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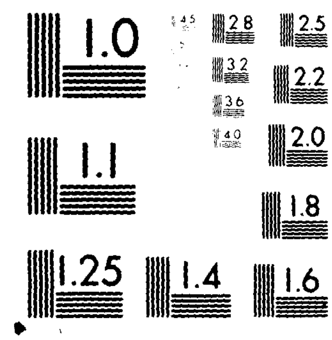

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LORAN-C DISPLAY SYSTEM TEST REPORT

LT T. M. DROWN, USCG

JULY 1980

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
United States Coast Guard
Office of Research and Development
Washington, D.C. 20593

NOTICE

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16. Abstract

THE COAST GUARD IS INVESTIGATING ALTERNATIVE MEANS TO AUGMENT THE EXISTING VESSEL TRAFFIC MONITORING CARRIED OUT BY ITS VESSEL TRAFFIC SERVICE CENTERS. ONE ALTERNATIVE IS TO REQUIRE VESSELS TO TRANSMIT THEIR POSITIONS TO THE CENTER IN TERMS OF LORAN-C TIME DIFFERENCES. THE TIME DIFFERENCES ARE THEN PROCESSED AND DISPLAYED. THE LORAN-C DISPLAY SYSTEM (LDS) IS AN EXPERIMENTAL SYSTEM DESIGNED TO TEST THE CONCEPT OF VESSEL POSITION MONITORING USING LORAN-C TIME DIFFERENCES.

THIS REPORT DESCRIBES THE SYSTEM, THE STEPS TAKEN TO VERIFY PROPER OPERATION AND THE RESULTS OF TESTS MADE IN SAN FRANCISCO, CA.

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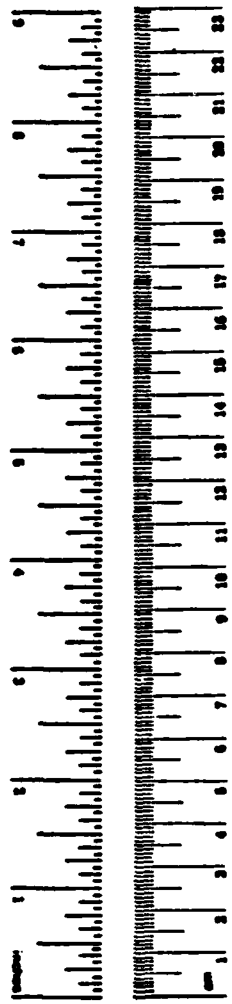
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

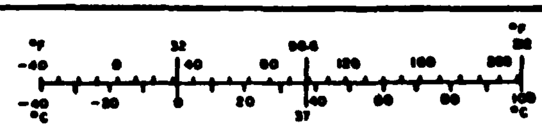
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2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

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

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



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1.0 INTRODUCTION AND OBJECTIVES

1.1 INTRODUCTION

The Ports and Waterways Safety Act of 1972, Public Law 92-340, provides the Department of Transportation the statutory authority to "... establish, operate and maintain Vessel Traffic Services and systems for ports harbors and other waters subject to congested vessel traffic...". Under this law, direct control of vessel traffic can be exercised during especially hazardous conditions. Also, vessels operating in a vessel traffic service area can be required to utilize and comply with the service's established operating procedures. The Coast Guard is the agency responsible for implementing this law and has established Vessel Traffic Services (VTS's) in a number of ports throughout the U. S..

The normal method of operation of a VTS is to provide an advisory to vessels operating in the VTS service area. Information contained in the advisory includes vessel movements, hazards to navigation and weather. This information is collected and disseminated by one station in each VTS area called the Vessel Traffic Center (VTC). The majority of information concerning vessel movements is provided by the mariner on a voluntary basis. A typical information gathering scheme is for a vessel's master (or pilot) to report to the VTC when he either gets underway in or enters a service area. The VTC then monitors the vessel's progress by means of periodic voice reports received from the vessel as it passes predetermined check points; this monitoring scheme is called a Vessel Movement Reporting System (VMRS). In many VTS areas, the VMRS is augmented with radar and/or closed circuit television (CCTV) surveillance. This augmented surveillance serves to provide a higher surveillance data rate with reduced radio communications and improves the ability to detect and resolve potential traffic conflicts.

In a continuing effort to improve VTS surveillance capabilities, the Coast Guard's Office of Research and Development has undertaken a project to design and evaluate a prototype position monitoring system that uses Loran-C as a surveillance sensor. The system concept involves the automatic transmission of position information, in terms of Loran-C time differences, from a target vessel to a shore station where the information is processed and displayed for use by a VTS watchstander. The monitoring of the the location of a target using retransmitted Loran-C information dates back a number of years. The orginal concept was to retransmit the analog Loran-C signal to a base station for processing and display. This concept worked, but it did not work well enough to be used in a broad range of position monitoring applications. The latest generation of loran receivers, using digital electronics, has reduced the problem of transmitting Loran-C position information by providing the capability to easily code time difference values in digital form. This greatly reduces the problem of transmitting positional information and decreases the amount of processing required at the monitoring site.

1.2 OBJECTIVE

The goal of this project is to test the feasibility of a loran based position monitoring system that can extend and/or augment the existing surveillance capabilities of a VTS. There are three specific objectives to be addressed. They are:

(1) Characterize a Loran-C surveillance system for use in VTS operations. Determine whether or not such a system can be implemented using easily available, off-the-shelf components. Identify basic operating characteristics of a Loran-C based surveillance system that lend themselves to VTS operation. Establish baseline operating parameters to aid in designing future Loran-C based surveillance systems.

(2) Characterize the data communications link required for a Loran-C based surveillance system. Establish whether or not sufficient data can be collected with an asynchronous reporting scheme over a shared channel. Estimate minimum requirements for a data channel.

(3) Assess the potential accuracy of the system and evaluate the system's usefulness in enforcing vessel traffic separation standards. Currently, vessel traffic separation zones are established to separate the inbound and outbound flows of vessel traffic in the major ports of the United States. These zones define one-way traffic lanes in which ships are supposed to travel in both their approach to and transit in the port areas. The separation between these lanes depends on the geography of the port. In some instances, only a line of buoys separates the traffic. Where possible, a buffer zone is designated to separate the traffic lanes. This objective is intended to establish a baseline for positional accuracy both to demonstrate under what conditions the prototype system can be used to enforce vessel separation standards and to provide a basis for future system improvement.

2.0 SCOPE

It is not the intent of this project to assess Loran-C as a potential harbor-harbor entrance navigation system. Rather, it is intended to show the feasibility of using it as a sensor and to compare it to an existing VTS sensor (RADAR). As related to the stated objectives, the scope of this project is limited to:

(1) The design and implementation of a Loran-C based surveillance system which incorportates features that might be required for easy operation in a VTS environment. The most important feature to be explored is man/machine interface.

(2) The demonstration of an asynchronous data communication scheme.

(3) The demonstration of the effects of sharing a communication

channel between voice and data.

(4) The evaluation of the display subsystem's potential accuracy using radar as a reference.

3.0 SYSTEM DESCRIPTION

3.1 OVERVIEW

The prototype system is called a Loran-C Display System (LDS). It is designed to receive position reports from a number of cooperating vessels equipped with LDS Telemetry Units and show the positions of the vessels on a geographic map displayed on a CRT. The display incorporates a number of operator support features that are useful to a VTS watchstander in the performance of his duties.

The LDS equipment can be divided into two categories: (1) the shipboard equipment and (2) the base station equipment. Figure 1 is a block diagram of the Loran-C Display System separated into these two categories.

3.2 LORAN-C TELEMETRY UNIT (LTU)

The shipboard equipment consists of a Loran-C receiver, a VHF-FM marine band transceiver and an interface between the two. Called a Loran-C Telemetry Unit (LTU), the shipboard equipment transmits a fixed format digital message at regular, preselected intervals on a marine band VHF-FM frequency. The digital message is ASCII coded and is transmitted at 300 bits per second. The transmitter is modulated using standard Bell 202 audio tones. It takes 0.8 seconds to transmit one message.

The Loran-C receiver is a TDL-708 which provides continuous readout of two time differences for any operator selected Loran-C chain. The time difference information is displayed on the front panel of the receiver to the tenth of a microsecond resolution. The time difference display for each Loran-C pair is updated approximately every four seconds. TDA and TDB, however, are not updated simultaneously; they are updated in a staggered fashion. First TDA is updated and then, approximately two seconds later, TDB is updated. Each update is the average value of time difference observations sampled over a time period equal to 16 Loran-C Group Repetition Intervals.

The same time difference information appearing on the front panel display is output at a rear mounted 50 pin connector in parallel, BCD format. Also available at the 50 pin connector is an inhibit strobe to indicate that the information is being updated and, therefore, not useable. This connector is a modification specified by the Coast Guard for all the TDL-708 receivers it purchases. The LTU makes use of this modification to obtain time difference information for inclusion in the digital message.

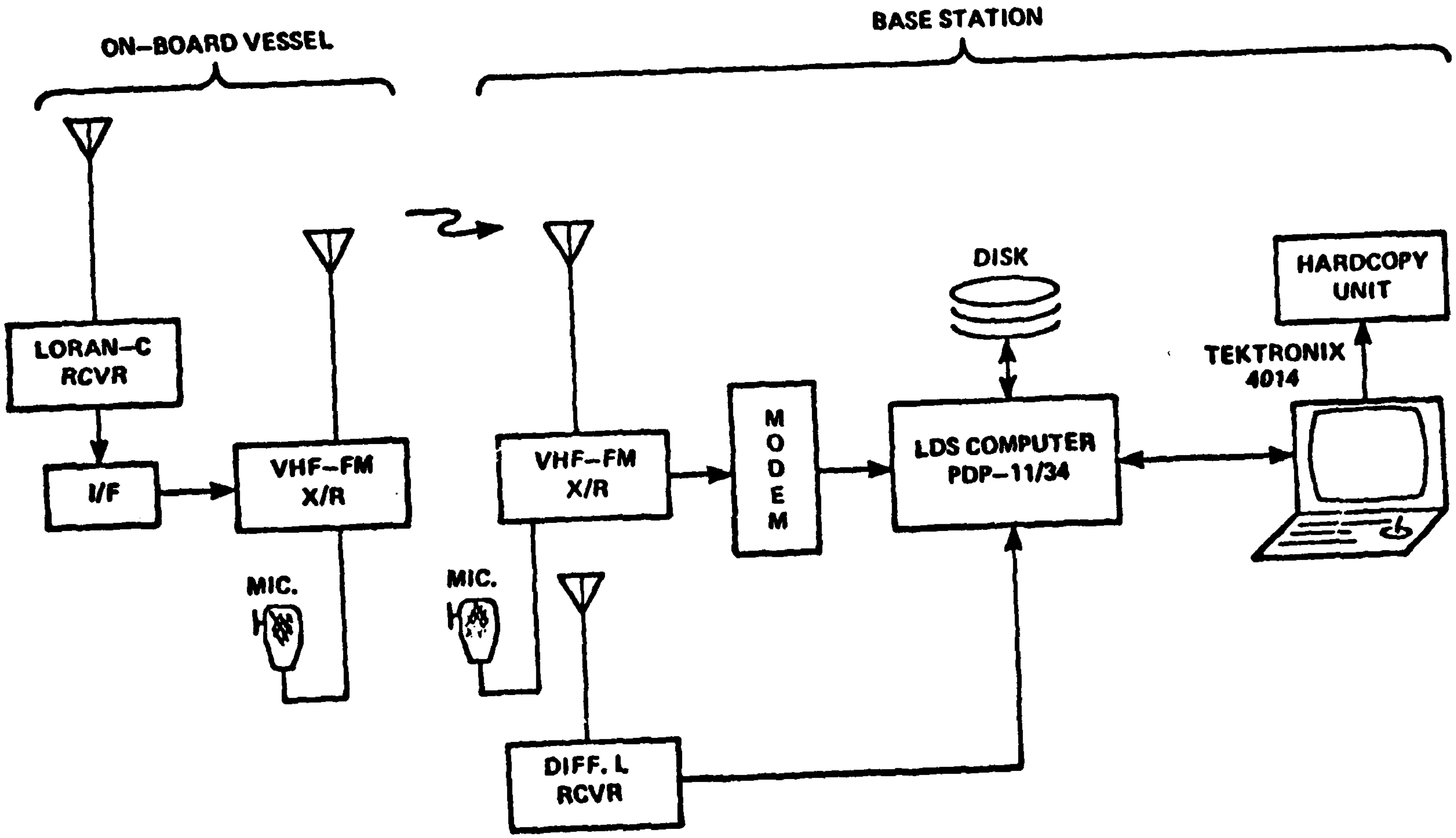


FIGURE 1 LORAN - C DISPLAY SYSTEM BLOCK DIAGRAM

The VHF-FM transceiver is a marine band radio manufactured by Motorola. The audio tones that modulate the transmitter are input at the transceiver's regular microphone input. A relay that is controlled by the interface circuitry automatically switches between voice and digital input. In the LTU, voice transmission has priority over digital input, and the interface locks out the digital message until any voice transmissions are completed.

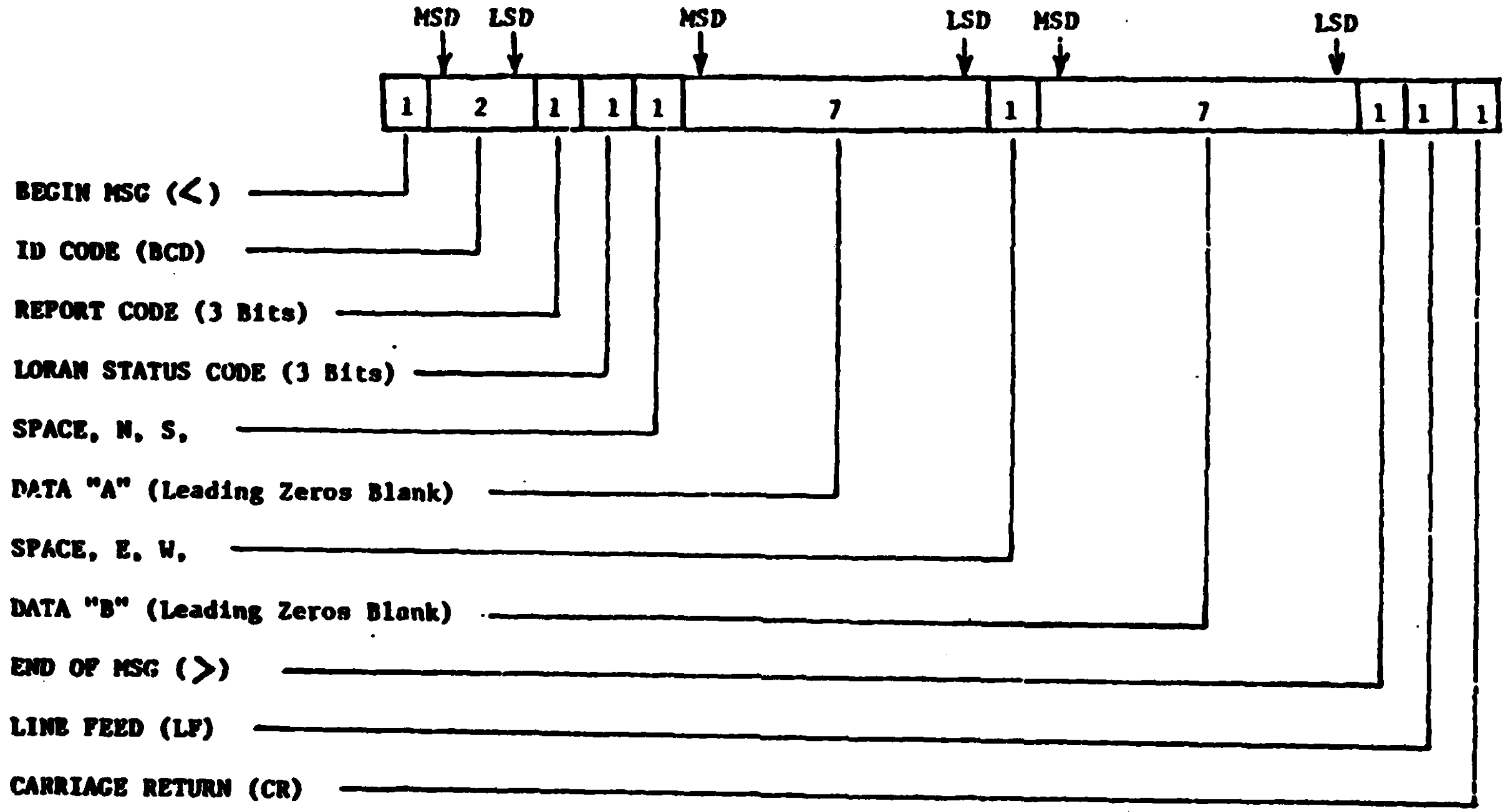
The interface composes the LTU's digital message, Figure 2. It also provides the interval timing for message transmission, the FSK modulation for the digital message and transmitter keying. Position information, in the form of time differences is input from the TDL-708. Additional information such as an identity code, a report code and a loran receiver status code, are manually selected from switches on the interface front panel. Each LTU message contains 24 ASCII characters which represent the information accumulated by the interface as well as begin and end message characters and line feed and carriage return characters. These additional characters are automatically inserted into each message by the interface.

Each LTU has the capability of transmitting a digital message at regular intervals ranging from 3 seconds to over 30 minutes. The transmission interval is manually selected by an operator at each LTU. This type of asynchronous operation requires manual synchronization of all LTU's that operate in the Loran Display System at any given time. A more complete description of the LTU is contained in Appendix A.

3.3 BASE STATION EQUIPMENT

The base station equipment consists of a DEC PDP-11/34 computer, a Tektronix 4014 Direct View Storage Tube Display, a Tektronix Hard Copy Unit, a DEC Dual Floppy Disk Storage Unit, a Modem and a VHF-FM transceiver. The audio tones that represent a LTU digital message are received at the VHF-FM transceiver and converted to binary code for input to the computer. Operator commands are input via a keyboard on the 4014 console and computer generated information is output on the 4014 display. The display provides two modes of presentation: (1) storage and (2) refreshed. Information written to the display in storage mode remains in view until the entire display is erased and a new display presented. Refreshed information can be selectively replaced without having to rewrite an entire display. Any information written to the 4014 display in storage mode can be copied by the hard copy unit. Both LDS computer programs and incoming telemetry data are stored on the floppy disk storage units.

The LDS computer has both electrical and software interfaces for a differential receiver. It was planned to experiment with differential loran applications for both increasing the accuracy of the display subsystem and for calibrating the digitized map of the Loran-C grid. The opportunity to carry out this part of the project did not arise. However, long term stability averages which were established at



LEGEND: MSD - Most Significant Digit
LSD - Least Significant Digit

FORMAT: ASCII, 10 Bit
1 Start, 7 Data, 1 Parity, 1 Stop

STANDARD: BELL 202 tones
4 Cycles(1200 Hz = MARK 1)
7 1/3 Cycles(2200 Hz = SPACE 0)

MSG LENGTH: 24 chars.(0.8 sec)

BAUD RATE: 300 chars/sec

ASCII DATA LINK MESSAGE FORMAT

FIGURE 2 LDS TELEMETRY MESSAGE

approximately the same time as the LDS test, by another project which was analyzing Loran-C RF propagation characteristics in San Francisco showed that the resolution required for differential applications was on the order of ten nanoseconds where the LDS receiver only provided 0.1 microsecond (100 nanosecond) resolution. The LDS is capable of monitoring the position of any combination of eight vessels and vehicles at once. The digital message transmitted from each mobile unit is received and processed by the PDP-11/34 computer. The computer checks the message for bit parity, checks the data for reasonableness, updates the 4014 map display and stores the data in the correct track history file. LDS can store up to 1000 data points in each track history file. An error file is also provided to store messages that do not pass the computer checks.

The display sub-system is a major component of the LDS base station. It has a number of operator support features that are intended to help a VTS watchstander perform his duties. Some of the features are:

(1) Provide continuous zoom-in/zoom out display of a geographic map.

(2) Allow the operator to preselect fixed windows on a geographic map to facilitate faster display of areas of interest.

(3) Provide an information block to identify each target displayed.

(4) Determine lat/long of a position on the geographic map indicated by a cursor.

(5) Indicate a position on the geographic map when a lat/long is entered by an operator.

(6) Measure range and bearing between a reference point and a number of object points.

(7) Display the stored positions of selected targets.

(8) Provide a dynamic playback of the track of selected targets in real or accelerated time.

(9) Provide operator prompting to improve the man/machine interface.

4.0 SYSTEM DEVELOPMENT

4.1 GENERAL

System development consisted of three phases: (1) design and fabrication of the shipboard equipment (LTU) (2) design and implementation of the system software, and (3) acceptance testing. The design and production of the LTU was performed by Teledyne Systems

Co.; Northridge, CA. Development of the LDS base station and systems engineering were carried out at the Transportation System Center (TSC); Cambridge, MA. Software design and implementation was done by Input, Output Computer Services, Inc (IOCS); Cambridge, MA.

Teledyne Systems Co. delivered six Loran Telemetry Units for the project. They were able to keep the design of the LTU as simple as possible by using both an existing Loran-C receiver and an existing communications transceiver. A Teledyne designed interface provided the circuitry necessary to control the LTU operation and generate the telemetry message.

4.2 COORDINATE CONVERSION ROUTINE

An analysis effort was carried out to aid in developing the LDS coordinate conversion routine. This effort can be divided into distinct phases: (1) development of both the coordinate conversion algorithm and a computer simulation program based on the algorithm (called the Loran Tracker), (2) initial simulation runs, collection of calibration data and a comparison with the simulation results in order to adjust the site-dependent parameters, and (3) final simulation runs.

The conversion of time difference (TD) outputs of the Loran-C receivers to latitude/longitude values was accomplished using a technique originally developed for a airborne Loran-C application at the Transportation System Center (TSC). In essence, the algorithm:

(1) Computes geodetic ranges over the surface of the earth from an initial estimate of position.

(2) Uses these ranges to estimate received TD values.

(3) Computes differences between measured and estimated TD values.

(4) Uses the differences to compute corrections to the initial position estimates, and outputs position in latitude and longitude.

(5) Begins another cycle by using computed latitude/longitude as the initial position estimate, and repeating the above steps.

