminate energy track strobe and set $\Delta B = 2$ (Phaselock Loop Gain)



- NOTES:
1. SHIP MOORED AT U.S. COAST GUARD DOCK, SAULT STE. MARIE, MI.
 2. RABIDIUM FREQUENCY STANDARD CONTROLLING MICROLOCATOR OSCILLATOR.
 3. MICROLOCATOR PROGRAMMED FOR ENERGY TRACK STROBE AND $\Delta_B = 2$.

T111907

Figure 7-3. Present Position Distribution (Modified Configuration) With Rubidium Oscillator

Table 7-3. St. Marys River Waypoint Calibration Data

WP	Description	Measured Lat/Long				Measured TD _S			Date	Time	LORAN Stations Used	Weather Conditions	Remarks			
		Latitude	Std Min	Dev (ft)	Longitude	Std Min	Dev (ft)	TD _X						TD _Y	TD _Z	
J	100° 5/8 mi to Bayfield Dike Lt.	46° 30.006'	0.005'	(32)	84° 19.888'	0.010'	(40)	11,260.283	22,369.69	33,162.172	9-2-76	1100	M, X, Z	Good	Ship at Anchor	
K	303° 1/2 mi to Bayfield Dike Lt.	29.663'	0.0043'	(27)	18.342'	0.0099'	(32)	11,264.897	22,370.367	33,174.006	9-2-76	0930	M, X, Z	Good	Ship at anchor, fairly stable	
L	159° 1/2 mi to B89	27.038'	0.0026'	(16)	16.460'	0.0072'	(30)	11,261.066	22,364.294	33,202.671	9-1-76	1545	M, X, Z	Windy, 15-25 mph	Ship at anchor Not much ship movement	
M																
M	274° 1/8 mi to B87	26.015'	0.0063'	(36)	15.363'	0.0130'	(54)	11,261.009	22,361.725	33,215.827	9-1-76	1430	M, X, Z	Windy 15-25 mph	Ship at anchor, used autotape	
N	030° 1/8 mi to RN87	25.854'	0.0050'	(30)	15.183'	0.0093'	(36)	11,260.976	22,361.359	33,217.901	9-1-76	1315	M, X, Z	Windy 15-25 mph	Ship at anchor, used autotape	
O	Abseam Lt 80	23.563'	0.0083'	(57)	13.897'	0.0097'	(32)	11,254.151	22,352.868	33,237.942	9-1-76	1100	M, X, Z	Windy, 15-25 mph	Ship at anchor, used autotape	
P	122° 1/2 mi to B59	19.874'	0.0045'	(27)	10.867'	0.0042'	(17)	11,245.357	OFF AIR	33,272.048	8-30-76	1700	M, X, Z	Good	Ship at anchor	
Q	Abseam RN42	18.828'	0.0045'	(27)	07.153'	0.0048'	(50)	11,259.490	OFF AIR	33,298.830	8-30-76	1600	M, X, Z	Good	Ship at anchor	
R	117° 1/2 mi to FW (Front Dark Hole Range)	16.121'	0.0088'	(53)	06.914'	0.0179'	(75)	11,238.117	OFF AIR	33,304.046	8-30-76	1435	M, X, Z	Good	Ship at anchor	
S	Abseam RN20	15.402'	0.0059'	(36)	05.909'	0.0105'	(47)	11,237.937	OFF AIR	33,310.446	8-30-76	1345	M, X, Z	Good	Ship at anchor	
T	Abseam Lt 48	21.146'	0.0059'	(36)	12.780'	0.0072'	(30)	11,243.952	22,341.373	33,255.292	8-23-76	1022	M, X, Z	Good	Ship at anchor	
U	Abseam BC35	17.268'	0.0067'	(41)	12.928'	0.0083'	(36)	11,212.528	22,317.172	33,266.266	8-23-76	1155	M, X, Z	Good	Ship at anchor	
V	Abseam R24	15.433'	0.0040'	(24)	10.892'	0.0120'	(50)	11,208.304	22,305.005	33,282.155	8-23-76	1348	M, X, Z	Good	Ship at anchor	
W	Abseam B15	13.299'	0.0059'	(36)	10.260'	0.0175'	(73)	11,293.232	22,288.897	33,288.916	8-23-76	1545	M, X, Z	Good	Ship at anchor	
X	Abseam BC7	12.382'	0.0085'	(52)	07.328'	0.0115'	(48)	11,202.918	22,280.062	33,305.242	8-31-76	1315	M, X, Y	Overcast	Ship at anchor	
Y	318° 0.46 mi to HB	46° 10.533'	0.0093'	(57)	84° 05.206'	0.0120'	(50)	11,200.380	22,262.526	33,316.023	8-23-76	1708	M, X, Y	Good	Ship at anchor	

T105521

The positional accuracy of the measured waypoints was limited due to the following factors.