The algorithm was used to develop a computer simulation of the LDS system in San Francisco, the major elements of which were:

(1) Vessel trajectory generation

(2) Computation of ideal TD values

(3) System processing functions

(4) Loran Tracker conversion from TD to latitude/longitude

(5) Error computation

A routine was developed to simulate the position of a vessel as it traversed a rectangular course, thus allowing vessel dynamics to affect the problem. At preselected time intervals, ideal values of TD were computed, to simulate periodic vessel updates. These "ideal" values were truncated to 0.1 microsecond, to simulate LTU receiver output limitations. The simulated TD outputs were processed by the Loran Tracker to yield position estimates and, after comparison with actual position values, to calculate errors.

Using nominal values for the site-dependent variables, several simulation runs were made. The first result achieved was to show that, for perfect TD inputs, the Tracker was accurate to better than 1 foot; in other words, there was no computational inaccurancy introduced by the algorithm. A second result was that, when the TD inputs were quantized to the nearest 0.1 microsecond, the average position error was 50 feet. This is understandable since the gradient of the Loran grid in the San Francisco area is approximately 1000 feet per microsecond. Thus, quantizing the TD inputs to 0.1 microseconds will introduce errors randomly distributed between 0 and 100 feet, or about 50 feet on the average.

The third observation made from the simulation runs was that the time between TD updates is critical to the performance of the coordinate conversion module. The simulated vessel moved at 20 knots along a straight path, and through turns. At that speed, the dynamics of the vessel significantly degraded the accuracy of the module for update rates greater than 1 minute. Therefore, based on the results of the simulation, approximately 1/2 mile of vessel motion between updates, appears to be the maximum allowable without significant degradation of the accuracy. Because of this, the recommendation was made that the update rate during actual tests be kept below 20 seconds, where possible, and never allowed to be large enough that the vessel moves 1/2 mile between updates.

Once the computer simulation model was validated, sample loran data was obtained for the San Francisco Bay area. During February and early March of 1978, a rented car was equipped with one of the Teledyne equipped 708 receivers which was to be used in the vessel tests, a power supply, and a loran antenna. Data was collected either manually, by observing the TD display, or at times automatically, on a digital tape recorder.

The sites at which data was collected were selected for both the ability to be located on survey maps and easy access away from interference. Data from over 30 sites around San Francisco Bay, was recorded, both day and night, in fair weather and foul. TD data was used to calibrate two coordinate conversion variables: the values of speed of propogation of the loran signal along the path from both secondary stations X and Y. A nominal value of 983.577 feet per microsecond was used initially, which resulted in a average error of over 2 microseconds between estimated and measured TD values. Using the calibration data, the speed of propagation was adjusted to 981.0 and 981.6 feet per microsecond, for secondary X and Y respectively, reducing the average TD errors by an order of magnitude. In April 1978, additional data was collected at some of the initial sites, and new sites as well, which further verified the model and set the parameters which would be used during actual testing.

As a result of the processing of the calibration data by the simulation program, a final equation set for the conversion of TD values to latitude/longitude was developed for both system contractors, who were responsible for both the real-time display system and the post test data reduction and analysis. Further improvements were made to allow computation of the local gradient and compensation for shifts in the loran grid sensed by a benchmark receiver.

It has already been stated that there were two sources of system error: (1) the truncation of TD outputs to 0.1 microsecond and (2) the variable update rate. Another consideration to be made was the manner in which the TD values were sequenced for output in normal operation after achieving LTU receiver lock-on. The updated value of TDA is computed, then 2 seconds later an update of TDB (holding TDA constant), then alternating back to TDA, and so forth. Thus, because of the manner in which the receiver updates, the values of TDA and TDB in the display register, there was the possibility that a delay of up to 4 seconds could be randomly introduced, which would then translate into a position error.

4.3 LDS SOFTWARE

The LDS software was designed to meet two specific operational objectives:

(1) That the man/machine interaction be as natural to the operator as possible.

(2) That the operator/watchstander be capable of operating the LDS by means of prompting aids displayed on the CRT screen.

IOCS, the LDS contractors, was further directed to modularize the software and to implement it in Fortran whenever feasible.

As previously stated, LDS accepts the periodic telemetry messages, checks the validity of these messages and stores them in the appropriate vessel files on the floppy disk. At the same time the messages are relayed to a Data Collect System, for real-time and post analysis (See Test and Evaluation). Similarly, differential Loran-C time difference values can be periodically input and the long-term average values of the time differences computed to use in generating correction factors of TDA and TDB. These values can also be passed along to the Data Collect Computer.

The dynamic time difference values, representing the current positions of vessels, are converted into lat/long values which are in turn aligned with the displayed area map. Associated with each target is a leader and a full data block which consists of the vessel ID and the time of reception of the position report. The CRT screen is updated once every 10 seconds with the most recent position information, thus simulating the movement of vessels against a background map.

NOAA charts (Mercator Projection) covering the San Francisco Bay area were digitized off-line and, together with software tables and pointers, was stored on floppy disk. A display module provides for user definition of submaps, which can be called by name for screen display. The system also provides for software centering and zoom-in zoom-out on these geographic maps. A file containing annotations of pertinent buoys, lighthouses and landmark identification was generated during map digitization. The software map select routine overlays these annotations, as appropriate, on the selected geographic presentation. In addition, the operator may make temporary annotations on the display and delete them when they are no longer needed. The 4014 display terminal serves as both data entry and display for the LDS. By using the alphanumeric keyboard, the operator interacts with the computer, instructing it to perform specific functions, with the computer's response being returned to the operator by way of the display screen. Figure 3 shows the screen display with the map presentation on the left and system information on the right. The system information consists of the real-time clock, six lines of scratch pad, a menu of operator instructions and a list of vessels being monitored.

Figure 4 shows the logical flow of the operation of the LDS. Essentially the software is divided into two primary sections:

(1) The Operator Command Console Interface (OCCI) Module which performs all the man-machine interfacing, including the command functions and graphics software, and

(2) The Loran Asynchronous Routine (LAR) which accomodates both the asynchronous reception and the processing of LTU messages.

The OCCI serves as the software interface for man/machine interaction. Control is transferred to the module upon completion of system initialization. The routine issues a prompt, ENTER COMMAND, in the scratch pad area to notify the operator that it is ready to receive a command. OCCI then stays in a loop cycle awaiting operator command except for servicing demand interrupts caused by the reception of LTU messages.

An operator command is entered by keying the first two or three alphabetic characters which uniquely identify the appropriate instruction as depicted in the menu. OCCI performs command verification and, should the entered command not match a recognized command, an error diagnostic message is displayed in the scratch pad area. If the command is valid, OCCI transfers to the appropriate command routine

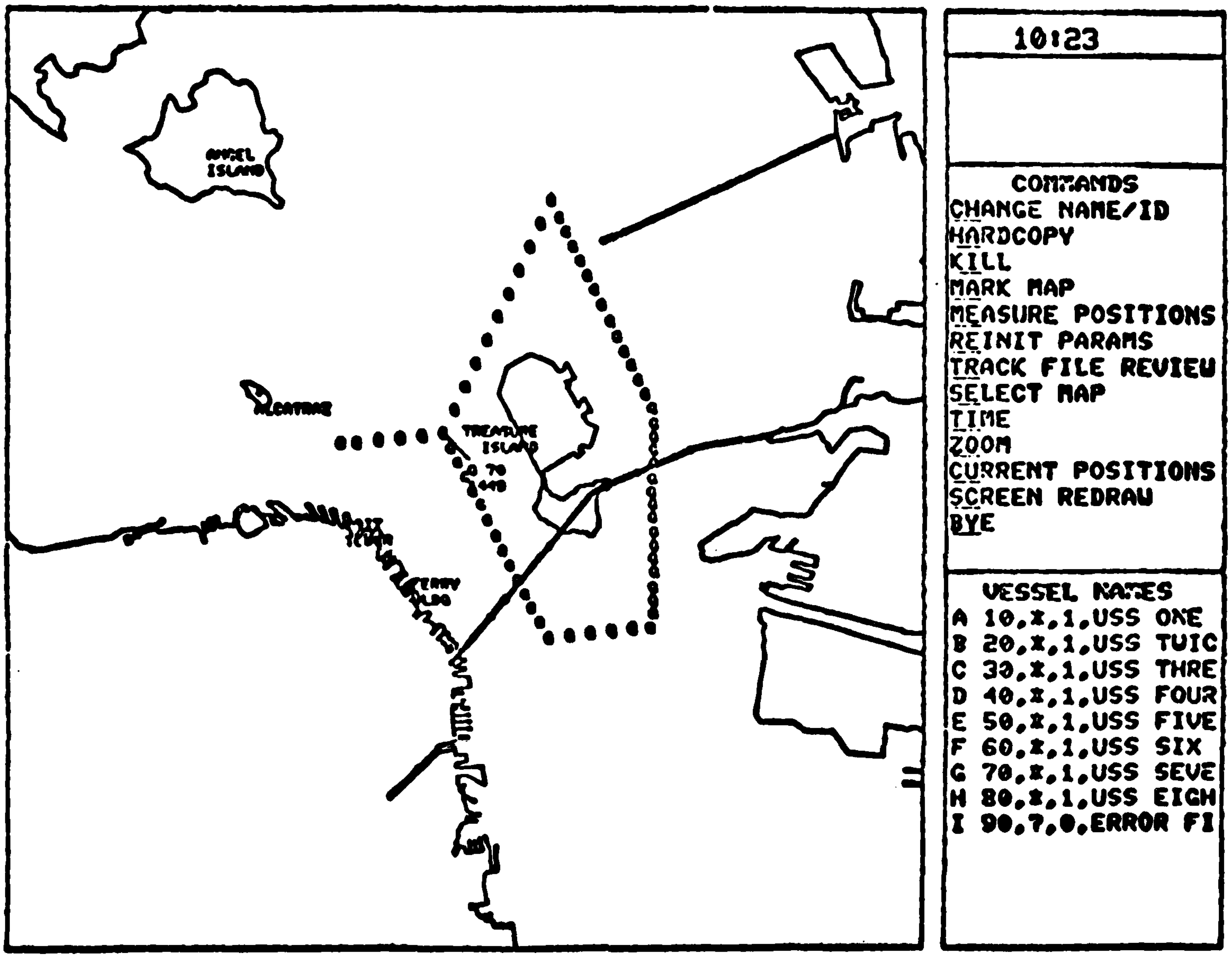


FIGURE 3 LDS DISPLAY FORMAT

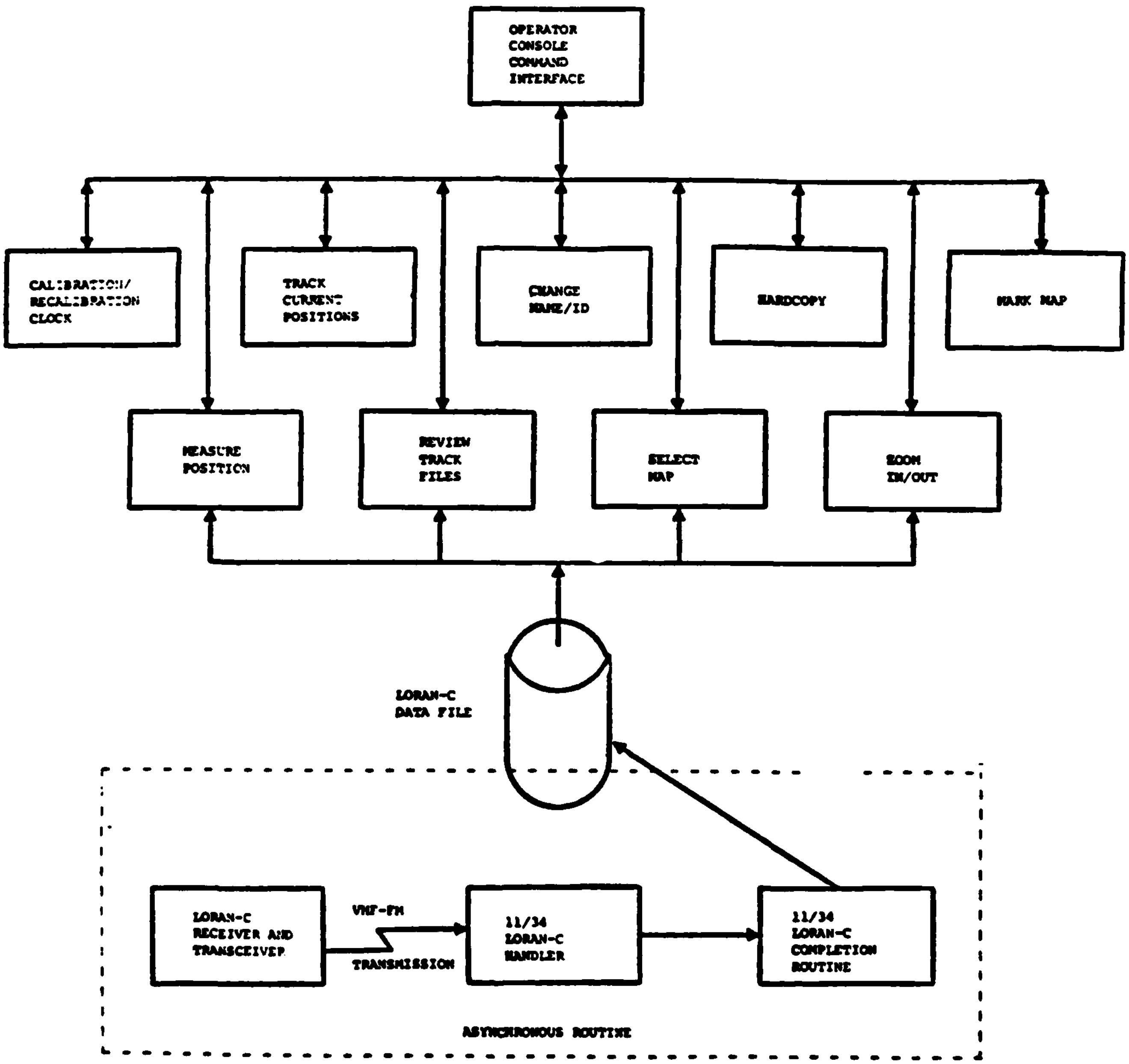


FIGURE 4 LDS LOGIC FLOW

to process the command. The command process routine then writes its subcommands in the scratch pad area of the display presentation. Similarly, the operator selects a subcommand by keying in its first two or three alphabetic characters. Again, the command process routine, if needed, writes additional "prompts" into scratch pad for use as operator aids. Subsequently, the command process routine completes its function and returns control to OCCI which waits for the next operator request.

A detailed description of the command functions is contained in Table 1.

LAR is called each time an LTU message is received. A software handler receives each message and writes it to a buffer. When the handler recognizes the end of a message, it interrupts OCCI to call LAR. LAR performs the necessary conversion and validity checks and writes the results into either the appropriate vessel file or into an error file. LAR also contains both the basic coordinate conversion routine and the correction factors input during system initializaton.

LDS memory requirements are listed below. Due to the 32K core memory limitaion, the LDS software is structured in terms of root software and overlay software. Root software consists of those routines (e.g. operating system, LAR, Handlers, OCCI), tables and buffers that are resident in core throughout the operation of LDS. Overlay software is called into core memory as needed by OCCI.

Appendix B contains the functional software specification.

4.4 SOFTWARE VALIDATION

LDS software performance was validated at TSC. The validation was conducted in three parts: (1) man/machine interface, (2) Lorantelemetry data handling and (3) system positional accuracy.

The man/machine interface validation consisted of testing all functions that required operator/computer dialogue. This included system initialization functions as well as all the functions controlled by OCCI. The tests consisted of making entries that would give predetermined results and observing LDS operations to see way, erroneous entries were made to test operator input error diagnostics.

Loran telemetry data handling functions were tested first by simulating telemetry data input and then by inputting telemetry data recorded from LTU's operating in the San Francisco area. These tests showed that the LDS could receive the message transmitted by the LTU's, perform error detection functions and provide the prescribed raw data ouput to the Data Collect system. Display positional accuracy was validated by playing tape recordings of LTU messages made at known fixed sites in the San Francisco area. By observing the LDS geographic display as the message were played into the system the position shown on the CRT could be compared with the known positions of the LTU's.

Command Functions

COMMANDS AND SUBCOMMANDS	FUNCTION
CHANGE NAME/ID	Add a telemetry ID to the File Table, or delete one, or change the vessel name, type, or size category associated with an ID. An ID may also be deactivated but its data saved.
SELECT MAP	Select by name a previously defined map window (submap) for display.
ZOOM:	Magnify or demagnify the map currently displayed.
IN	Magnify by entering with the crosshairs two points defining a new window.
OUT	Demagnify by entering with the crosshairs a new centerpoint and keying in a demagnification factor (1, 2, 3 . . . times current area displayed).
MARK MAP:	
ANNOTATE	Add temporary map annotation in storage mode.
DELETE ANNOTATION:	Delete existing temporary annotation.
ALL?	Answering yes deletes all current temporary annotation. Answering no allows deleting individual annotation by using the crosshairs.
MARK POSITION	Mark the current map in refresh mode at a point defined by entering a latitude and longitude. (Entering "C" instead of a latitude or longitude clears existing marks.)
FLIP LEADER	Reorients the block identifier of a vessel position to NW, NE, SW, or SE.
HARDCOPY	Stores refresh images and takes a hardcopy on the Tektronix 4636.
TIME	Sets the system clock and LDS time display.

TABLE 1 DISPLAY COMMAND FUNCTIONS

COMMANDS AND SUBCOMMANDS	FUNCTION
KILL	Functional only in PLAYBACK, DISPLAY TRACKS, and when a map is being drawn. Entering "K" stops those three functions and sends control to the next logical phase.
REVIEW TRACK FILE:	
PLAYBACK	Dynamic playback in refresh mode of any vessel or group of vessels.
DISPLAY TRACK	Display in storage mode the complete track history or any vessel.
TYPEOUT	Type out on screen all the messages for any vessel and permit hardcopy to be taken of any or all pages.
MEASURE POSITION:	
GET LAT/LONG	Type out in the scratch pad area the geographic coordinates of a point entered on the map with the crosshairs.
COMPUTE RANGE/BEARING	Type out in the scratch pad area the range in yards and bearing in degrees true and magnetic between a base point and any number of subsequent target points.
DRAW LINE	Draw a line between two points entered with the crosshairs.
REINIT PARAMS:	
ACCESS SUBMAPS?	Answering yes allows definition or redefinition of the windows accessible by means of SELECT MAP.
CLEAR VESSEL FILES?	Allows clearing of all ID's from the vessel File Table.
LORAN CORRECTION FACTORS?	Entering this module permits computing (or directly entering) the static correction factor adjusting the LORAN grid to the area map.
INITIALIZATION PARAMS?	This allows setting the maximum number of errors allowed before an alarm is sounded, and deciding whether or not data is to be sent to the I-816.

TABLE 1 (CONT'D) DISPLAY COMMAND FUNCTIONS

COMMANDS AND SUBCOMMANDS	FUNCTION
SCREEN REDRAW	Allows redrawing the map, keeping the current window size and position. Generally activated after LDS and anti-burn erase is performed, or to get rid of storage mode marks on screen or for clearing vessel name section of screw presentation.
BYE	Normal system shutdown.

TABLE 1 (CONT'D) DISPLAY COMMAND FUNCTIONS

4.5 MEMORY AND STORAGE REQUIREMENTS

Memory Requirements	
Root Software Components	15,720 words
Root Buffers and Data Base Storage	4,560 words
Operating System	5,260 words
	25,540 words
Overlay Software Components	23,000 words
Storage Requirements	
Diskette 1:	
digitized map data	38,400 words
annotated data	10,240 words
Diskette 2:	
Loran-C file data	111,360 words

5.0 ANALYSIS

Some analyses were made to develop operating parameters against which to evaluate the system. An analysis of the coordinate conversion routine yielded some expected results with regard to position accuracy of the system. A communication channel analysis gave some insight into the expected performance of the communications link.

5.1 COORDINATE CONVERSION ROUTINE

The coordinate conversion routine was analyzed in a computer program that simulated a vessel traveling over a fixed course in San Francisco Harbor. The simulation model performed the following functions:

(a) Vessel trajectory was simulated by automatically calculating a number of lat/long points along the simulation track in a time sequence that simulated desired vessel speed.

(b) The lat/long points were converted to ideal time difference values. The ideal time difference values are exact values for the input lat/long.

(c) The exact time difference values were either used to calculate lat/long or truncated to 0.1 microsecond resoultion to simulate LTU receiver time difference information and then used to calculate lat/long.

(d) The original lat/long position was compared to the calculated lat/long position to determine error.

Figure 5 is a block diagram of the simulation routine. Figure 6 shows the geographical area represented in the simulation model.

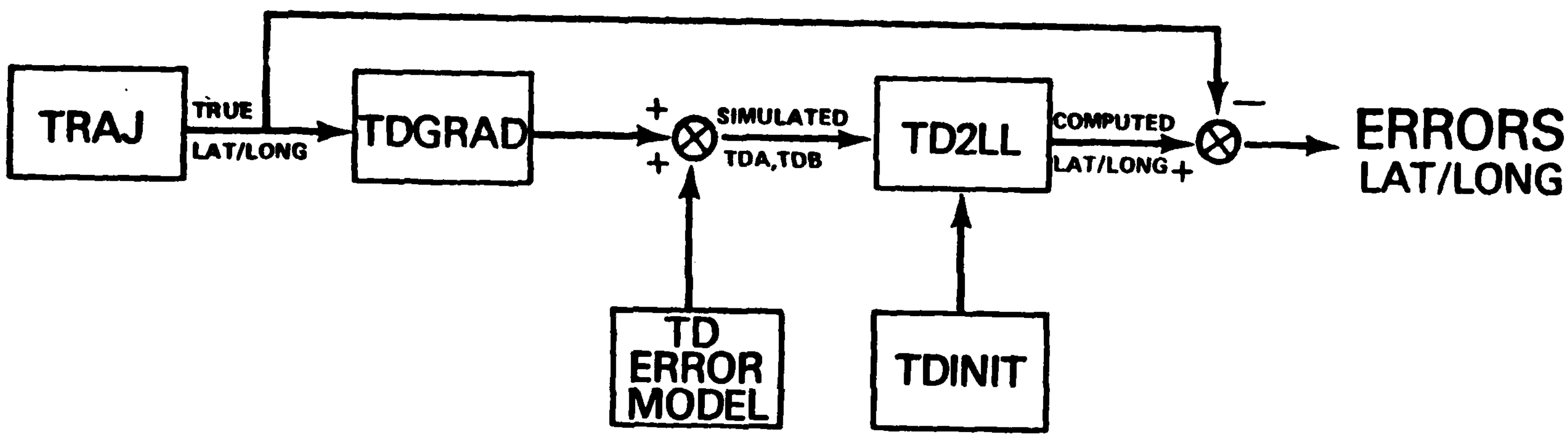
The simulation was run using the following site dependent variables:

Station	Latitude (North)	Longitude (West)	Coding Delay
Fallon, NV	39-33'-6"	118-49'-56"	MASTER
George, WA	47-3'-48"	119-44'-39"	13,796.92 (W)
Middletown, CA	38-46'-57"	112-29'-44"	28,094.50 (X)
Searchlight, NV	35-19'-18"	114-48'-17"	41,967.28 (Y)

GRI= 9940

Using the above values, loran gradients were calculated for the San Francisco Harbor area.

FIGURE 5 SIMULATION BLOCK DIAGRAM



TRAJ— Generates LAT/LONG Positions To Simulate A Moving Vessel

TDGRAD— Converts LAT/LONG Into "Ideal" TD Values

TD ERROR MODEL— Quantizes "Ideal" Values To 0.1 Microsecond Values

TD2LL— Converts TD Values To LAT/LONG Values

TDINIT— Specifies Site Dependent Variables Such As LORAN Chain Parameters and Physical Constants

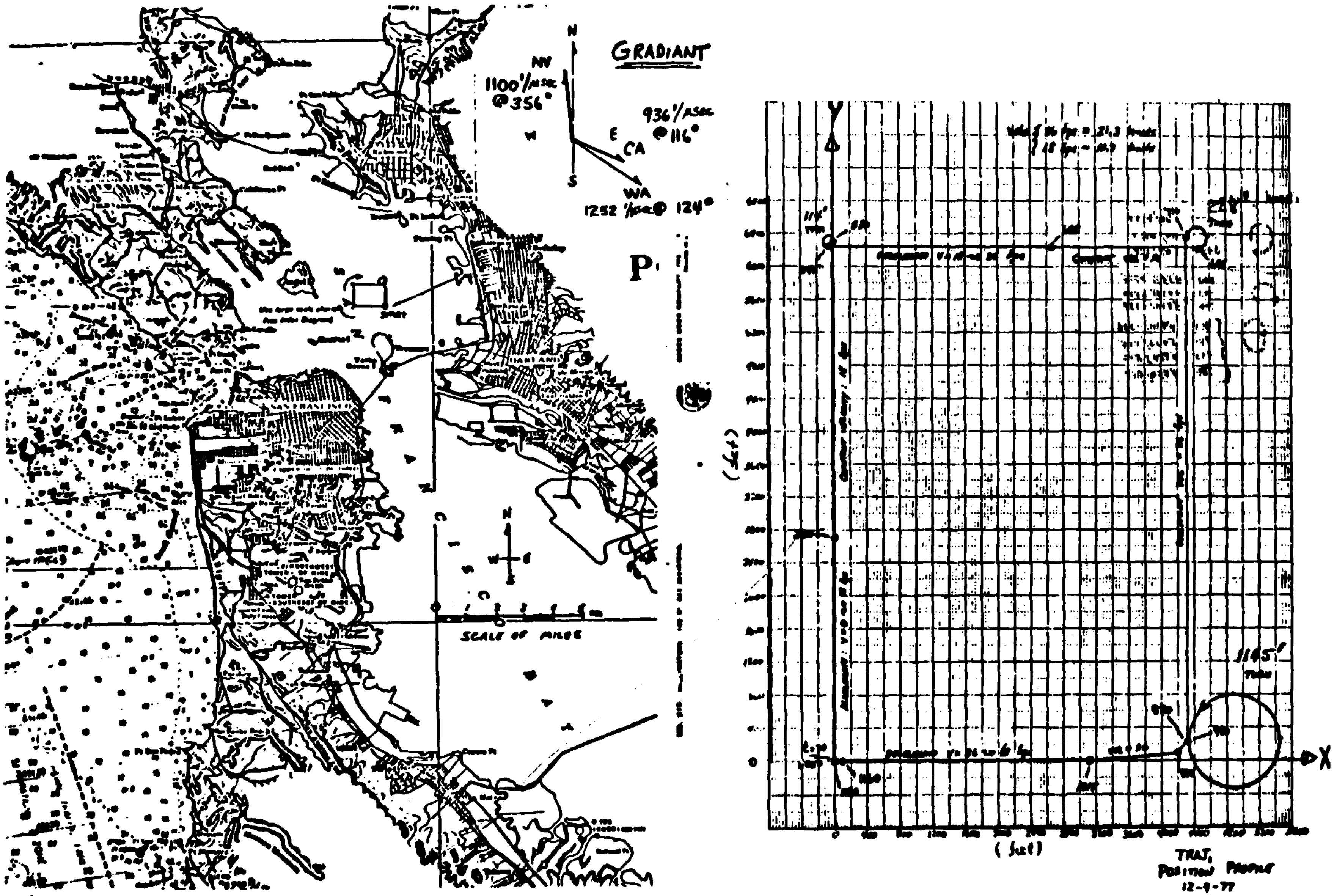


FIGURE 6 AREA USED IN SIMULATION

	(M-W)	(M-X)	(M-Y)
Feet/Microsec	1252	936	1100
Degrees from True North	124	116	356

The first step of the simulation was to test the convergence of the coordinate conversion routine using ideal time difference values. This test showed that the routine converged to within one foot of the originally input lat/long.

The second step in the analysis was to simulate vessel travel over the fixed course and observe the effects of various speeds and various time difference input rates on the accuracy of the system. Figure 7 shows the results of the simulation using ideal time difference values. Graph 1 shows the effect of various speeds and various time difference input rates (position since last update) on position accuracy. The graph indicates that a maximum of 1/2 mile of travel between time difference updates is allowable to insure consistent position accuracy from the system. The 1/2 mile travel limit is site dependent and, therefore, pertains to the San Francisco area only.

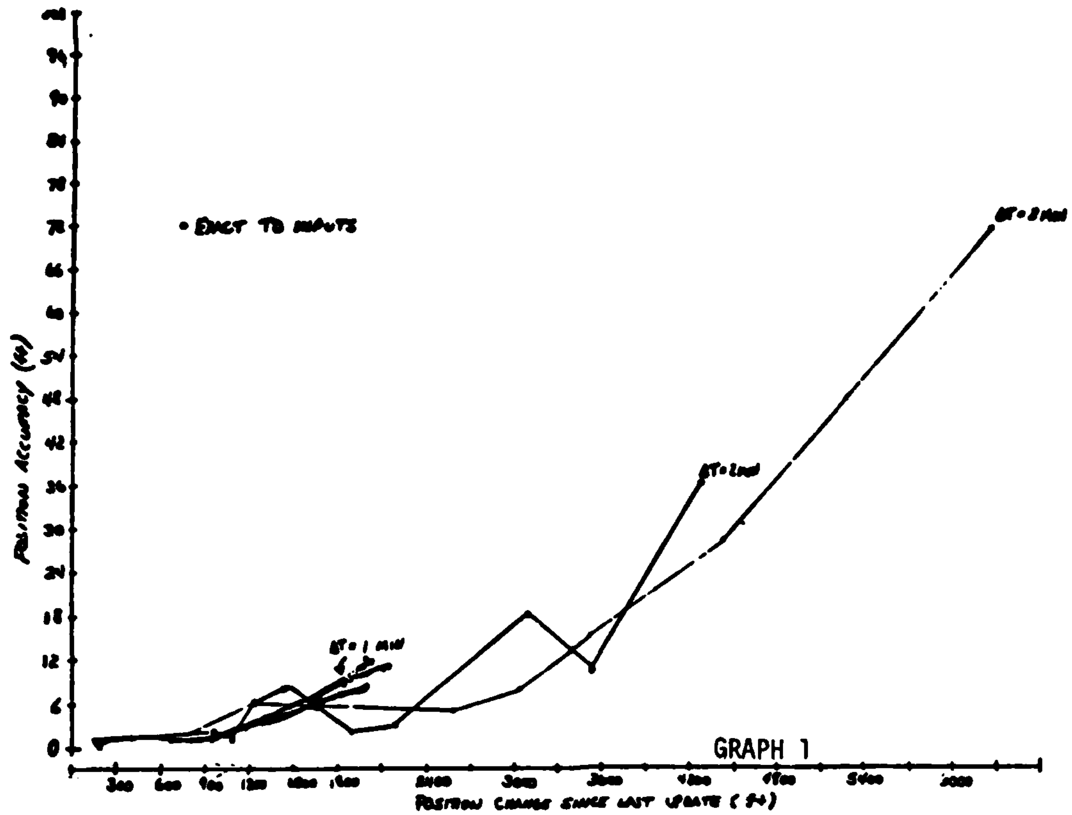
Graph 2 shows the overall effect of the various conditions encountered along the simulated course. Maximum position error was caused during the period of maximum position change between updates.

The last step was to use truncated time difference values to simulate TDL-708 output. Figure 8 shows the results of this test using M-X and M-Y Loran transmitting pairs. Inspection of the graphs show that the mean error to be expected from the coordinate conversion routing is approximately 50 feet when time difference inputs are truncated to 0.1 microsecond resolution and when time difference updates are received at a rate that prevents the vessel being tracked from travelling farther than 1/2 mile between updates. Table 2 is a tabulation of the errors observed during the simulation.

TABLE 2

SIMULATION ERROR DATA

Update Rate (min)	Exact input (ft) Mean ± STD DEV	Truncated Data (ft) Mean ± STD DEV
1/2	2.1 ± 1.8	46.4 ± 20.1
1	3.7 ± 1.2	42.4 ± 18.5
2	7.5 ± 10.6	47.6 ± 22.3
3	16.8 ± 23.7	62.0 ± 24.5



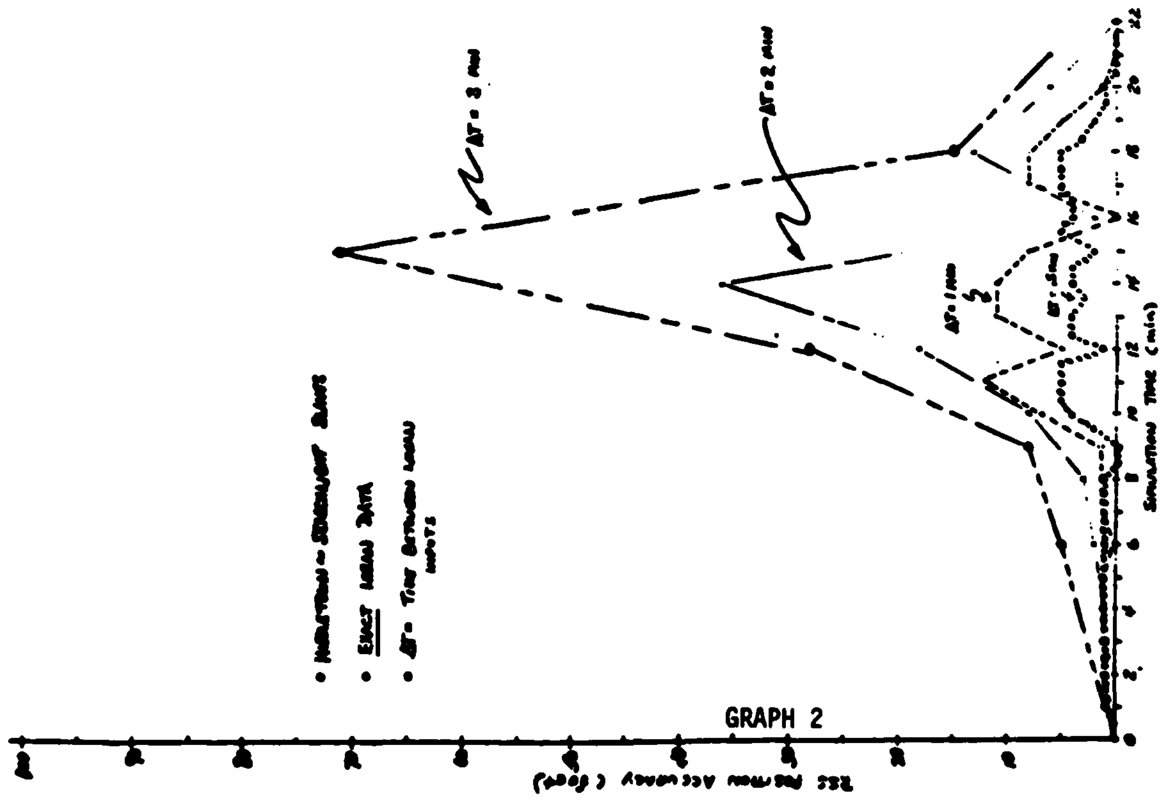
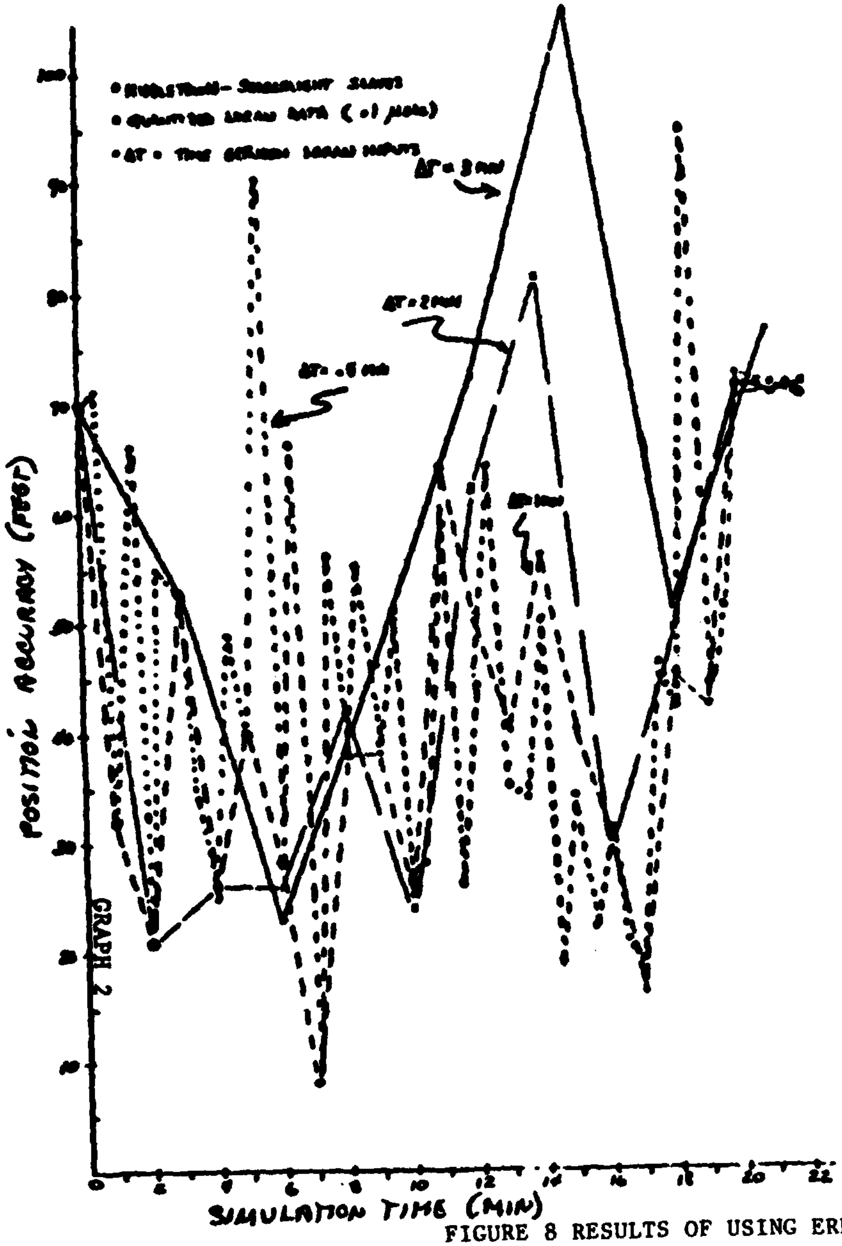


FIGURE 7 RESULTS OF USING IDEAL TIME DIFFERENCES



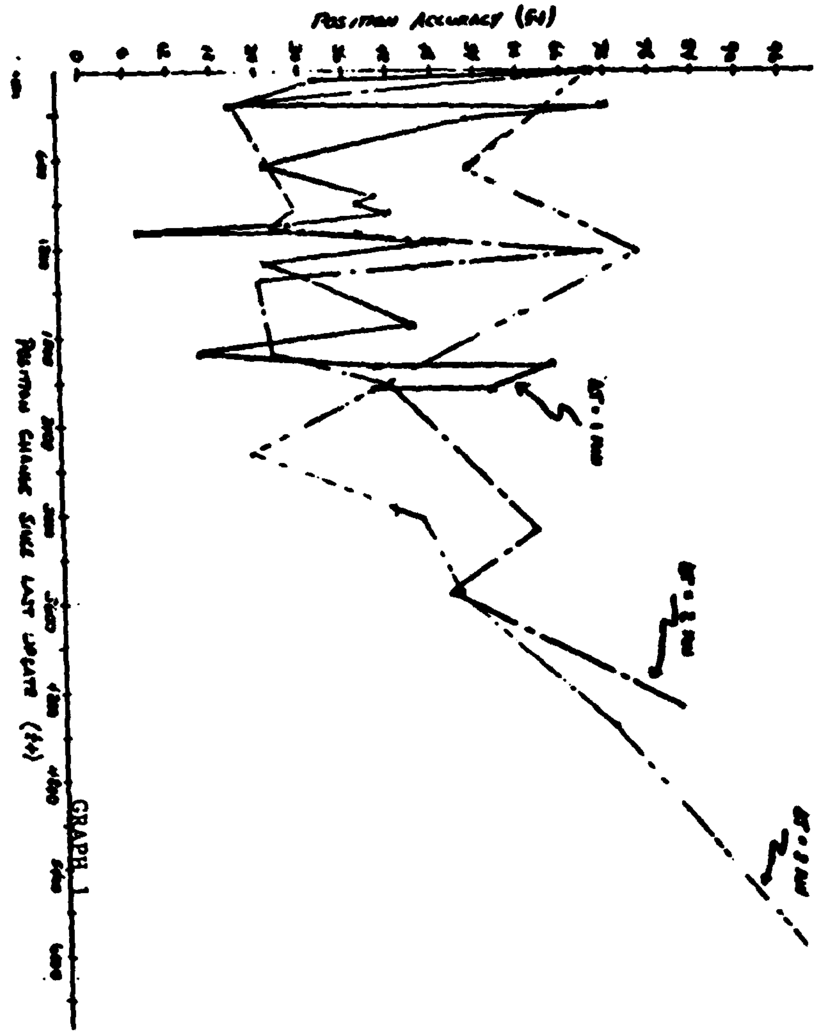


FIGURE 8 RESULTS OF USING ERROR MODELED TIME DIFFERENCES

5.2 EXPECTED ACCURACY OF THE SYSTEM

The expected accuracy of the system relates to both the accuracy of the coordinate conversion routine and the stability of the time difference values observed in the San Francisco area. The published stability of observed time difference values is a standard deviation (SIGMA) of 0.1 microseconds. By applying the loran gradient values to the published stability figure, an ellipse can be constructed that represents the probable area covered by approximately 95% of all position reports made by a stationary LTU. The ellipse is constructed inside a parallelogram defined by one standard deviation of two loran lines of position (LOP) about a mean value for each LOP. (Refer to Appendix C). Using the transformation described in Appendix C, a 2 drms value of 333.7 feet was calculated.

The 2 drms value indicates that for a given pair of observed time difference values, there is an approximate 95% probability that the position indicated will fall in a circle which has a 333.7 feet (111 yards) radius around the actual position. Because the simulations with the coordinate conversion routine show errors within the routine are much smaller than the area of the 2 drms circle, it is expected that position accuracies approaching $\pm$ 111 yard can be realized in the San Francisco area.

One issue of system accuracy was not addressed in this preliminary analysis. This was the issue of system biases. Biases are constant offsets that appear regularly in the system's calculation and display of a vessel's position. It is anticipated that once a bias is identified and the cause of the bias located, appropriate offsets can be invoked to keep the system's positioning accuracy within the 2 dr s calculated value.

5.3 COMMUNICATIONS

One limiting factor in LDS operations could be the message errors caused by signal propagation in the communications link. In LDS, only those LTU messages that are received at the LDS computer without any errors are processed to show a vessel position. A limit of 5% unusable digital messages was established for the prototype system. Therefore, it is of interest to estimate the potential for receiving messages with errors. This potential can be expressed as the probability of receiving an erroneous data bit at the computer input i.e. the FSK modem. The probability is derived through an analysis of the signal propagation in the communications link. The analysis excludes the effects of simultaneous emissions such as a simultaneous transmission from another transmitter or noise external to the communications link.

The details of the analysis are in Appendix D.

The analysis shows that the communications link should not be a limiting factor in LDS operations. Using a worst case example where the S/N ratio approaches 13.3dB, the bit error rate approaches one bit error in 10^5 bits of information. There are 240 bits of information in an LDS message. It takes 416 LDS messages to make up a $1X10^5$ bit sample population. If LDS messages were continuously transmitted, the probability is that for a 13.3dB S/N ratio condition, one LDS message out of 416 would contain a bit error and would probably be lost. This condition provides better than 99% communications reliability.

The environment of the LDS tests will never approach the conditions used in the analysis. The communication ranges will be on the order of 25% of the range used in the analysis. The transmitter output power can be increased from the 1 watt postulated in the analysis to 25 watts in actual operations. Therefore, it is not expected that any LDS messages will be lost due to signal propagation in the communications link.