- (1) Ability to position ship on waypoint by physically siting in land range markers located at distances up to 2 miles. At several waypoint intersections the range markers are ideally located so that the vessel could be guided to the waypoint within several feet. However many of the other waypoints were difficult to determine the intersection lines within 25 to 50 feet.
- (2) Ship movement caused by river current and/or wind and ship swinging around anchor. In narrow sections of the channels, river current of several miles-per-hour or more are present. A current this fast moved the anchored ship out of positions very quickly thereby limiting the amount of reliable waypoint data that could be collected.
- (3) Stability of Mini-LORAN-chain. Several times while taking waypoint data, the Mini-LORAN monitor personnel inserted LOP (Line-of-Position) corrections of 10 nano-seconds to bring the chain back into tolerance of ± 15 nano-seconds. Since then, the chain has demonstrated to maintain an accuracy of ± 15 nano-seconds.

Several problems were discovered during the calibration tests that increased the positional jitter. A hardware problem in the gyrocompass interface board was causing the Kalman filter to constantly change gains. This increased present position jitter.

A LORAN receiver with maximum 1st order phaselock loop gain was used when recording waypoint position. This has the adverse side-effect of very tightly coupling radio noise into the present position calculations which increases jitter.

7.6 DYNAMIC TESTS

Dynamic tests were conducted on 23 September 1976 to evaluate the systems performance and accuracy by repeatedly navigating between two calibrated waypoints.

For these tests waypoints "N" and "O" were used. The vessel cruised at approximately 10 miles per hour between the waypoints using land range markers to steer on. Data were recorded simultaneously from the AUTOTAPE, which has an accuracy of approximately two feet, and the LORAN Precision Guidance System. Figures 7-4 and 7-5 show the dynamic performance of the LPGS vs AUTOTAPE during one run.

Tests were conducted with Kalman filter gain set to $Q_p = 5$ and $Q_v = 1$ (normal setting), and LORAN receiver phaselock loop gain at 2 with no energy track strobe.

Additional tests were performed between waypoints "N" and "O" with the ship doing "S" maneuvers across the waypoint to evaluate response of the system with various Kalman filter gain settings. Without the ship's gyrocompass input aiding the Kalman filters gain because of a gyrocompass interface problem, the system response was slower than desired.