6.0 TEST AND EVALUATION

6.1 GENERAL

Field testing of the LDS took place at the Coast Guard R&D Sensor Tracking System located at VTS San Francisco, CA. The Sensor Tracking Test System (STTS) consists of a computer based automatic surface radar tracker that makes use of the VTS high resolution radar, and a Data Collect Subsystem. The system is capable of automatically tracking a number of surface targets and simultaneously storing both radar data and system under test (LDS) data for later data reduction and analysis. Established STTS system accuracy is $\pm$ 30 feet in range and $\pm$0.15 degrees in azimuth in the area where the tests were conducted.

The Test and Evaluation Plan called for simultaneous collection of both LDS and radar data for later data reduction and analysis. It was felt that a direct comparison between LDS and VTS radar would provide a good measure of LDS position monitoring capabilities for the San Francisco area and thereby allow the formation of some general conclusions to use as a basis for further LDS development.

The operator support functions were to be evaluated during the data collection effort. The basis for evaluating these features would be a qualitative assessment as to their usefulness to VTS operations as implemented. This assessment would be based on both operator acceptance and the ease with which an operator could manipulate each function.

6.2 TEST ENVIRONMENT

Testing took place at VTS San Francisco from 19 to 30 June 1978. Three boats were used in the test. One boat, GRIZZLY, was a steel hulled harbor tug operated by the Army Corps of Engineers. The two other boats, CHARLENE II and SEA DOG, were wood hulled and fiberglass hulled respectively; these boats were operated by members of the Coast Guard Auxiliary. An LTU was installed on each boat along with radar reflectors to enhance each boat's radar image.

Loran-C pairs M-X and M-Y of the West Coast Chain (GRI-9940) were selected to be used throughout the test. There was little trouble locking onto the master and X secondary, but occassional problems were experienced in locking onto the Y secondary. This problem was caused, for the most part, by interference from a strong continuous wave signal at approximately 119kHz. Some of the problem however, was caused by lack of a good electrical ground in the temporary LTU installations.

Static tests consisted of placing the LTU's in a fixed location and monitoring their operation.

The dynamic tests consisted of tracking the test boats under four modes of operation: (1) anchored, (2) underway on a defined course, (3) underway enroute from one location to another, and (4) anchored at prescribed distances from one another. Both radar data and LTU information were collected, time annotated and stored by the Data Collect Subsystem. In order to prevent the overlapping of LTU data messages, a five second buffer zone was established. This spaced the LTU messages five seconds apart. The radar provided a data point on each boat every three seconds. Each boat sent a loran data point once every fifteen seconds.

Early in the test, it was discovered that the automatic radar tracker had difficulty tracking both the wood and fiberglass boats. Even with the reflectors, the radar image presented by these two boats was not of sufficient quality for the tracker to hold track. This was particularly true whenever either boat passed near an object which provided a stronger radar return. The radar tracker merged the two targets, dropped track on the smaller boat and maintained track on the larger object. In reviewing the reduced data it is apparent much of the data is of little value because it is not known if the radar tracker was indeed locked on. There was, however, three good days of data from the GRIZZLY, and that can be used to draw some basic conclusions.

6.3 POSITION MONITORING

Initial position monitoring was tested during the static tests. These tests were conducted by placing the LTU's in a fixed location on Yerba Buena Island and collecting data. Figure 9 shows a distribution

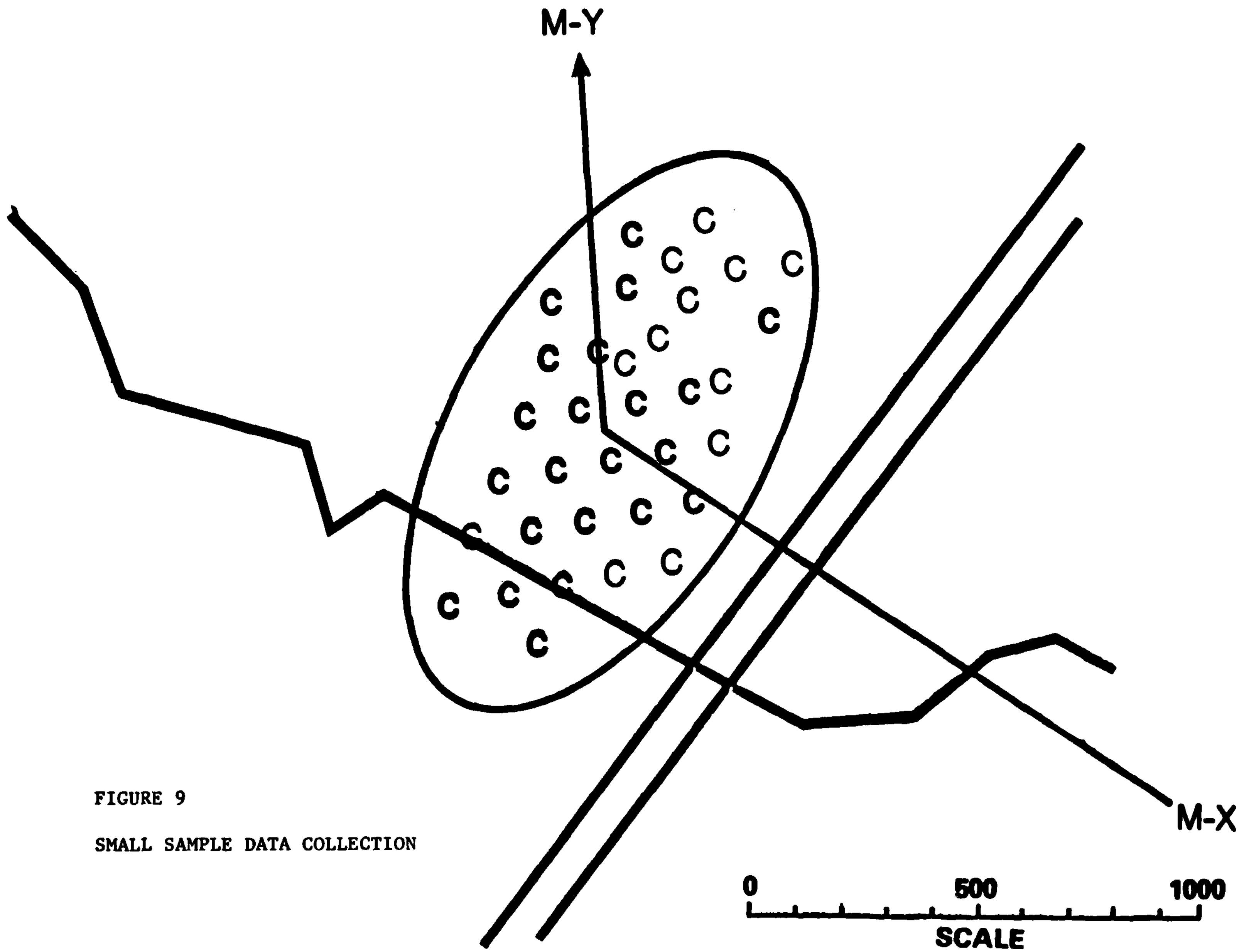


FIGURE 9

SMALL SAMPLE DATA COLLECTION

of reported positions from one of the LTU's. The letter "C" denotes from one to approximately five position reports; the boldly printed letter "C" denotes more than five reports for the same position. The observed time differences ranged from ± 0.3 micro seconds for M-X (TDA) to ± 0.5 micro seconds for M-Y (TDB) for this small sample.

A statistical analysis of the distribution of time differences used to plot the positions in Figure 9 would show that the two sigma values are slightly less than .1 microseconds for TDA and less than .2 microseconds for TDB (see Table 2). The problem with such an analysis is that the LTU's report position to a resolution of 0.1 microseconds. This makes it unrealistic to consider time difference values with a resolution better than 0.1 microsecond as achievable using the present LTU's and causes one to use values rounded up to the nearest tenth microsecond for use in computing areas of error probability. Using the transformation and gradient values outlined in Appendix C, a 2 drms value of approximately 184 yd can be calculated.

TABLE 3

STATISTICAL DISTRIBUTION

OBSERVED TD	FREQUENCY	OBSERVED TD	FREQUENCY
27243.0		41395.0	3
27243.1	5	41395.1	7
27243.2	40	43195.2	23
27243.3	48	43195.3	25
27243.4	16	43195.4	26
27243.5	1	43195.5	18
27243.6	1	43195.6	5
27243.7		43195.7	3
27243.8		43195.8	1
	111		111

MEAN	27243.27 microsec	MEAN	43195.34 microsec
Std Dev =	.086 microsec	Std Dev =	.157 microsec
=	80.5 ft	=	172.7 ft

The portion of the test involving vessel tracking was marginally successful. Much of the data collected is of questionable value because the radar tracker had difficulty holding the test vessels in track. There were also periods of poor loran data because the loran receiver would not lock-on. However, three days of good data was taken on the GRIZZLY. During this time 2088 useable data points were taken.

An analysis of the three days of data gives the following results:

TABLE 4

TEST DATA

DAY	MEAN ERROR/AZIMUTH	2 drms VALUE
5	240 yds/49 deg (T)	188 yds
6	225 yds/46 deg (T)	201 yds
7	245 yds/50 deg (T)	199 yds

The approach to data reduction and analysis is contained in Appendix E.

6.4 COMMUNICATIONS

For the purpose of the evaluation, a Coast Guard VHF-FM radio channel was chosen as the communicatons link. The VHF-FM band was chosen because of its availablity and because it was representative of the equipment used in the VTS environment. The channel used was the maritime mobile channel 23 with a center frequency of 157.15 MHz. The message format used to broadcast the information is as described in Figure 2. The information coding scheme used in the formatted message was the seven-bit American Standard Code for Information Interchange (ASCII). An eighth parity bit was used, and when the stop and start bits for asynchronous transmission were added, a total of 10 bits were used to send each character. Bell standard 202 modulation and Frequency Shift Keying (FSK) were used. Data was transmitted at a 300 bits per second.

With a message length of 24 characters, it can be calculated that each message required 0.8 seconds to transmit. Because of a desire to obtain as many data points as possible using the three vessels available for the testing, a broadcast repetition rate of 15 seconds was chosen. This gave each vessel a five second time slot in which to fit its 0.8 second message. Each vessel operator manually synchronzed the LTU aboard his vessel into one of the five second slots. The clock in each LTU was accurate enough so that drift respective to each LTU did not occur during the testing periods and messages did not overlap. As a result, no Loran-C data transmissions were lost due to overlapping data transmissions during the testing. However, voice communications that occuring simultaneously with digital communications obliterated the digital message because the LDS computer communications handler did not accept digital messages that were less than 100% correct. Any digital message that was not 100% correct was filed as an error message and not used for position calculation.

6.5 MAN/MACHINE OPERATIONS

Evaluation of the operator support functions was conducted during the tests. The major test, that of easy operator acceptance, was considered to have been passed successfully when a previously untrained operator learned to operate the LDS Display in four halfdays of instruction. Success in passing this test can be attributed to the emphasis placed on the man/machine interface.

Each of the operator support functions (see Table 1) was tested in turn. Each function was found to be useful in its own right. Some functions could have been designed to lesser tolerances. For instance, it was possible to zoom in on the geographic map to a point where the map features were unrecognizable. The inputs and outputs of certain functions need to be standardized. For instance, latitude/longitude should be input and output in the same format.

7.0 CONCLUSIONS

7.1 CHARACTERIZE A LORAN-C SURVEILLANCE SYSTEM FOR VTS

The feasibility of using a Loran-C based surveillance system has been successfully demonstrated. Three major aspects of such a system (position monitoring algorithm, communications link and man/machine interface) were implemented and tested. Although none of the functions were subjected to a rigorous test as might be expected of an operatonal system, enough information was gathered to draw the following conclusions:

(a) A Loran-C based surveillance system can be implemented using a minimum of special purpose equipment.

(b) It is feasible to use Loran-C receivers and VHF-FM equipment of the type presently commercially available to the maritime industry. One must realize, however, that radar-like position accuracies are not achievable using this system.

(c) If computer based second generation VTS equipment is planned, a Loran-C based surveillance subsystem could be implemented as a module of computer software.

(d) Man/machine interface is extremely important in computer based systems in general. Lengthy operator training can be avoided by designing the system to interact with an operator during system operation. This is accomplished through prompting, selection from menus, and operator input error diagnostics.

7.2 CHARACTERIZE THE DATA COMMUNICATION LINK

The theoretical analysis showed that the VHF-FM marine band can support LDS data communications between stations within line-of-sight of one another at a range of up to 30 nautical miles. The limiting factors noted during the LDS tests were as follows:

(a) Manual synchronization of the LTU's severely limits the number of ships that can be tracked in the system. Experience has shown that it is necessary to have about 2 seconds of "Guard Time" on either side of an LTU message to allow for the manual synchronization. The analysis described in Section 5.1 indicates that, to keep position error constant, a vessel should travel no more than 1/2 mile between updates when LDS is used in the San Francisco area. If this constraint is observed, and if it is assumed that the highest vessel speed will be 20 knots, then a nominal reporting rate for each participating vessel can established as every 90 seconds. When an LTU message has 2 seconds of "Guard Time" on either side of it, a total of 5 seconds is required to transmit one LTU message. This allows only 18 vessels to report in the system.

(b) Voice communications occuring simultaneously with data transmissions can obliterate the data transmissions. This makes it unrealistic to expect that the LDS asynchronous digital communications scheme would provide satisfactory service when operated on a shared voice communications link unless a high percentage of lost LDS messages could be tolerated.

(c) The LDS computer eliminates some potentially useable LTU messages because it ignores anything but a 100% correct message. In some instances, only one or two data characters in a message were incorrect. Some of the message characters such as begin message, end message, carriage return, line feed and space do not contain information essential to position monitoring. Yet if these characters are incorrect when a message is received, the entire message is ignored.

In terms of ease of implementation, the following communications characteristics were found beneficial:

(a) ASCII character coding - ASCII coding is a national standard for computer equipment. It is easy to get component parts for use in the LDS equipment that generate ASCII code. In addition, the reception and interpretation of the code is simple and does not require additional logic as do some block type and forward error correcting and detecting codes.

(b) Bit parity - This error detection feature was inherent in the ASCII character coding scheme used. Although parity error will not detect all forms of error, it is felt that it is sufficient under the predicted bit error conditions.

(c) BELL 202 characteristic modulation - This type of modulation was selected because the modems were easy to procure and work well. There are, however, a variety of modems that are also readily available, some of which might provide better operation.

(d) VHF-FM communication channel - The VHF-FM provides excellent service. The bandwidth of the channel will support BIT rates higher than 300 baud and still provide acceptable bit error rates.

(e) 300 bit per second transmission rate - 300 baud was shown to be relatively error free for the communications link used. In addition, it is a speed that allows the direct use of a number of inexpensive terminal devices to directly monitor the communications link.

(f) Message format - The message format was easy to implement and, because it was in plain language, lent itself to easy monitoring of the communications link by connecting a terminal device to the base station modem. The vessel identification block allowed discrete identification of up to 100 vessels. The information contained in the message was adequate for LDS operations.

In general, it was felt that the communications link performed well. The two major drawbacks were the asynchronous mode of operation and voice transmission interference. It is felt that these two factors prevent the system from being operationally acceptable. This is not to say that LDS would not work in some very low vessel population port areas, but that it could not be expected to work in all port areas.

7.3 ASSESS THE SYSTEM'S POTENTIAL ACCURACY

A comparsion of the system's positioning capabilities with the expected accuracy is made in the table below:

TABLE 5

COMPARISON OF POSITION ACCURACIES

DESCRIPTION	OFFSET	2 drms VALUE
Expected Accuracy	None	111 yds
Limited Sample	None	184 yds
"GRIZZLY" Day 5	240 yds/49 deg	188 yds
"GRIZZLY" Day 6	225 yds/46 deg	201 yds
"GRIZZLY" Day 7	245 yds/50 deg	199 yds
AGGREGATE of "GRIZZLY" DATA	238 yds/49 deg	193 yds

The nature of the test and evaluation did not allow an analysis to identify the cause of the difference between the expected accuracy and the observed accuracy. However, it does show the consistency of positioning during the three days of data collection. This indicates, that for the San Francisco area, there is a 95% - 98% probability that a position calculated and displayed on LDS would fall in a circle with an average radius of 193 yards and whose center is an average of 238 yards at 49 degrees (T) from the actual position. Assuming that the system bias can be calibrated out, it appears that vessel position accuracy in San Francisco Bay is approximately ± 200 yards.

The accuracy of the LDS depends on a number of factors which are influenced by the location where the LDS is installed.

(a) One important factor is the loran gradient, i.e. the distance between loran Lines Of Positions (LOP's). The gradient changes depending upon where the LDS installation site is located relative to the Loran-C system that serves the area. For example, the distance between loran LOP's is different in Los Angles, CA; San Francisco, CA; and Portland, OR, but these locations are all served by the same Loran-C system. This prevents the assignment of an accuracy figure to LDS and expecting the figure to be applicable in all VTS locations.

(b) The ratio of Loran-C signal to noise is important. As demonstrated in San Francisco, the presence of a strong interfering signal makes it difficult to lock on to a weak Loran-C signal and causes a wider variation of the time difference observations than expected. This decreases the accuracy of the system.

(c) System biases reduce the accuracy of the system. As shown above, an average bias of 238 yards appears to exist when LDS is compared to the VTS San Francisco radar. Although it is probable that the bias can be reduced, its presence points to a potential problem in integrating a Loran-C based surveillance system with a radar surveillance system.

7.4 LIMITATIONS OF THE TEST

This project was limited to testing the feasibility of using a Loran-C based surveillance system in a VTS environment. The project demonstrated that a system can be implemented using commercially available equipment. Shipboard units can be assembled using a currently available Loran-C receiver and a standard VHF-FM marine band transceiver, although the circuitry necessary to interface the Loran-C receiver with the transceiver is not readily available from commercial sources. The shore based equipment is all commercially available.

It would not be prudent to force the existing LDS into a full operational situation. There are some issues that must be addressed before a truly satisfactory Loran-C sensor system can be implemented.

A list of questions to be answered includes:

(a) What is the optimum display system configuration?

(b) Can the system perform consistently when operated in a number of VTS areas?

(c) Do currently available Loran-C receivers provide sufficient data for operation with an optimized system?

7.4.1 OPTIMIZED SYSTEM

The basic question of how to make a Loran-C surveillance system work best in a VTS environment has not yet been addressed. No alternatives to existing LDS design have been considered. No attempt has been made to use LDS in even a limited operational environment to identify short falls of the existing system from an operational standpoint.

7.4.2 CONSISTENT PERFORMANCE

The LDS operation is influenced heavily by site dependent parameters. Conditions such as Loran-C system geometry and Loran-C signal-to-noise ratio influence the potential accuracy of the system. At present no effort has been made to predict LDS performance in areas of likely use. Nor has any consideration been given to identifying sources of constant system bias and developing a means to correct them.

7.4.3 LORAN-C RECEIVER DATA OUTPUT

Currently it is anticipated that time difference information can easily be obtained from a number of commercially available shipboard Loran-C receivers. It is also anticipated that this information will be generated by a variety of processing techniques. For instance, the TDL-708 provided time difference values that were the result of averaging over 16 Loran-C Group Repetition Intervals and truncating the values to 0.1 microsecond resolution. Another receiver may average longer and round the values to the nearest 0.1 microseconds. This raises the question as to how an optimized Loran-C Display System will be affected by the varying qualities of data available from a variety of Loran-C receivers.

There is also a question as to whether or not receiving only time difference values provides sufficient information. It is conceivable that an LDS would need telemetry information as to whether or not a loran receiver was in track. It is possible, depending on the extent of the surveillance area, that an LDS would need telemetry information as to which Loran-C Group Repetition Interval (GRI) was being monitored by an LTU. An example of this potential situation exists in the Seattle, WA area where it is possible to monitor either 5990 or 9940 GRI.

8.0 RECOMMENDATIONS

8.1 APPLYING THE EXISTING LDS TO VTS OPERATIONS

While it is not recommended that the present LDS be implemented for widespread use as a VTS sensor, it is felt that limited use in an operational environment would provide information necessary for integrating a Loran-C based vessel surveillance system into existing VTS operations. If LDS was installed in a VTS with low traffic volume, and if a careful calibration was carried out, it could become a useable part of a VTS surveillance system. A data collection effort could be initiated which would be carried out during regular operations. The data collected could provide both documentation on the applicability of system operating features to VTS operatons and additional data for evaluating the coordinate conversion routine.

8.2 AREAS OF LDS OPERATIONS THAT SHOULD BE FURTHER INVESTIGATED

Because it was a feasibility test, this project has not provided sufficient information to implement a Loran-C based surveillance system optimally suited to VTS operations. There are five general areas of interest that should be addressed prior to attempting to design and implement an operational system. They are (1) improving system performance, (2) system compatibility with VTS operations, (3) methods of predicting, measuring and insuring consistent system performance, (4) data required in each telemetry message and (5) optimizing the communications link.

8.2.1 IMPROVING SYSTEM PERFORMANCE

The LDS was designed and implemented using the best information available with the funds provided and in the time allotted. Because the purpose was to produce a feasibility model, there was no concerted effort to build the optimum system. There are a number of areas that shold be investigated further if an operational Loran-C surveillance system is to be implemented. Some areas to be investigated are: (1) system calibration, (2) data processing and (3) equipment selection.

8.2.1.1 SYSTEM CALIBRATION

The process of displaying the position of a vessel on the LDS display involves a number of computer performed calculations. The most involved calculation is the conversion of the time difference information received from each participating vessel to a latitude longitude position. This calculation makes use of numerical constants whose selection was based on theoretical concepts. In actual operation, the constants are proven to be in error, and this causes a bias error in displaying each vessel's position. A careful calibration of the system prior to being placed in operation will show the existence of any such errors. However, some means of identifying the exact causes of the errors has yet to be developed. Future effort in developing a Loran-C based surveillance system should include the identification of various sources of system error and possible methods of off-setting the error through calibration and adjustment.

8.2.1.2 DATA PROCESSING

The issue of data processing affects total LDS operation. The processing of data includes such functions as LTU digital message error detection, file management, computer output to the CRT display, operator input to the computer and the coordinate conversion routine. All of these functions are candidates for improvement. Future effort in developing LDS should include a review of the software functions of the present LDS and their method of implementation for the purpose of improving the efficiency and making the entire system more compatible with VTS operating requirements.