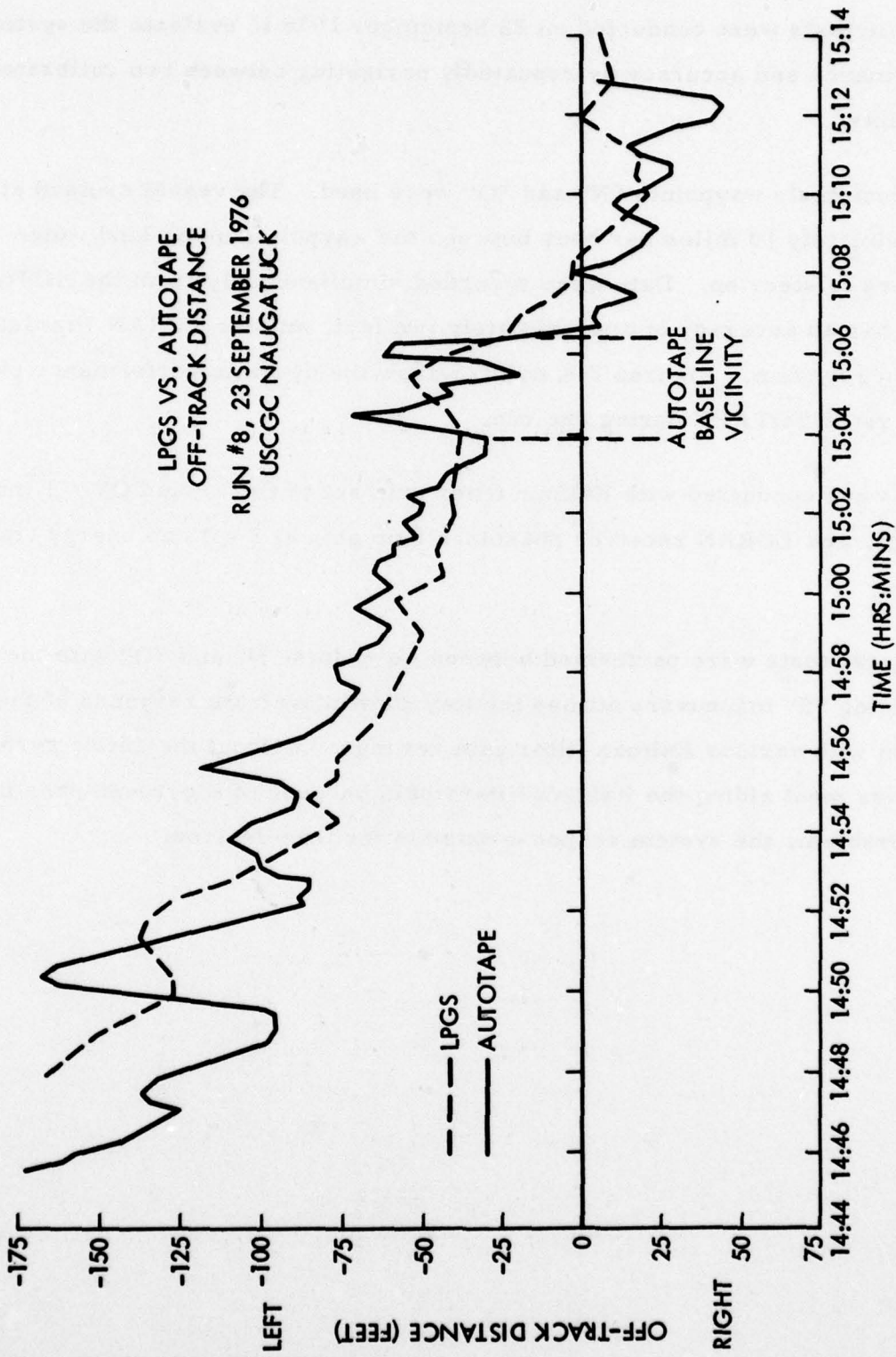


Figure 7-4. Dynamic Performance of LORAN Precision Guidance System

LPGS ABSOLUTE DEVIATION
FROM AUTOTAPE

RUN #8, 23 SEPTEMBER 1976
USCGC NAUGATUCK

AUTO
BASELINE
VICINITY

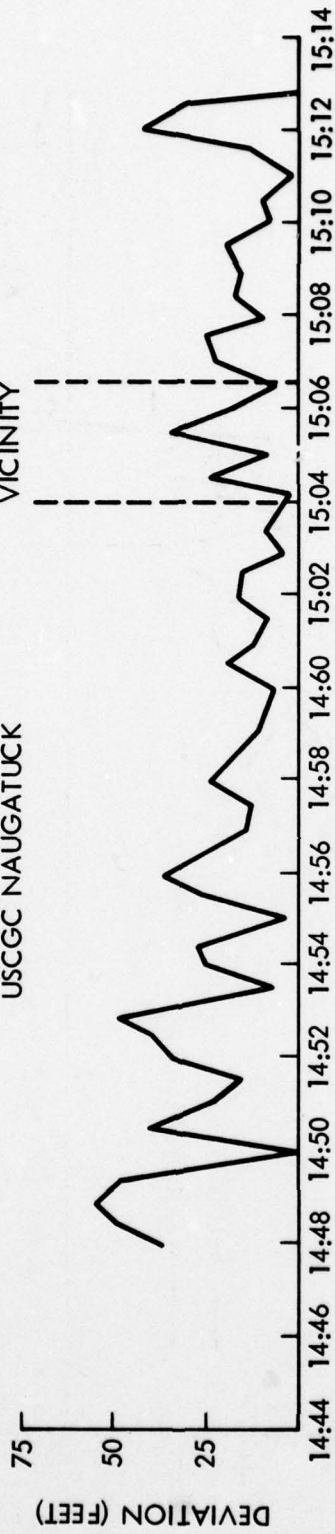


Figure 7-5. Deviation from Reference System

SECTION 8

RELIABILITY OF LORAN PRECISION GUIDANCE SYSTEM

This section details the history of hardware failures and problems encountered in the LORAN Precision Guidance System (LPGS) from time of integrating hardware into a system to completion of testing system during winter operations aboard the USCGC Mackinaw.

8.1 RELIABILITY HISTORY

The LPGS has been operated more than 3,000 hours within a one-year period (April 76 - April 77) averaging 10 hours a day of continuous use. During that period, the hardware failed eight times. It has been operated in temperature ranges from approximately to 50° to 95° F and was subject to severe vibrations, primary power fluctuations, and line frequency variations. Table 8-1 lists the malfunctions and problems encountered in a chronicle order.

A good test for reliability and mechanical ruggedness of the LPGS was during the period the system was installed on the USCGC Mackinaw during ice-breaking missions from January through March 1977. No failures or malfunctions were attributed to the severe vibrations encountered during the winter operations.

8.2 PRIMARY POWER PROBLEMS

When the LPGS was operated on the USCGC Mackinaw, primary power spikes induced when the ship's power winches were activated caused the 21 MX computer to halt. Voltage drops from 115 VAC to 85 VAC were noted. Also the line frequency varied between 58 to 62 Hz but no problems were noted from the frequency changes. Problem was corrected by using an isolated power source (non-interruptible power supply).

Table 8-1. Malfunctions and Problems

<u>Month</u>	<u>Approximate Operating Time (Hours)</u>	<u>Equipment</u>	<u>Problem/Malfunction</u>
May 76	700	21MX Computer	One Memory Module failed (intermittent)
June 76	1200	21MX Computer	Two Memory Modules failed (intermittent)
July 76	1600	Sykes Flexible Disk System	Top drive was intermittent. Caused by a worn felt head pressure pad.
August 76	First time interfaced to ship's gyro.	Gyro Interface Board	Excessive noise spikes (14V P/P) from ship's MK-14 gyro compass caused interface board to output unreliable gyro data to 21MX. Redesigned gyro interface board.
August 76	1800	Microlocator	Power supply failed. Broken etch on printed circuit board.
September 76	2000	Microlocator	Induced failure by ground wire removed. A 70 VDC ground loop between ship's gyro and LORAN precision guidance system caused an I/O integrated circuit component to burn-out on two microlocators. Problem was corrected when redesigned gyro interface unit was used.
October 76	2200	Sykes Flexible Disk System	Intermittent operation. Problem caused by a broken wire to read/write head in bottom drive and top drive read/write head was out of alignment.

Table 8-1. Malfunctions and Problems (Continued)

<u>Month</u>	<u>Approximate Operating Time (Hours)</u>	<u>Equipment</u>	<u>Problem/Malfunction</u>
January 77	2700	HP-1317 Graphics Display Unit (CRT)	No display. Problem caused by frost from the ship's ceiling structure to melt and drip into the CRT and short circuit low voltage power supply. Corrected problem by covering repaired CRT with a plastic bag.
	2800	21MX Computer	Intermittent operation. Problem was caused by a cumulation of foreign substance between two I/C pins on memory control board. Cleaned board to correct problem.
	2850	LORAN/Gyro Interface Board	Intermittent data input to 21MX computer. Found a broken wire which apparently was broken by handling board.
March 77	3000	Sykes Flexible Disk System	Top drive intermittent. Diskette pressure arm moved due to holding screw being loose.

A non-interruptable power system was installed on the Mackinaw in March 1977 for operating the LPGS. This configuration prevented the voltage drops from appearing at the LPGS input when winches were operated thus halting the system.

8.3 RELIABILITY DESIGN CONSIDERATIONS

To increase the reliability of the LPGS the following items were implemented during fabrication:

1. The equipment cabinet, which houses the 21 MX computer, Sykes Flexible Disk System, Megatek Graphics Interface Unit, interface boards, and Microlocator receiver, is shock mounted by four shock absorbers on the bottom and two vertical shock absorbers on the side which secure to the ship. The HP-2644 Mini Data Station and the HP-1317 Graphics Display are shock mounted (Standard Configuration) by rubber legs on the bottom.
2. A muffin-fan is installed in the equipment cabinet for cooling the housed equipment.
3. The Microlocator antenna coupler is located in a water-tight housing on the antenna assembly which is sealed by a rubber gasket and sealing compound around the antenna lead-in cable.