8.2.1.3 EQUIPMENT SELECTION

The question of selecting equipment for an operational LDS has not been addressed. The development of equipment specifications should be an essential part of any future LDS development so that consistency of equipment operation can be maintained between various LDS installation sites.

8.2.2 SYSTEM COMPATIBILITY

If a Loran-C based surveillance system is to become part of the VTS surveillance suite, some consideration must be given to making it compatible with VTS operations and equipment both now and in the future. Compatibility with existing ooperations can be achieved through operating experience. A test bed system could be implemented in an operating VTS where the system could be tested and modified until satisfactory performance was obtained. This procedure is an iterative process which requires some additional effort from the personnel of a VTS in operating the test bed system and identifying functions that should be provided and/or modified. Periodic software support is also required to make the necessary system modifications.

The use of a Loran-C based surveillance system in the second generation of VTS equipment should also be investigated. LDS could easily become a software module in the computer based second generation equipment. However, such details as implementation and hardware and software interfaces must be addressed before the subsystem can be integrated into a second generation system.

8.2.3 CONSISTENT PERFORMANCE

In order to provide a system for use in a number of VTS operating areas, some means of predicting and measuring system performance must be provided. Because some of the constant values used in the LDS coordinate conversion routine are site dependent parameters, LDS cannot be automatically expected to perform with the same positioning accuracy in a variety of VTS environments. In addition, experience in the San Francisco test showed that there was a constant bias between a position determined by radar and a position determined by LDS. This indicates a potential problem in situations where a Loran-C based surveillance system is used with a radar surveillance system. The effects of factors such as site dependent parameters and bias offsets should be identified and documented so that LDS performance can be predicted prior to implementing a system.

Once a Loran-C based surveillance system is put in place, a measure of system performance should be carried out. Such a measurement would document existing system accuracies for a particular VTS environment and provide reference data for periodic checks of system performance. The procedures for conducting measurements of system performance should be standardized for use in all VTS Loran-C based surveillance systems.

8.2.4 TELEMETERED DATA

Presently, LDS data messages include two time difference values and an indicator as to whether or not an operator considers the shipboard Loran-C unit to be locked on. This indicator is manually selected by the operator. Recently, there has been interest expressed in the Coast Guard in developing a Loran-C based vessel surveillance for use out to the 200 mile limit, both LDS and a 200 mile surveillance system could use the same shipboard unit, but it is not clear that the information provided in the present LDS is sufficient for a 200 mile surveillance system. Similarly, it is not clear that the manually set indicator to show Loran-C receiver lock-on is a desirable mode of LDS operation. Some consideration should be given to developing a specification for Loran-C receiver output to accomodate either the anticipated requirements for future VTS operations alone or the combined requirements of VTS and the proposed 200 mile surveillance system.

8.2.5 COMMUNICATIONS LINK

The analysis performed by the Transportation Systems Center indicated that the existing 300 bits per second communications link would provide essentially error free communications. However, by increasing the bit rate, more information can be passed over the link. In addition, digital coding schemes other than ASCII could be employed to pass the same amount of information in a shorter time span; this would allow more messages to be transmitted in a given time period. The alternatives available for optimizing the communications link should be investigated both to relieve the conditions noted in Section 7.2 above and to provide the communications link best suited for the system.

APPENDIX A

TECHNICAL MANUAL

INSTALLATION, OPERATION AND THEORY

VESSEL TRACKING SYSTEM

LORAN C TELEMETRY UNIT

Part Number 8015338

1 April 1978

Prepared for

UNITED STATES COAST GUARD

Contract No. DOT-CG-73865A

By

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

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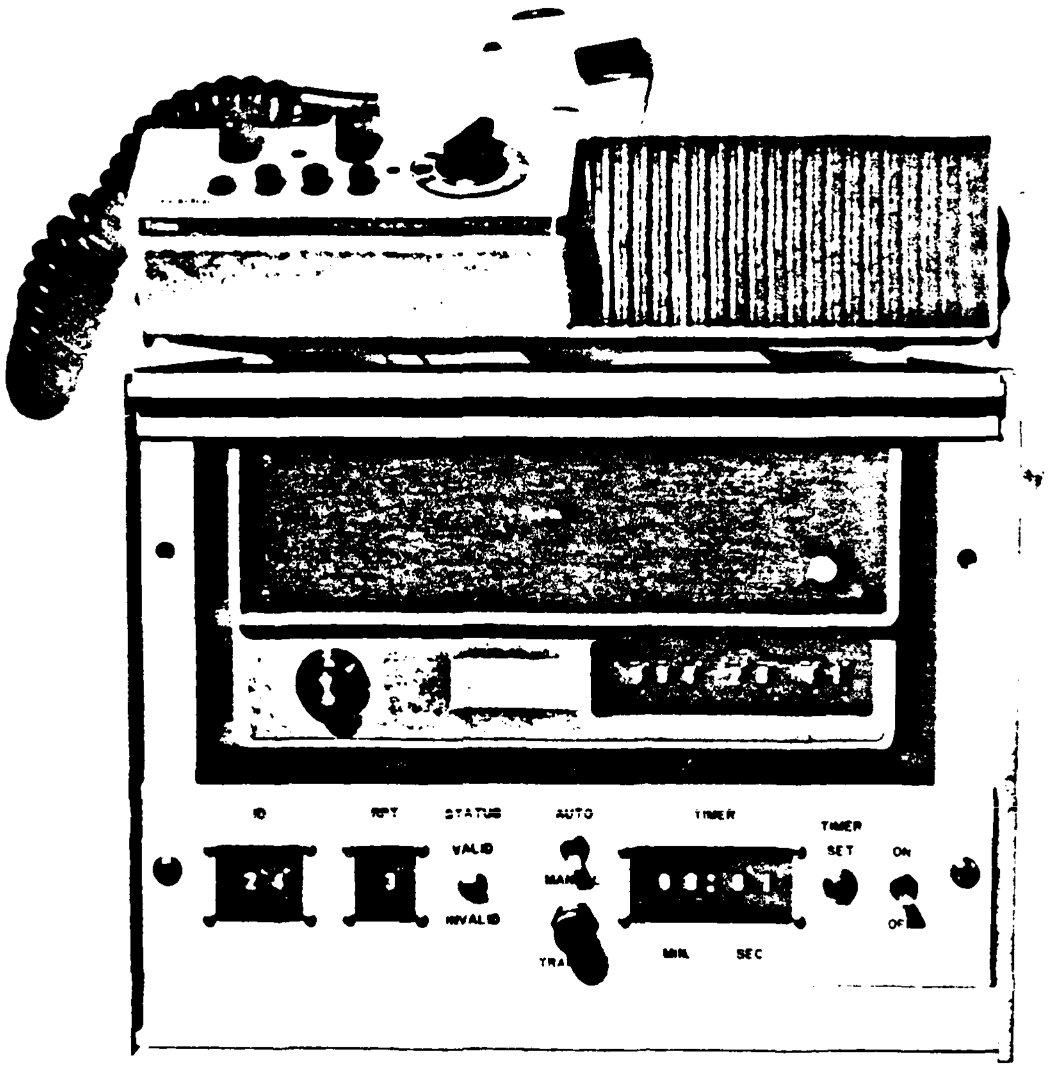

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Figure 1-1. Loran C Telemetry Unit

Section I. INTRODUCTION AND DESCRIPTION

1-1. PURPOSE AND SCOPE OF MANUAL.

1-2. This manual provides information to support installation and operation of the Vessel Tracking System Loran C Telemetry Unit, part number 8015338, manufactured by Teledyne Systems Company, Northridge, California. See figure 1-1. The Loran C Telemetry Unit consists of a Teledyne Systems Loran C Marine Microlocator (also designated TDL-708 or Loran C receiver) and antenna (8014600), and Triton Modar VHF-FM Transceiver, 6 1/2 channel, 25 watt (D33ABA1520CK), and an interface printed wiring board assembly together with front and rear panel switches, indicators, and connectors contained in the unit housing. Two external power supplies are also provided to accommodate different ac and dc ship's power provisions.

1-3. This manual provides instructions for the Loran C Telemetry Unit as a whole and for the interface circuitry in detail. Complete installation, operation and maintenance instructions for the Loran receiver are contained in the Technical Manual of Installation, Operation and Maintenance, supplied with each unit. Installation and operation instructions for the VHF transceiver are contained in the Triton Owner's Manual supplied with each unit. Instructions for the external power supplies are contained in Lambda Instruction Manual for LXS-D series power supplies, also provided with each unit. Detailed theory of operation of the Loran receiver is contained in Depot Repair Documentation manual for the Loran-C 708 Receiver.

1-4. PURPOSE OF EQUIPMENT.

1-5. The Loran C Telemetry Unit is part of the USCG Vessel Tracking System, used to automatically track and display the location of surface vessels operating in Loran C Coverage areas. Each participating vessel has aboard one Loran C Telemetry Unit, which transmits at selected intervals a digital message containing Loran time difference information. This message is received at a base station, where it is demodulated and processed. A display subsystem automatically plots the position of each vessel on a geographic display. The Telemetry Unit operates as a voice communications system as well as data link transmitter, giving priority to voice. The ASCII format of the digital message is compatible with that of the TDL-424 airborne Loran Navigator.

1-6. FUNCTIONAL DESCRIPTION.

1-7. GENERAL.

1-8. The Loran C Telemetry Unit (LTU) transmits either voice or digital information by means of VHF-FM radio link. The digital information is output in serial, ASCII format and contains ship identification number, Loran receiver status, a report code definable by the user, and two Loran time difference measurements representing ship's position to tenths of a microsecond. This message is transmitted at operator-selected intervals either automatically or manually under operator control. Each message is 24 characters long and 0.8 seconds in duration. The baud rate is 300.

1-9. This message format is compatible with the data output of the TDL-424 airborne Loran Navigator. The two messages are identical, except that there are seven more characters: space and six time characters. (See figure 4-7.) Also, the LTU has six-digit time difference resolution, whereas the TDL-424 has seven-digit resolution to hundredths of a microsecond. To compensate for this, the least significant digit (LSD) of each seven-character time difference data block is a numerical zero.

1-10. The LTU consists of the following sub-units, each discussed more fully below:

Loran-C 708 Receiver (also designated TDL-708)
Triton VHF-FM Transceiver
Interface
External power supplies
Antennas

1-11. The Loran C 708 receiver is a self-contained, miniaturized, fully automatic Loran-C navigation receiver, capable of providing continuous position information wherever Loran-C coverage is available. The receiver can derive position from any Loran-C chain in the world. Position is displayed in Loran time differences, directly convertible to position on Loran-C charts. Thumbwheel switches are used to enter the desired three-digit group repetition interval (GRI) and two secondary coding delays identifying the master and two secondaries from which navigation information is desired. The TDA and TDB displays display Loran time differences to tenths of a microsecond. The OUTPUT connector on the rear of the receiver provides buffered parallel binary coded decimal Loran time differences (or other selectable data) plus an inhibit strobe signal. This data is sent to the interface circuitry in the LTU for conversion to ASCII format and transmission via the VHF-FM transceiver.

1-12. Two tunable notch filters at the rear of the Loran receiver can be set to reject interferring frequencies in the area of operation. An end-to-end built in test, activated in TEST position, automatically checks operation of the rf circuitry, processor and displays. Loran receiver status can be displayed to the operator in the STATUS position. The LTU will insert any information shown on the 708 display into the two seven-character data blocks of the digital message. Thus, whenever the 708 MODE switch is in either the TEST or STATUS position, the information displayed can be transmitted over the data link.

1-13. TRITON VHF-FM TRANSCEIVER.

1-14. The Triton transceiver is a 6 1/2 channel, crystal controlled marine VHF-FM radio operating in the band from 150 - 160 MHz. Nominal power output is 25 watts. The transceiver is compatible with communications equipment used by the Coast Guard and operates on 12 volts dc. Audio output of the LTU interface circuitry comes into the transceiver via the shielded cable that connects to the 4-pin plastic connector on the rear of the LTU. Loran time difference data is thereby introduced in parallel with the transceiver microphone input and is transmitted the same way as voice input. The transceiver has an automatic reverting circuit that automatically switches the radio to channel 16 (distress, safety and calling) each time the transceiver is switched off and on.

1-15. There are two timing modes: one related to use of the mike switch for voice transmission and one independent of the mike switch. Voice has priority over Loran data transmission. Whenever a voice communication is made, data transmission is inhibited. Data transmission is resumed when voice transmission is completed. A data transmission is made immediately after each voice transmission, and timing of the interval between data transmissions begins with that data transmission. Thus, the transceiver operates not only as a voice communications transceiver, but also as a data link transmitter for transmission of the asynchronous digital Loran data at 300 bits per second. The transmitter can also be keyed automatically from the interval timer in the interface circuitry or manually be the TRANSMIT switch-indicator.

1-16. INTERFACE.

1-17. The interface circuitry is contained on an Augat board, which is attached to the bottom LTU panel by four standoff spacers and screws. The interface receives Loran position data in parallel from the Loran receiver OUTPUT connector in binary-coded decimal format. Vessel identification number, report code and Loran status are entered by the operator via front panel switches. The interface circuitry takes this BCD data and gates it into the data stream together with the Loran position data. It converts this data into ASCII format with one start bit and one stop bit for each ASCII character. It assembles a 24-character (10 bits per character) word and modulates it with 1200 or 2200 Hz (mark and space) and provides timing for transmission of the message at selected intervals from two seconds to 59 minutes 59 seconds with one-second resolution. The interface circuitry also provides priority of voice over Loran data transmission, inhibiting data transmission when a voice communication is made. There is an inherent time delay of two seconds; actual data link interval is the TIMER setting plus two seconds.

1-18. EXTERNAL POWER SUPPLIES.

1-19. The Loran C Telemetry Unit operates on +12 volts dc. Two separate external power supplies are provided to convert ship's power to +12 vdc. One converts 115 vac, 60 Hz to +12 vdc; the other converts 20.5 - 32 vdc to 12 volts dc. Each of these is provided with an output cable and connector for attaching to the +12 VDC connector on the rear of the LTU.

1-20. ANTENNAS.

1-21. Two antennas are provided with the LTU. One is the Loran receiver antenna (part number 8014600). The other is for the Triton VHF transceiver (part number TAD 6140A). The Loran antenna contains an integral antenna coupler unit, containing a printed circuit card providing impedance matching and bandpass preamplification of the Loran signals.

Section II. INSTALLATION

2-1. GENERAL.

2-2. This section contains installation instructions for the Vessel Tracking System Loran C Telemetry Unit. The heart of the Loran C Telemetry Unit is the Loran C 708 Receiver (TDL-708 Marine Microlocator). The shipboard environment has every kind of potential hazard for electronic navigation equipment. Proper installation is the single most important factor in minimizing such limitations so the full capabilities of the system can be realized. The Technical Manual of Installation, Operation and Maintenance for the Loran C receiver is supplied with each Loran C Telemetry Unit so proper installation of receiver and antenna can be made. The following installation instructions make reference to but do not include procedures from this manual. Unless these procedures are followed, proper operation cannot be guaranteed.

2-3. INSTALLATION CLEARANCES.

2-4. The overall mounting clearance dimensions for the Loran C Telemetry Unit, including cables and connectors, are listed below:

Height	12 1/2 inches
Width	12 1/4 inches
Depth	16 inches.

When selecting site, allow room for mounting microphone hangup box and room at the rear of the unit for access to connectors, fuses, and push-to-talk deselect switch.

2-5. INSTALLATION PROCEDURE.

2-6. Use the following procedure to install the Loran C Telemetry Unit. An interconnection diagram is shown in figure 2-1.

a. Perform installation planning in accordance with section II of Technical Manual of Installation, Operation and Maintenance for the Loran C 708 receiver and antenna.

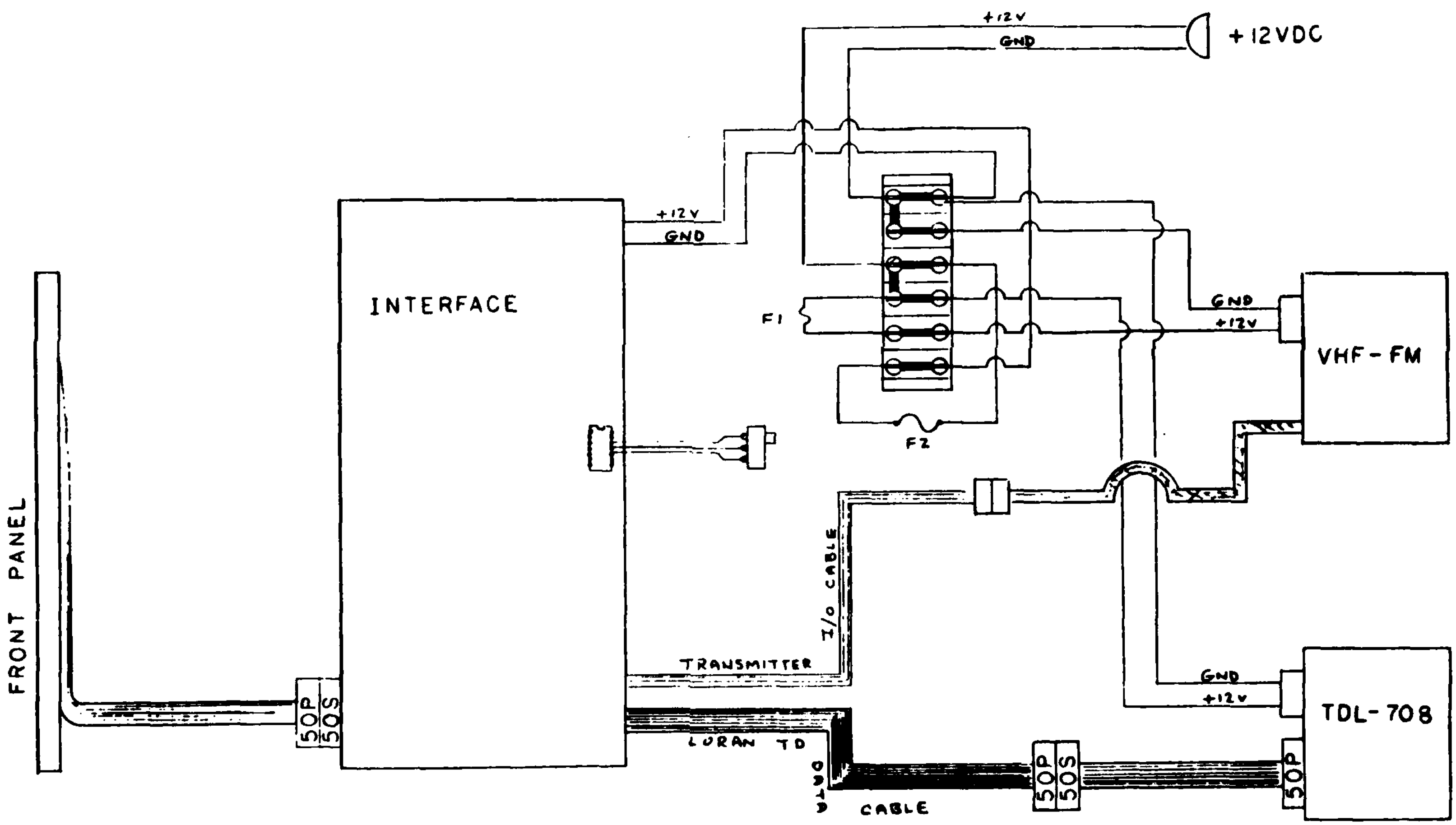


Figure 2-1. Loran C Telemetry Unit Interconnection Diagram

b. Select appropriate external power supply (one of two provided with unit) and connect output to +12 VDC input power connector at rear of unit. When ship's supply is 115 vac 60 Hz, use 115 volt external supply. When ship's power is between 20.5 - 32 vdc, use the dc-to-dc converter. When ship's supply is 12 vdc, connect directly to +12 VDC connector at rear of unit, observing proper polarity: pin A is +12 vdc, pin B is ground. Allow at least 3/8 inch ventilation clearance around all surfaces of either external power supply. Be sure to observe proper polarity when using the dc-to-dc converter.

c. Connect power cable located below fuse F2 into Marine Microlocator input power receptacle. Connect VHF transceiver power cable (below fuse F1) into mating receptacle on transceiver. (Refer to Figure 3-2.)

d. Install Marine Microlocator (Loran C 708 receiver) receiver and antenna in accordance with installation instructions in section II of Technical Manual of Installation, Operation and Maintenance for the Loran C 708 receiver. Pay special attention to antenna siting and receiver and antenna grounding, as applicable. Determine that Loran receiver is operating properly.

CAUTION

The VHF transceiver must be mounted no less than six feet (two meters) away from its antenna. Mount antenna as high as possible and at least ten feet (three meters) from other antennas or metal objects. See Triton owner's manual.

e. Install VHF transceiver antenna and lead-in in accordance with Triton Marine Radiotelephone owner's manual.

f. Install VHF transceiver microphone hangup box in accordance with Triton Owner's manual.

g. Connect Loran C 708 receiver OUTPUT connector to 50-pin connector on back of unit with cable provided. Secure each connector by tightening two mounting screws in each connector shell.

h. Connect I/O cable from transceiver (shielded) to plastic VHF transceiver connector on back of unit and press in so two plastic retaining clips lock onto panel edges.

i. Perform tests for radio frequency interference in accordance with section III of Technical Manual of Installation, Operation and Maintenance for the Loran C 708 receiver and take remedial action if required.

NOTE

Both the Loran C receiver and Triton VHF transceiver may be removed from the Telemetry Unit housing and placed elsewhere. Observe installation instructions when doing so, in accordance with applicable technical manual noted above, especially proper grounding of the Loran receiver. If over 15 feet of cable are used to connect the Loran receiver OUTPUT connector and the Telemetry Unit, check that no data is lost due to attenuation.

NOTE

The Loran C Telemetry Unit is designed to be semi-portable. If it is desired to mount the unit to a horizontal surface, use existing holes for the four rubber standoffs and longer screws. Fabricate any required hardware, as needed.

NOTE

Depending on installation peculiarities, a separate chassis ground for the Loran receiver is sometimes required in addition to the third-wire power ground. If such a ground improves receiver performance in accordance with guidelines set forth in sections II and III of the Loran C receiver maintenance manual, ground the chassis of the Loran receiver to the grounding lug on the rear panel of the Loran C Telemetry Unit per instructions in figure 2-6 of the maintenance manual and then run a separate ground from the Telemetry Unit grounding lug to ship's ground per section II of the maintenance manual. This ground should not be tied to any other equipment ground and should be as short as practical.