SECTION 9

CONCLUSIONS AND RECOMMENDATIONS

A brief review of the significant results of the St. Marys River LORAN Precision Guidance System are presented in this section. Important conclusions drawn from the analytical and operational use are listed, and finally, recommendations for additional work to improve capability are presented.

9.1 OPERATIONAL RESULTS

Based upon the favorable results that have been obtained thus far, the LORAN-C Precision Guidance System (LPGS) has the capability and accuracy required to have a wide usefulness as a precision navigation system in restricted waterways which have Mini LORAN-C coverage. Mini LORAN-C chains are relatively high precision and are free from skywave and excessive grid distortion errors because stations are more accurately controlled and closer together. There is presently insufficient controlled data to determine exactly how well the system meets the Coast Guard's accuracy objective of ± 25 feet maximum cross-track error 95% of the time.

The Calibration and Verification tests were performed aboard the USCGC NAUGATUCK. Unfortunately, an interface problem between the ship's gyrocompass and the LPGS hampered evaluation during the tests. Time did not permit redesign and checkout, therefore the demonstration tests had to be conducted without gyrocompass aiding to improve accuracy and increase system response during course changes. Since then, a redesign gyrocompass interface has been implemented. The implementation of the gyro's heading information into the LPGS software works well under most conditions. Some spurious results have however been noticed. This item needs further investigation under operational conditions.

During the tests the LORAN receiver's phaselock loops were optimized for less jitter output. Optimization consisted of reducing the gain of the first-order loop and not using energy track strobe since signal strength was very good. Net result was a reduction of positional jitter by about 1/3.

Many software and several hardware changes have been made to improve the LORAN and the gyrocompass processing since the system was initially tested on the USCGC NAUGUTUCK. After the changes, encouraging results were obtained when the LPGS was installed on the USCGC MACKINAW for its winter ice breaking mission. During the winter operations in January and March 1977 on the St. Marys River, additional software changes were made which improved the operational performance of the LPGS. Positional jitter between 20 to 30 feet (one-sigma standard deviation) was achieved with gyrocompass aiding the Kalman filter. In addition, the severe vibrations caused by the ice breaking operation of the MACKINAW was a good test of the system's mechanical ruggedness.

Additional operational testing is required, on larger vessels such as ore carriers, to fully evaluate the system's navigational capability, repeatability, and accuracy from end to end of the St. Marys River. To determine the system's accuracy and repeatability and to determine if any LORAN grid warpage exists, the waypoints must be calibrated more accurately.

9.2 GRAPHICS ASSESSMENT

The LPGS was basically designed for use as a research and development tool to evaluate LORAN-C navigation, therefore ease of operation and graphics capability were sacrificed. To provide provisions to write the software in a high-level language and obtain a mass memory storage, a DOS III (Disk Operating System) operating system is used. Unfortunately, DOS III is not a multiple task system therefore updating graphics is much slower than desirable. Approximately two minutes are required to search the data files each time the CRT screen is redrawn. By using a different operating and graphics system, the update rate could be improved.

9.3 RECOMMENDATIONS

There are several general areas in which additional effort is merited;

- a. Graphics upgrading
- b. Capability to display location of nearby vessels by using LORAN Data Link equipment on all vessels.

The graphics would be greatly improved by using a high resolution 17 or 19 inch color display which has at least three colors to highlight the important channel points such as channel, banks, track lines and navigational aids thereby making graphics much easier to view. It is recommended that separate displays be used for alphanumeric data. This would reduce the clutter on the display.

By knowing the location of nearby vessels in the channel, the LORAN-C Precision Guidance System (LPGS) could be used to navigate safely in restricted waterways when visibility is zero. This could be implemented by either interfacing the LPGS positional output into a radar display or using LORAN Data Link. Data linking would require all vessels traversing restricted waterways to be equipped with a LORAN receiver and Data Link unit for transmitting time difference position to the LPGS. The LPGS would process the received data linked time differences and display a "bug" on the graphics screen showing position of nearby vessels in the channel. The equipment required to provide data link capability is low cost considering the mariners' safety goals.