Section III. OPERATION

3-1. GENERAL.

3-2. This section contains operating instructions for the Loran C Telemetry Unit (LTU). Controls and indicators are illustrated in figures 3-1 and 3-2 and described in tables 3-1 and 3-2.

3-3. OPERATING INSTRUCTIONS.

3-4. Use the following procedure to turn on and operate the LTU:

a. On LTU front panel, set AUTO MANUAL switch to MANUAL.

b. On LTU front panel, set ON OFF switch to ON.

c. Turn on VHF transceiver by turning volume control clockwise and adjust listening level.

d. On Loran receiver, set mode switch to TEST. Both displays should momentarily show all eights for display test. Both warning indicators should light during internal self test. Unit is operating properly when both warning indicators go out, left display reads 11000.0 ±0.2 and right display reads 25000.0 ±0.2.

e. On Loran receiver, using GRI thumbwheel switches, enter three most significant digits of Loran chain GRI using revised Coast Guard notation.

f. On Loran receiver, using TDA and TDB thumbwheel switches, enter two most significant digits of desired secondary coding delays for TDA and TDB.

NOTE

TDA should always be less than TDB. Secondary sequence is W, X, Y, Z. For example, if W and Y secondaries are desired, TDA = W and TDB = Y.

g. On Loran receiver, set mode switch to ON. Both warning indicators should light again until acquisition and track of Loran signals are accomplished. When both indicators go out, unit is providing valid navigation information in Loran time differences. Decimal point in fifth digit of display should remain on, signifying tenths of microseconds. (Refer to Loran receiver operator instructions for additional information.)

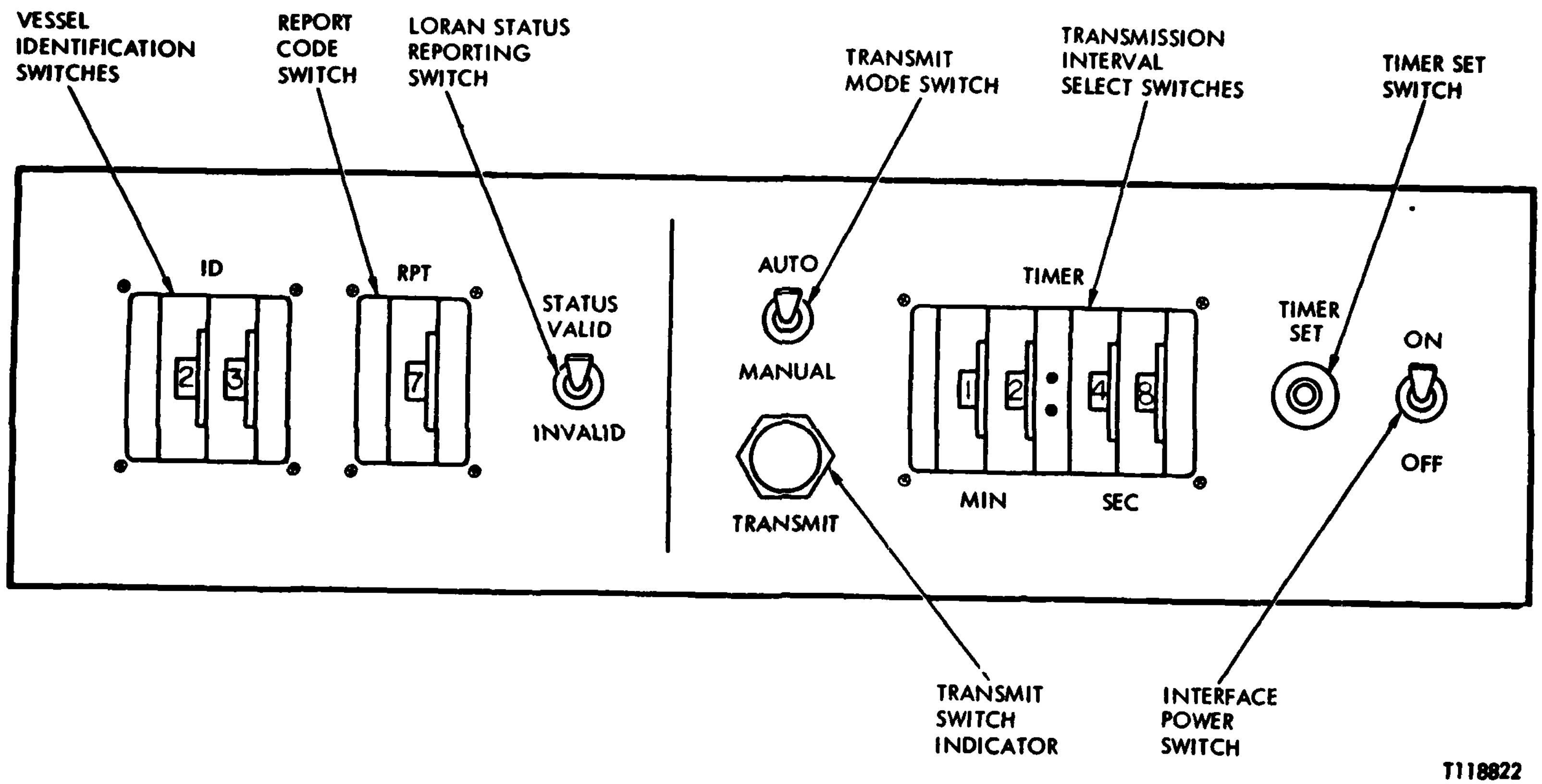


Figure 3-1. Front Panel Controls and Indicators

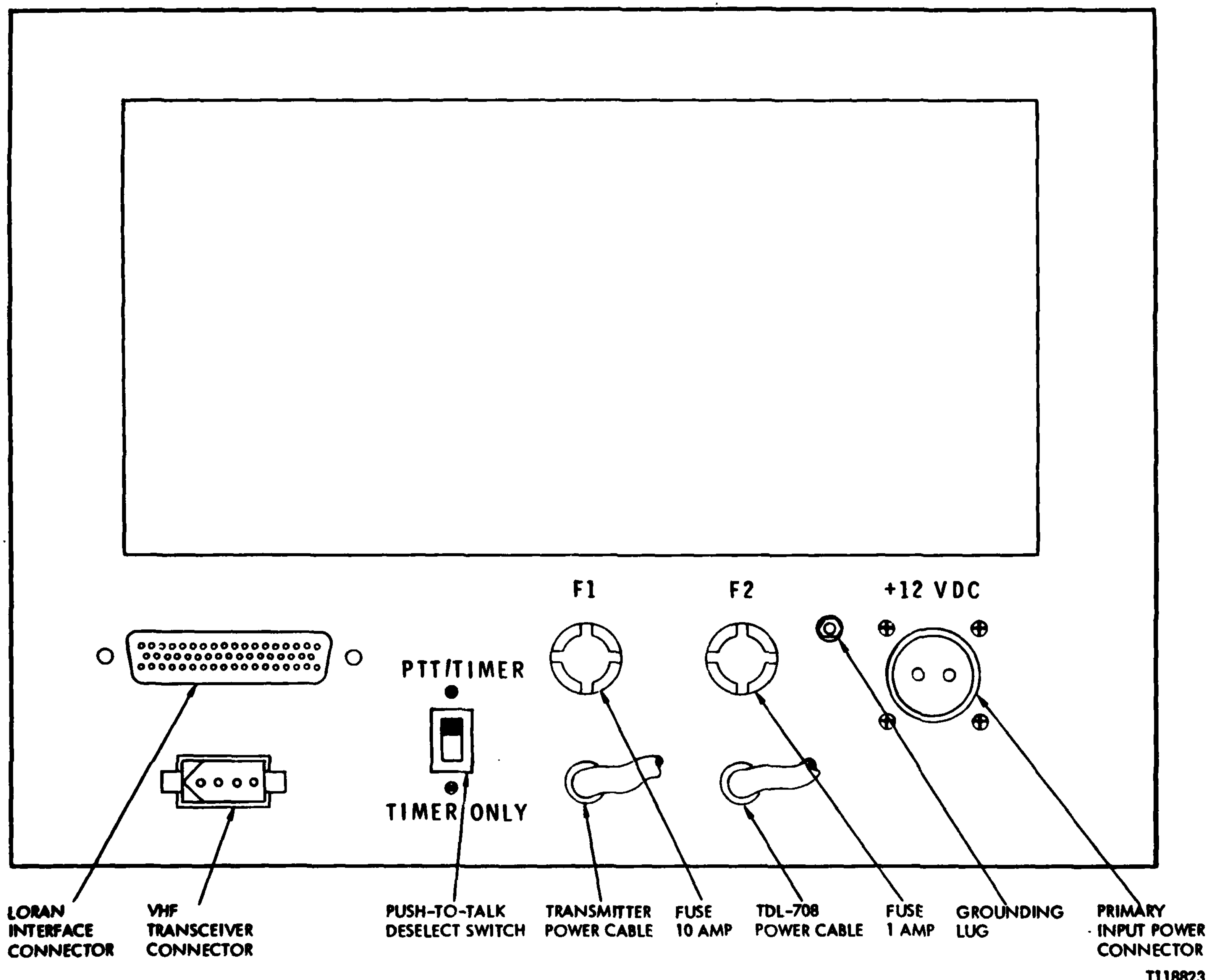


Figure 3-2. Rear Panel Controls and Connectors

Table 3-1. Front Panel Controls and Indicators

Panel Marking	Control/Indicator	Description
ID	Vessel identification thumbwheel switches (2)	Used to enter vessel identification number, transmitted as part of the data link message
RPT	Report code thumbwheel switch	Used to enter report code (0 - 7), transmitted as part of the data link message. (A user-defined option.)
STATUS	Loran status reporting switch	Used to indicate valid/invalid TD information in data link message. VALID - Signifies TDA and TDB are in track. INVALID - Signifies TDA or TDB is not in track. (Operator obtains track status from the TDL-708 receiver.)
AUTO MANUAL	Transmit mode switch	AUTO - Data link message is automatically transmitted at selected timer interval. MANUAL - Data link message is only transmitted when either TRANSMIT or

Table 3-1. Front Panel Controls and Indicators - Continued

Panel Marking	Control/Indicator	Description
AUTO MANUAL - Continued		push-to-talk switch on transceiver is depressed.
TRANSMIT	Transmit pushbutton switch and indicator	Initiates a data link message whenever depressed. Lights whenever any message is transmitted, regardless of mode of transmission.
TIMER	Transmission interval select thumbwheel switches	Used to select interval of data link transmissions. MIN - Used to enter minutes. SEC - Used to enter seconds. Note: Add two seconds to any timer setting.
TIMER SET	Timer set pushbutton switch	Depressed after every change in TIMER thumbwheel switch setting to load selected interval into logic interface.
ON OFF	Interface power switch	Applies primary power to logic interface power supplies

Table 3-1. Front Panel Controls and Indicators - Continued

Panel Marking	Control/Indicator	Description
PTT/TIMER TIMER ONLY	Push-to-talk deselect switch	Used to deselect transceiver push-to-talk switch. PTT/TIMER - Data link message transmission can be initiated from either push-to-talk switch on transceiver or automatically at the timer interval. TIMER ONLY - Transceiver push-to-talk switch is rendered incapable of initiating data link transmissions.
F1	Fuse 1	10 amp fuse for the VHF transceiver
F2	Fuse 2	1 amp fuse for the lotic interface
+12VDC	Primary input power	Brings primary external 12-volt dc power to VTS cabinet.
	Loran interface connector (50-pin)	Connects TDL-708 output data lines (output connector) to logic interface.
	VHF Transceiver connector (4-pin)	Connects audio output of logic interface to VHF transceiver. Supplies 12 vdc PTT relay voltage to sensing circuitry for voice priority feature.

h. On LTU front panel, enter vessel identification number using ID thumbwheel switches.

i. On LTU front panel, enter report code number using RPT thumbwheel switch.

j. On LTU front panel, enter desired data link message transmission interval in minutes and seconds using TIMER thumbwheel switches. Depress TIMER SET pushbutton switch to set timer.

NOTE

The interval timer has a plus two-second internal offset. If the TIMER thumbwheel switches are set to 10 seconds, the transmission interval will be 12 seconds; if set to 30 seconds, the interval will be 32 seconds, etc. For example, to achieve an accurate 15-second message interval, set the TIMER to 13 seconds.

k. On LTU front and rear panels, select desired data link transmission mode in accordance with the following chart. For example, with the rear panel switch set to PTT/TIMER and the AUTO MANUAL switch set to AUTO, a message will be transmitted automatically at the timer interval and can also be transmitted whenever the TRANSMIT or PTT switches are pressed. Whenever a message is transmitted, the TRANSMIT indicator should light.

PTT/TIMER TIMER ONLY Switch (rear panel)	AUTO MANUAL Switch	
	AUTO	MANUAL
PTT/TIMER	Automatically, at timer interval or TRANSMIT switch or PTT switch	TRANSMIT switch or PTT switch
TIMER ONLY	Automatically, at timer interval or TRANSMIT switch	TRANSMIT switch

l. As required during operation, determine Loran receiver signal status and set STATUS switch to VALID or INVALID, as applicable. To obtain Loran signal status, see paragraph 4-15 through 4-19.

m. To transmit a data link message at any time, with switches in any position, depress TRANSMIT switch on front panel. Pressing the PTT switch on the transceiver microphone will also transmit a message unless the rear panel switch is in the TIMER ONLY position.

Section IV. THEORY OF OPERATION

4-1. GENERAL.

4-2. This section contains theory of operation of the Loran C Telemetry Unit (LTU). The LTU transmits either voice communications or a 24-character digital message in ASCII format. Voice transmission are made using the transceiver microphone. The digital message is generated in the interface and consists of the following information elements:

a. Vessel identification code (0-99), identifying the ship or LTU.

b. Report code (0-7), an information element that can be assigned any arbitrary meaning.

c. Loran status code, signifying valid or invalid Loran data.

d. TDA data - information appearing in the TDA display of the Loran receiver. In standard operating procedure, this will be Loran time difference A in microseconds.

e. TDB data - information appearing in the TDB display of the Loran receiver. In standard operating procedure this will be Loran time difference B in microseconds.

A priority arrangement inhibits transmission of data during voice transmissions.

4-3. LORAN C 708 RECEIVER.

4-4. The only area of Loran receiver theory of operation that will be described in this manual is that portion relating to the OUTPUT connector and associated signals. For additional theory of operation, consult the maintenance manual or Depot Repair Documentation manual.

4-5. OUTPUT CONNECTOR LOGIC. (See figure 4-1.)

4-6. The same serial time difference data that is displayed in the 708 receiver TDA and TDB displays also goes to six serial-to-parallel shift registers on the TDL-708 DIU board (U26-U31) for output to the LTU interface circuitry. These registers consist of a shift register and a parallel holding register, so that data appearing on the OUTPUT connector appears simultaneously on all lines. Gated clock signals for these two registers come from control logic on the 708 digital

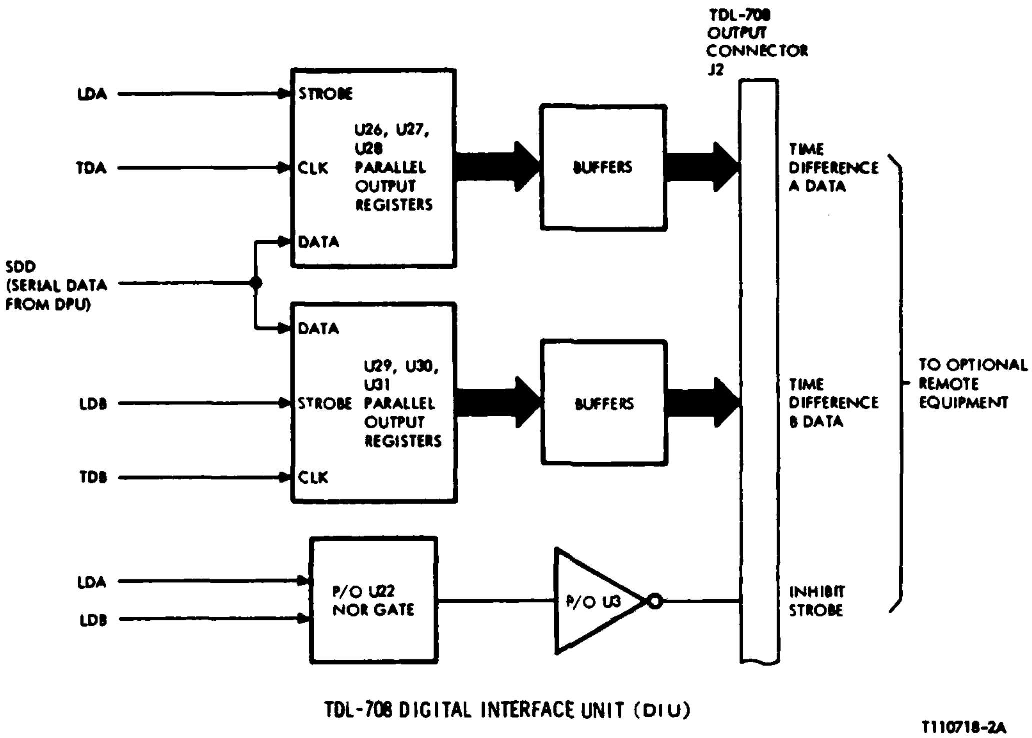


Figure 4-1. TDL-708 Loran Receiver Output Connector Logic

processor unit. The logic in this circuit mechanizes parallel output of time differences (or other data selected by the mode switch) onto the OUTPUT connector at the rear of the 708 receiver.

4-7. The six output registers on the 708 DIU board (U26-U31) correspond with the six digits of either display. (The TDA and TDB displays are updated alternately.) These are 8-stage shift-and-store bus registers, consisting of two registers each internally. One is a serial-in, parallel-out register, converting the incoming serial data stream to parallel format; the other is parallel-in, parallel-out, acting as a storage register. A simplified functional diagram of one of the 4094 chips is shown in figure 4-2. Serial data is shifted into the top register on positive clock transitions. Data in each shift register stage are transferred to the storage register when the strobe input (LDA or LDB) is high. Data in the storage register appears at the parallel outputs continuously because the output enable lines are all tied to +5 volts. Thus, serial sections of the chips are controlled by TDA or TDB DISP CLOCK signals; parallel sections are controlled by LDA or LDB.

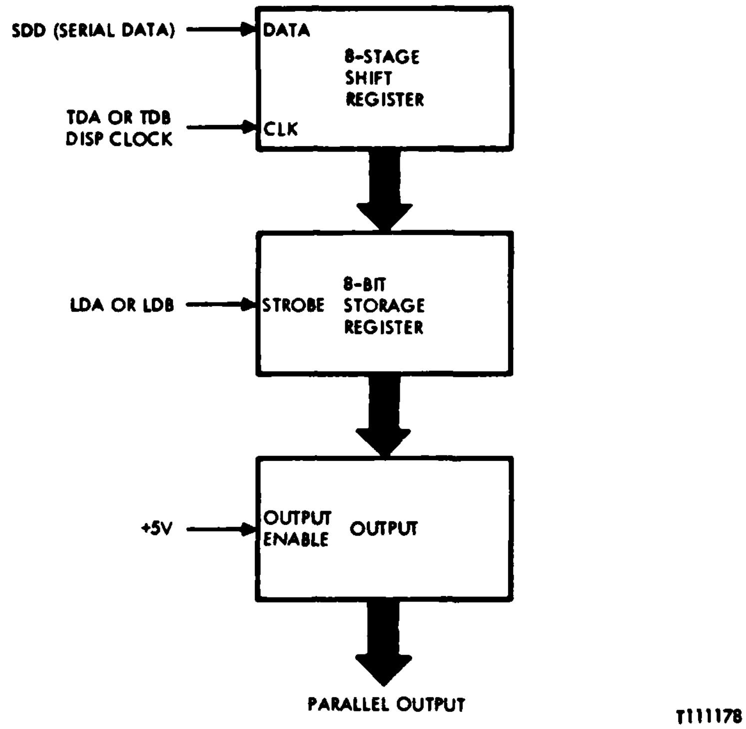


Figure 4-2. TDL-708 Parallel Output Register Simplified Functional Diagram

4-8. Parallel outputs of U26 - U31 are buffered with non-inverting buffers to become the parallel time difference A and B outputs. Each output line is capable of driving one TTL load.

4-9. With LDA and LDB high, output of U22 NOR gate is low, inverted in U3 to become the TDL-708 INHIBIT STROBE signal. Thus, whenever INHIBIT STROBE is high, the parallel output registers are being updated. This is the time when the serial input registers within U26 - U31 are being transferred to the parallel output registers. This signal provides the LTU interface circuitry with an inhibit line so data will not be read while in transition. The INHIBIT STROBE signal may also be interpreted as a "DATA READY" flag to peripheral equipment. That is, for a certain time after this signal occurs, data on the parallel output lines is valid.

4-10. OUTPUT CONNECTOR. (See table 4-1 and figure 4-3.)

4-11. The OUTPUT connector on the rear of the 708 receiver is a 50-pin connector providing buffered parallel-output display data (binary-coded decimal) to the LTU interface. Twenty four pins provide TDA data, and another twenty four pins provide

Table 4-1. 708 Receiver Output Connector Pin Assignments

J2 Pin Number	Signal	J2 Pin Number	Signal	BCD	Corresponding Display Digits
31	TDA18	38	TDB18	8	
15	TDA14	8	TDB14	4	
32	TDA12	24	TDB12	2	Least Significant Display Digit
16	TDA11	7	TDB11	1	
17	TDA28	9	TDB28	8	
33	TDA24	25	TDB24	4	
48	TDA22	40	TDB22	2	
47	TDA21	39	TDB21	1	
45	TDA38	22	TDB38	8	
46	TDA34	5	TDB34	4	
28	TDA32	21	TDB32	2	
12	TDA31	4	TDB31	1	
29	TDA48	37	TDB48	8	
13	TDA44	36	TDB44	4	
30	TDA42	23	TDB42	2	
14	TDA41	6	TDB41	1	
26	TDA58	1	TDB58	8	
41	TDA54	18	TDB54	4	
42	TDA52	35	TDB52	2	
43	TDA51	34	TDB51	1	
10	TDA68	20	TDB68	8	
27	TDA64	3	TDB64	4	Most Significant Display Digit
11	TDA62	19	TDB62	2	
44	TDA61	2	TDB61	1	

Pin 49 - INHIBIT STROBE

Pin 50 - SIGNAL RETURN (GROUND)

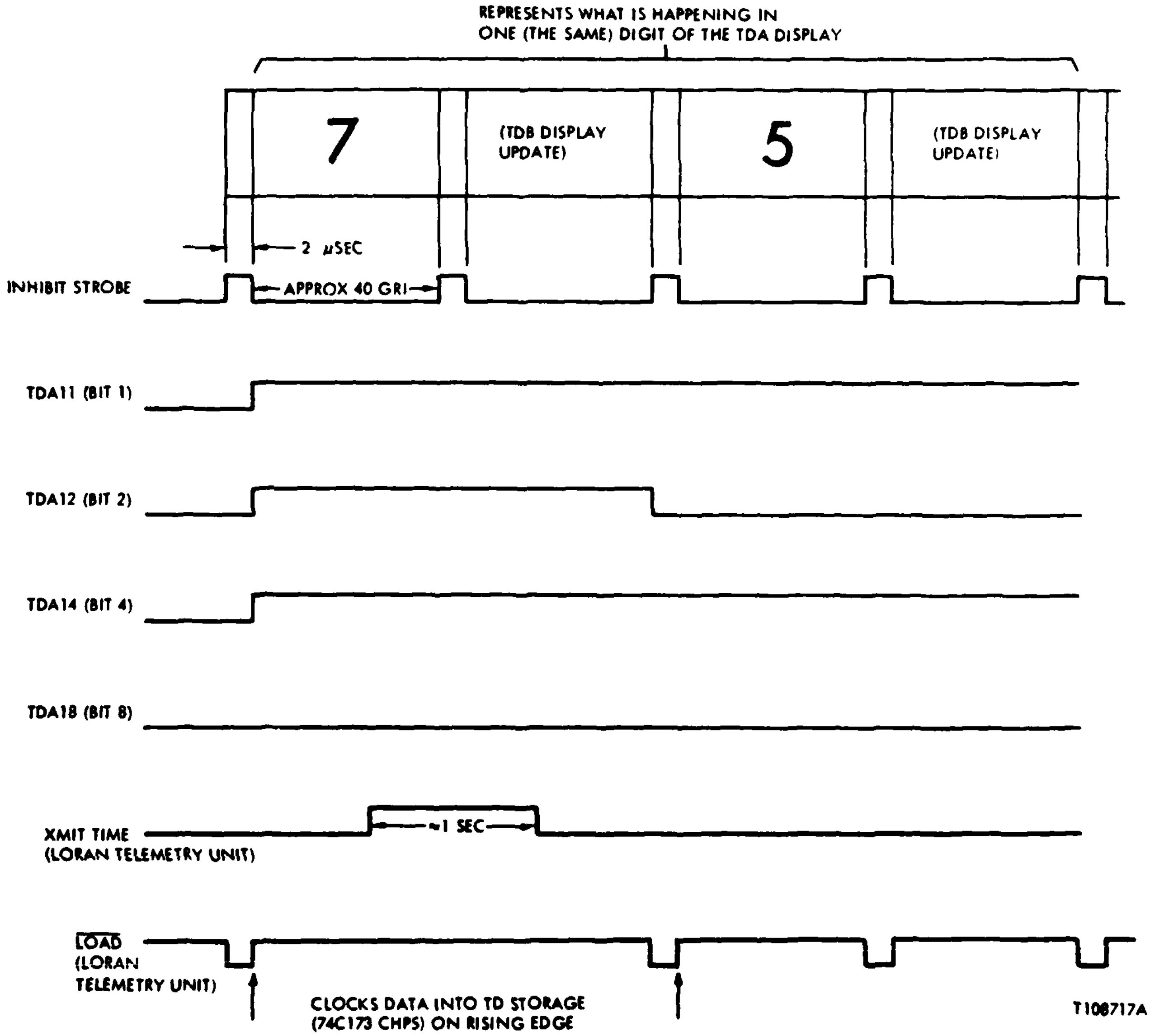


Figure 4-3. Typical TDL-708 Output Connector Timing Related to LTU Interface Circuitry Signals

TDB data or whatever else is selected on the mode switch or test card rotary switch (TDC, TDD, STATUS, SNR, ENV, or VEL). (See Maintenance Manual, section X.) Pin 50 is signal return (ground), and pin 49 is the INHIBIT STROBE signal, a positive-going two-microsecond pulse used to inhibit data during update.

4-12. Pin assignments and signal descriptions are provided in table 4-1. On figure 4-3, note that each of the six digits in the front panel TDA and TDB displays is controlled by four binary-coded-decimal (BCD) lines, which produce the number (shown at the top) to be displayed in that digit of the display. In the first TDA digit in figure 4-3, the four binary lines add up to 7; in the second TDA digit they add up to 5, with alternate update periods affecting the TDB display. Strobing of data is inhibited when it is being updated. Since there are twelve display digits, there are twelve groups of four signal lines, six for TDA and six for TDB.

4-13. Figure 4-3 shows a timing diagram of typical signals appearing on the OUTPUT connector. The rate at which data is output is proportional to GRI. TDA and TDB displays are updated on alternate inhibit strobes. The trailing edge of the strobe is a convenient clock point.

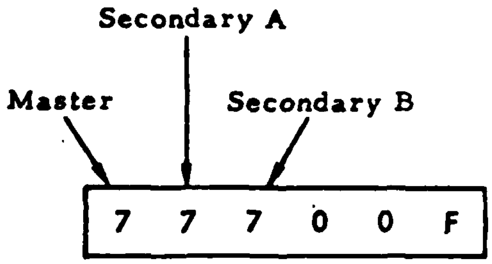
4-14. Data is updated with the INHIBIT STROBE pulse from the TDL-708 receiver. Every INHIBIT STROBE pulse clocks new time difference data into the interface circuitry. The INHIBIT STROBE pulse is a positive-going pulse from the 708 receiver. In the interface circuitry of the telemetry unit it is inverted ($\overline{\text{LOAD}}$) and clocks data on the rising edge. $\overline{\text{LOAD}}$ pulses are inhibited while the XMIT TIME signal is high, preventing data update while data is being transmitted on the air. Thus, there is no updating during the period (0.8 seconds) of radio transmission.

4-15. LORAN RECEIVER STATUS.

4-16. Status is checked by setting the mode switch on the 708 receiver to STATUS. Proper operation is suspect when the receiver does not pass self test in the TEST position or when either or both warning lights go on. For a description of self test, see the 708 Operator's or Maintenance Manual. Whenever you switch to

STATUS, the TDB warning indicator goes out (if it was on), indicating the TDB display is now showing status. The letter F also appears in the last digit. (This is an engineering code that has no meaning to the operator and is to be disregarded in all cases.) The first three digits of the TDB display are used to indicate status of the master and both secondary Loran signals being received. Ignore the last three digits. Any number from 0 through 4, 7 and 8 can appear in each of these first three digits according to the following scheme.

0 - Search
1 - Coarse envelope (narrow band)
2 - Coarse envelope (wide band)
3 - Fine envelope 1
4 - Fine envelope 2
7 - Track
8 - Energy track (float)



4-17. Thus, if 7's appear, as shown above, master and both secondaries are in track (if no warning indicators were on). This indicates normal condition. The warning indicators will not go out, signifying proper operation, until status is all 7's. Some examples of status messages indicating improper operation are listed in table 4-2. The first two columns show warning indicator status prior to setting the mode switch to STATUS.

4-18. LORAN RECEIVER STATUS LOGIC.

4-19. When the mode switch on the 708 receiver is set to STATUS, the STATUS COMM line is grounded, forcing pin 12 of U31 on the 708 processor printed wiring board low and pin 11 high. This forces bit 2 input to U37 high, commanding U37 to request status information be displayed in the TDB display. The same thing happens when the test card is connected and its rotary switch is set to STATUS. Pin 12 of U31 is latched to the low state through the diode, the same as grounding that line when the receiver mode switch is set to STATUS. The diode is required to protect the integrated circuit chip CD4011 when STATUS is selected on the receiver mode switch.

Table 4-2. Status Message Examples

Warning Indicator TDA	Warning Indicator TDB	TDB Display	Condition
ON	OFF	74700.F	Signal A cycle selection is incorrect
OFF	ON	77400.F	Signal B cycle selection is incorrect
ON	OFF	77700.F	Secondary A is blinking
OFF	ON	77700.F	Secondary B is blinking
OFF	ON	77800.F	Secondary B signal is lost (in float)
ON	OFF	78700.F	Secondary A signal is lost (in float)
ON	ON	88800.F	Master and both secondaries are lost (in float)

4-20. TRITON VHF-FM TRANSCEIVER.

4-21. Output of the interface circuitry is introduced in parallel with transceiver microphone input via the shielded cable attached to the VHF transceiver connector on the rear panel of the LTU. Amplitude of the digital message input to the transceiver is sufficient to modulate the transceiver from 3 - 5 KHz deviation. Amplitude is factory adjustment to the volume potentiometer R16 on the interface board (300 mv peak-to-peak). For theory of operation of the transceiver, consult Triton owner's manual.

4-22. INTERFACE. (See figure 4-4.)

4-23. GENERAL.

4-24. The interface takes the identification, report code and Loran status code information from the positions of switches located on the LTU front panel and combines it with the Loran time difference data that comes from the Loran receiver to form the digital message to be transmitted via radio data link. The interface also controls transmission of the digital message by providing for either automatic or manual keying of the VHF-FM transceiver. Schematic diagrams of interface circuits are located at the end of this section for ease of reference.

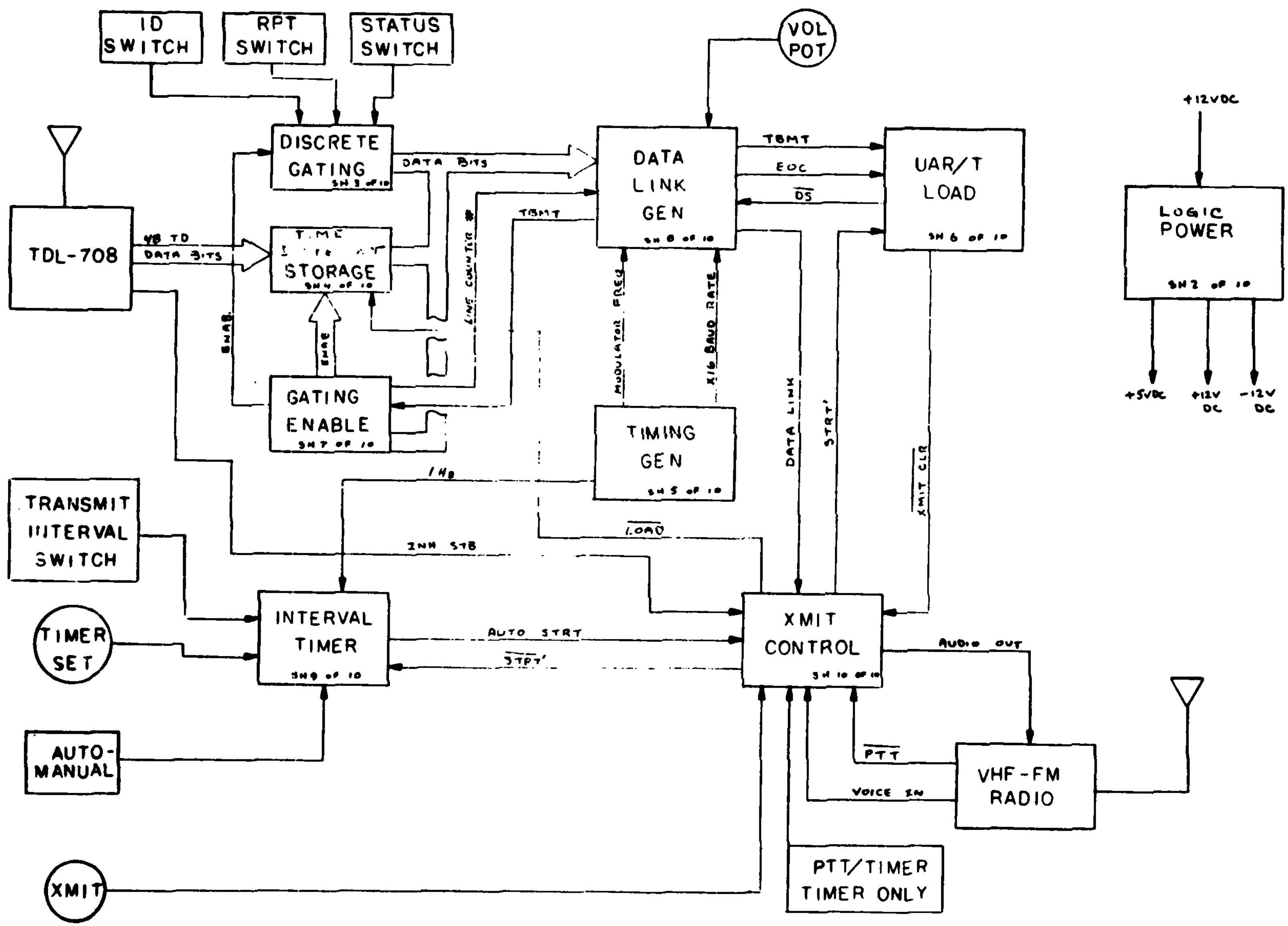


Figure 4-4. Loran C Telemetry Unit Functional Block Diagram

4-25. Figure 4-4 shows a block diagram of the interface circuitry as part of the Loran C Telemetry Unit. Loran position data is entered into the time difference storage circuitry by means of the $\overline{\text{LOAD}}$ pulse from the xmit control circuitry. This data, along with the identification, report, and status code data are presented to the data link generator for ASCII encoding. The gating enable circuitry controls the sequence of data flow to the data link generator. The interval timer generates the start pulse for data transmission every time the selected time interval has expired. The timing generator counts down the crystal oscillator output to produce the correct modulating frequency for the data bits. The 1 Hz time standard for the interval timer is also produced from the countdown circuit.

4-26. The UAR/T load circuitry receives the UAR/T's requests for data flags (TBMT) and converts these flags to data strobes ($\overline{\text{DS}}$) for loading the UAR/T with another ASCII character. The data link generator contains the programmable read only memory (PROM) used for ASCII encoding. The PROM's nine address lines include five line number bits plus four BCD data bits. The PROM output data will be the ASCII version of the four-bit BCD number. The ASCII character is loaded into the UAR/T on every $\overline{\text{DS}}$ pulse from the UAR/T load circuitry. The data link generator also encodes the FSK tones required by the serial data bits to produce the completed data burst.

4-27. The xmit control circuitry keys the transmitter and routes the data link burst to the VHF transceiver. This circuitry also generates the Loran data $\overline{\text{LOAD}}$ pulse and gating for the TRANSMIT indicator, the push-to-talk sensing, and the manual TRANSMIT switch gating.

4-28. The power circuitry converts the +12 vdc input power to a regulated +5 vdc, +12 vdc, and -12 vdc.

4-29. LOGIC POWER. (See figure 4-8 at end of section.)

4-30. The +12 vdc input is applied to dc-to-dc converters mounted on the interface Augat board. One converts 12 vdc to +5 vdc for the logic. The other creates +12 vdc regulated and -12 vdc regulated for the operational amplifier driving the data link output.

4-31. DISCRETE GATING. (See figure 4-9 at end of section.)

4-32. Data from the ID code, RPT code and STATUS switches is gated onto the bus lines via the DM80C97 tri-state buffer-drivers. When an enable line goes low, the high impedance output state of those gates switches to the data appearing at the gate inputs. The thumbwheel switches have pulled-up BCD complement outputs.

4-33. TIME DIFFERENCE STORAGE. (See figure 4-10 at end of section.)

4-34. Twelve storage chips are used to hold the 48 Loran time difference bits. The data is clocked into the holding register on the rising edge of the negative-going $\overline{\text{LOAD}}$ pulse. Each register, in turn, puts its four bits of data on the bus lines when its enable line goes low. The low enable line switches the tri-state outputs from the high impedance state to the data levels in that chip only. Each enable line corresponds to one output of the line counter in the gate enable circuitry.

4-35. TIMING GENERATOR. (See figure 4-11 at end of section.)

4-36. The timing generator creates three major frequencies: the modulator clock, a frequency 16 times the BAUD rate, and the 1 Hz interval timer frequency. The 12.8 MHz oscillator is divided by 89 (through chips BB41 and BD41) to produce the 143,820 Hz modulator clock. This clock in turn is divided by 30 (through chips BF41 and AE28) to produce the frequency of approximately 4,800 Hz, which is 16 times the required BAUD rate. The next divider chain divides the 4,800 Hz by 4800 (through chips BB32, BD32 and BF32) to produce the 1 Hz timer frequency. The power-on-reset pulses are produced from the long time constant of R16 and C13 through driver gate AC36.

4-37. UAR/T LOAD GENERATOR. (See figure 4-12 at end of section.)

4-38. With the arrival of the STRT' pulse, which is converted to the $\overline{\text{DS}}$ (data strobe) pulse by inverter AC28, the first line of data (line Ø) is loaded into the data bit holding register of the UAR/T (chip CB1 in the data link generator circuitry). When the UAR/T is able to accept more data, the TBMT signal goes high. Chip BB23 (dual one-shots) converts this high level into the $\overline{\text{DS}}$ pulse, which in turn loads the next line of data into the UAR/T holding register. After the 24th line of data (line 23) has been transmitted, the line counter (chips BB14 and AE28 in the gate enable circuitry) is incremented to 24 by TBMT pulses from the UAR/T. When a line number of 24 is decoded by chip AG36, a latch (chip AG36) is set. With this latch set, further DS gating is disabled, the line counter is cleared (returned to zero), and the transmit flip-flop (chip AE36 in the xmit control circuitry) turns off (is cleared). This sequence is repeated with the reception of another STRT' pulse.

4-39. UAR/T DATA STROBING. Figure 4-5 shows timing relationships between signals involved in strobing data into the UAR/T. The XMIT TIME signal lasts 0.8 seconds and represents the window in which data transmission takes place. The rising edge of the XMIT TIME signal starts the chain of events leading up to the loading of the UAR/T. This creates the STRT' signal in the xmit control circuitry out of chip BF23, a high-level pulse used to start data transmission. The delay between XMIT TIME and STRT', caused by one-shot BF23, is to allow the transmitter to be actually on the air before data transmission begins.

4-40. The $\overline{DS}$ signal (Data Strobe) is a low-level pulse that strobes data into the UAR/T. When the UAR/T is ready for more data, it outputs the TBMT signal (transmitter buffer empty) flag. Thus, the interval between $\overline{DS}$ and TBMT is the time required for the UAR/T to convert one character. The delay between TBMT and the next $\overline{DS}$ pulse ensures stability of data in storage registers. The various storage register enables signals are represented by the bottom waveform on figure . The point at which these signals are at zero transition represents the fact that no data is being kicked out of the storage registers onto the data bus into the UAR/T.

4-41. GATE ENABLE. (See figure 4-13 at end of section.)

4-42. The line counter (chips BB14 and AE28) counts from 0 to 23 (24 lines of data for transmission). The counter is cleared to a 0 after the last character is transmitted. When a transmission is initiated, the UAR/T outputs TBMT pulses, which increment the line counter. One character transmitted equals one TBMT pulse. The binary number from the line counter is decoded to 24 separate lines.

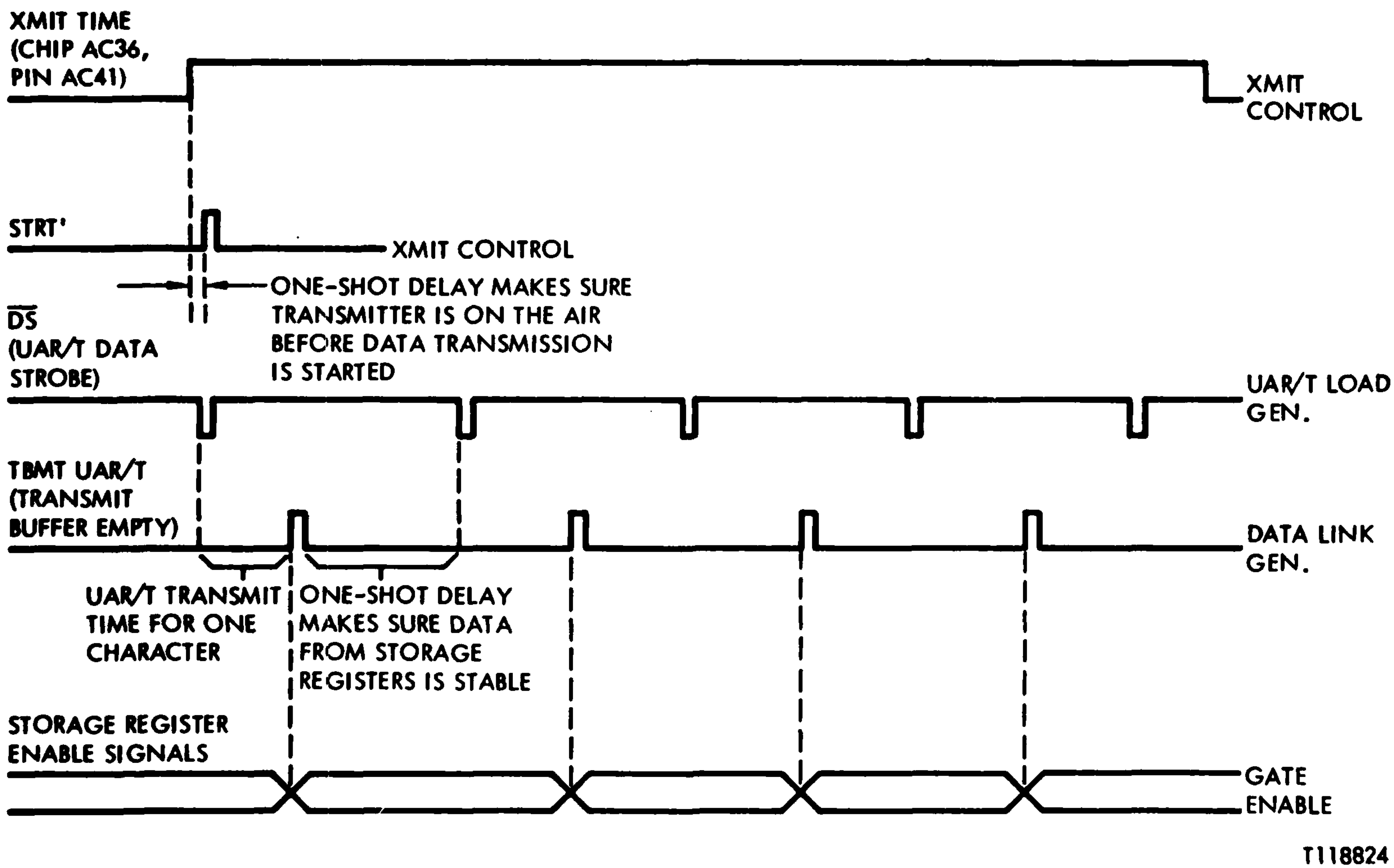


Figure 4-5. Data Strobing Into UAR/T

These lines, when low, enable tristate outputs to transfer data onto data bus lines making up part of the PROM address. Eight of the enable lines are ORed through chip AG28 to put all zeros on the bus lines when any of these enable lines goes low. The line counter outputs are routed also to the PROM to make up part of the PROM address.

4-43. DATA LINK GENERATOR. (See figure 4-14 at end of section.)

4-44. The PROM chip (BH1) address is composed of the line counters output number (A4-A8) and four BCD data bits (a Buss - d Buss). The contents of an addressed location is a seven-bit ASCII character of the BCD number, figure 4-6 . Symbols such as space, line feed, carriage return, etc., have a BCD address number of zeroes. Therefore, the line number address will define which location contains that symbol. The UAR/T clocks in the seven ASCII bits (DB1 - DB8) and outputs a 10-bit serial character on pin 25 at 300 BAUD. Counter chip BD14 modulates the marks (1) and spaces (0). Counter chip BF14 counts down the modulated marks and spaces to 1200 and 2200 Hz. The operational amplifier (LM118D) acts as a digital-to-analog converter, the output of which is a sine wave of the desired audio frequency. Potentiometer R16 controls amplitude of the audio output.

4-45. ASCII DATA LINK MESSAGE. The format of the 10-bit ASCII character is shown in figure 4-6. Figure 4-7 shows the complete data link message composed of 24 10-bit ASCII characters. The LTU can be reprogrammed to accommodate any data link message format.

4-46. INTERVAL TIMER. (See figure 4-15 at end of section.)

4-47. Data from the minutes and seconds thumbwheel switches in 9's complement BCD form is loaded into the counter chain when the TIMER SET pushbutton switch is pressed or when a $\overline{\text{STRT}}$' pulse from the XMIT control circuitry arrives. The TIMER SET switch contacts are "debounced" through flip-flops C9 and AE36. The AUTO/MANUAL switch breaks the 1 Hz clock line to the counters, allowing them to count or not. The circuitry surrounding counter chip CA41 enables one carry overflow from that chip after a load. Then it enables the counter as a

BIT NUMBERS b7	b6	b5						0 0 0	0 0 1	0 1 0	0 1 1	1 0 0	1 0 1	1 1 0	1 1 1
b_7	b_6	b_5	b_4	b_3	b_2	b_1	ROW \ COLUMN	0	1	2	3	4	5	6	7
			0	0	0	0	0	NUL	DLE	SP	0	@	P	`	p
			0	0	0	1	1	SOH	DC1	!	1	A	Q	a	q
			0	0	1	0	2	STX	DC2	"	2	B	R	b	r
			0	0	1	1	3	ETX	DC3	#	3	C	S	c	s
			0	1	0	0	4	EOT	DC4	$	4	D	T	d	t
			0	1	0	1	5	ENQ	NAK	%	5	E	U	e	u
			0	1	1	0	6	ACK	SYN	&	6	F	V	f	v
			0	1	1	1	7	BEL	ETB	'	7	G	W	g	w
			1	0	0	0	8	BS	CAN	(	8	H	X	h	x
			1	0	0	1	9	HT	EM	)	9	I	Y	i	y
			1	0	1	0	10	LF	SUB	*	:	J	Z	j	z
			1	0	1	1	11	VT	ESC	+	;	K	[	k	{
			1	1	0	0	12	FF	FS	,	<	L	\	l	|
			1	1	0	1	13	CR	GS	–	=	M	]	m	}
			1	1	1	0	14	SO	RS	.	>	N	^	n	~
			1	1	1	1	15	SI	US	/	?	O	_	o	DEL

ONE ASCII CHARACTER
(b_1 - b_7)

T118825

Figure 4-6. ASCII Character Format

divide-by-six rather than the normal divide-by-ten. The divide-by-six is required for the most-significant seconds digit. When the counter fills up and overflows, the most significant minutes digit, a pulse called AUTOSTRT, triggers the transmit start sequence. This sequence produces $\overline{STRT}$', which reloads the thumbwheel time data into the counter chain.

4-48. XMIT CONTROL. (See figure 4-16 at end of section.)

4-49. Pressing the TRANSMIT switch-indicator on the front panel or an AUTO-STRT pulse will set flip-flop AA36. TRANSMIT switch contacts are debounced

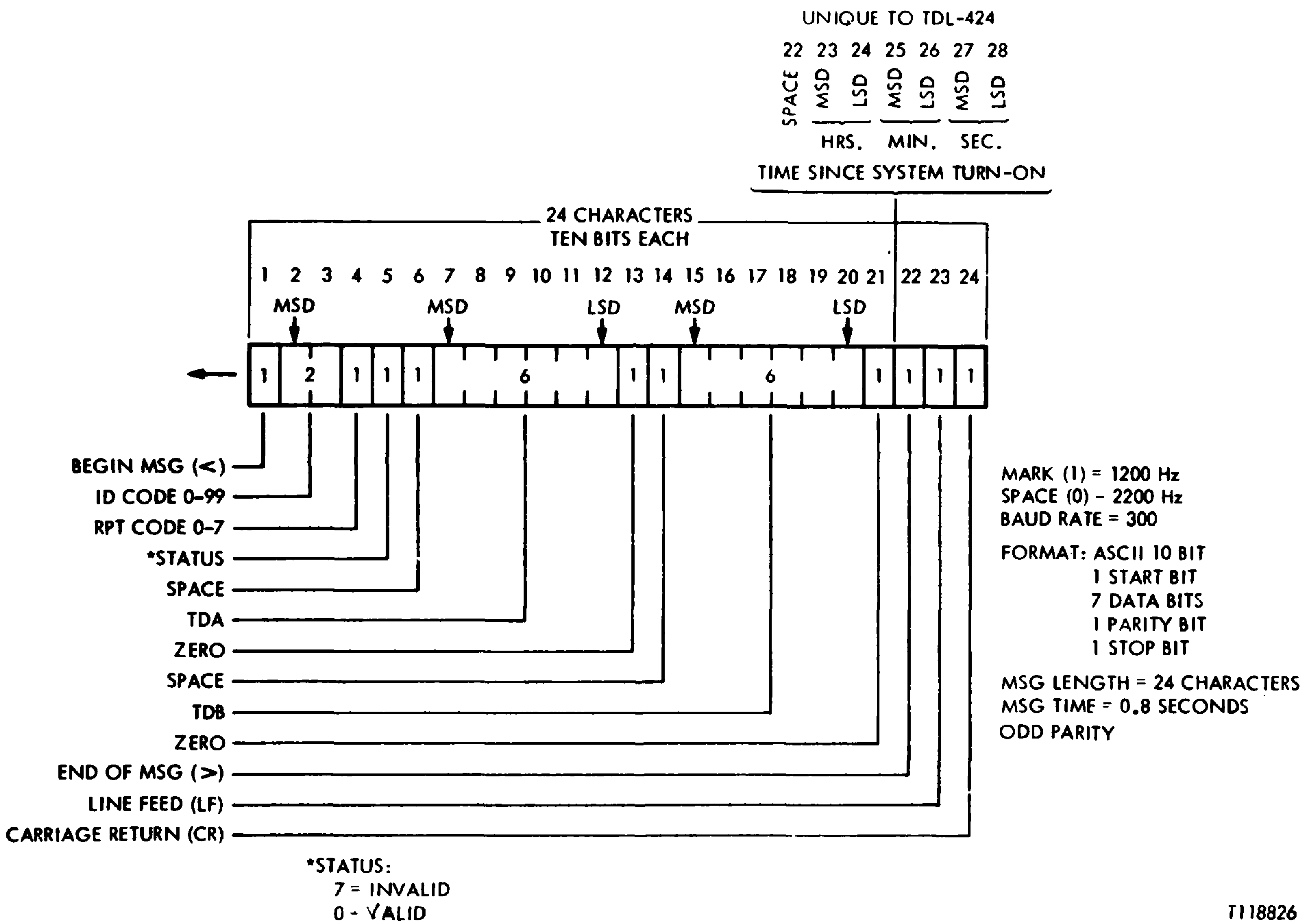


Figure 4-7. ASCII Data Link Message Composition

through flip-flop AC44. If the push-to-talk switch on the transceiver microphone is not pressed, flip-flop AA36 will set the transmit flip-flop AE36. AE36 will also be set with the push-to-talk switch in the released condition through flip-flop C9 and half of one-shot BF23. This half of one-shot BF23 is wired in a retrigger configuration, enabling it to ignore multiple push-to-talk depressions over a very short period of time. Output of this one-shot section goes through the push-to-talk deselect switch on the rear panel, which can be set to ignore all push-to-talk depressions.

4-50. Once the transmit flip-flop is set, it energizes relay RY1, turns on the TRANSMIT indicator driver, and generates the data transmit start pulse (STRT), through the other half of one-shot BF23. Relay RY1 turns on the transmitter by grounding the $\overline{\text{PTT}}$ (push-to-talk) line and switches out the voice audio and switches in data link data. The data link line is terminated in a 600 ohm impedance. The INHIBIT STROBE signal is ANDed with transmit flip-flop not set to generate the Loran data clock pulse ($\overline{\text{LOAD}}$).

4-51. EXTERNAL POWER SUPPLIES.

4-52. The two external power supplies provided with the Loran C Telemetry Unit are standard Lambda power supplies with cable and connector attached. For theory of operation and maintenance of these power supplies, consult Lamda Instruction Manual for LXS-D series power supplies, provided with each LTU.

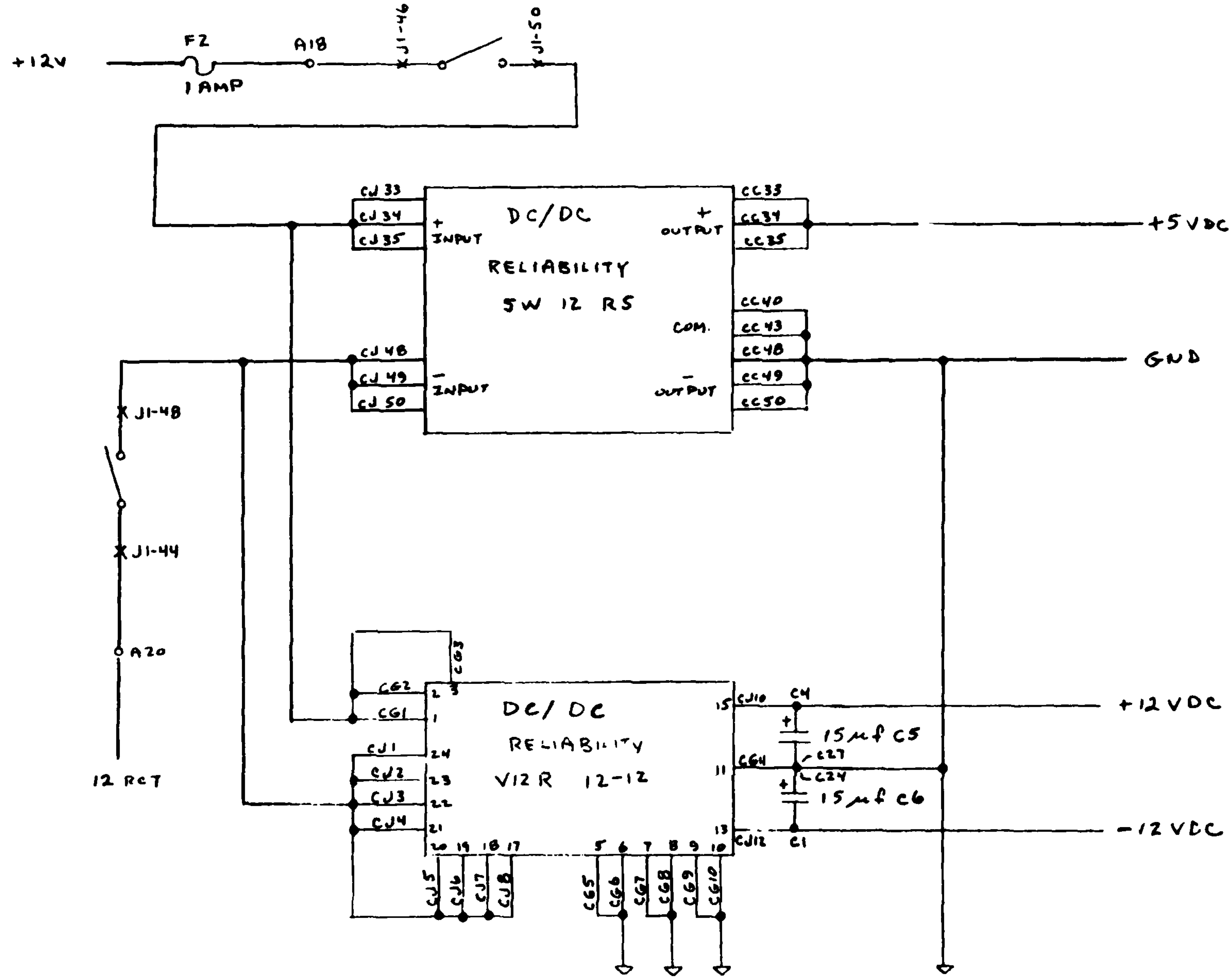
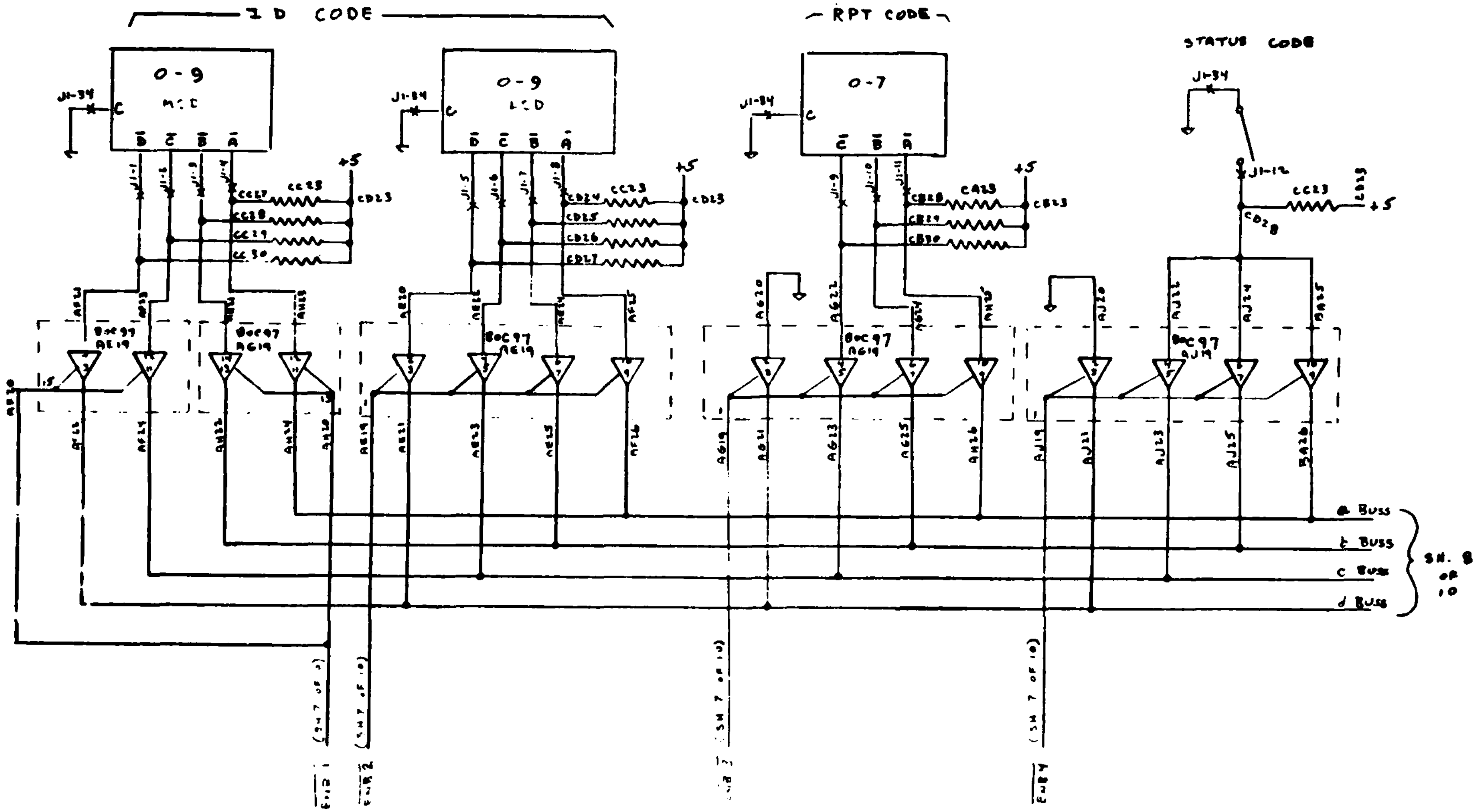


Figure 4-8. Logic Power Schematic Diagram



I D CODE
RPT CODE
STATUS CODE
0-9
MSD
0-9
LSD
0-7
J1-34
J1-12
+5
CD23
CC23
CA23
CD28
BOC97
AE19
AG19
AJ19
a BUSS
b BUSS
c BUSS
d BUSS
SH. 8 OF 10
(SH 7 OF 10)
ENB 1
ENB 2
ENB 4

Figure 4

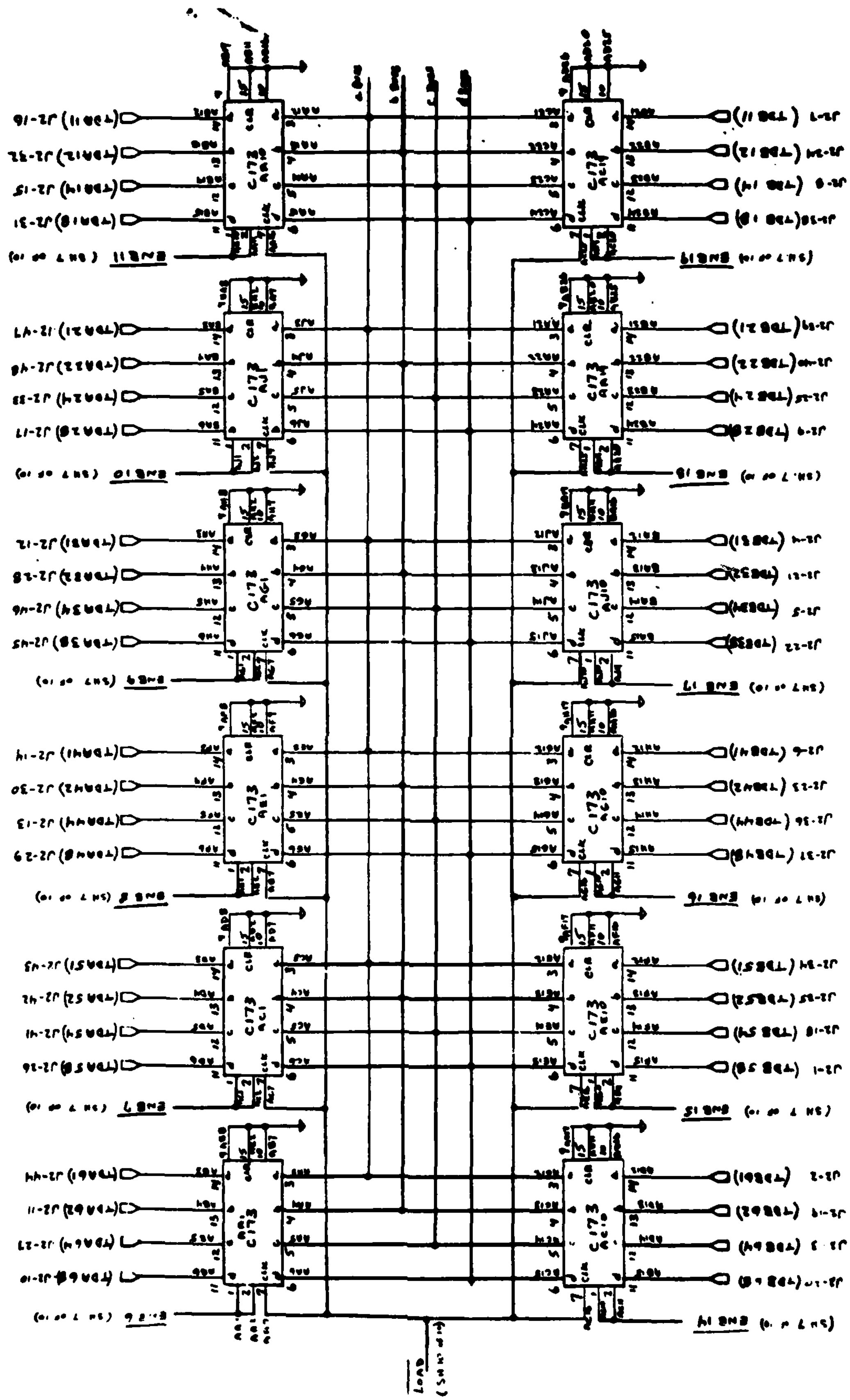


Figure 4-10. Time Difference Storage Schematic Diagram

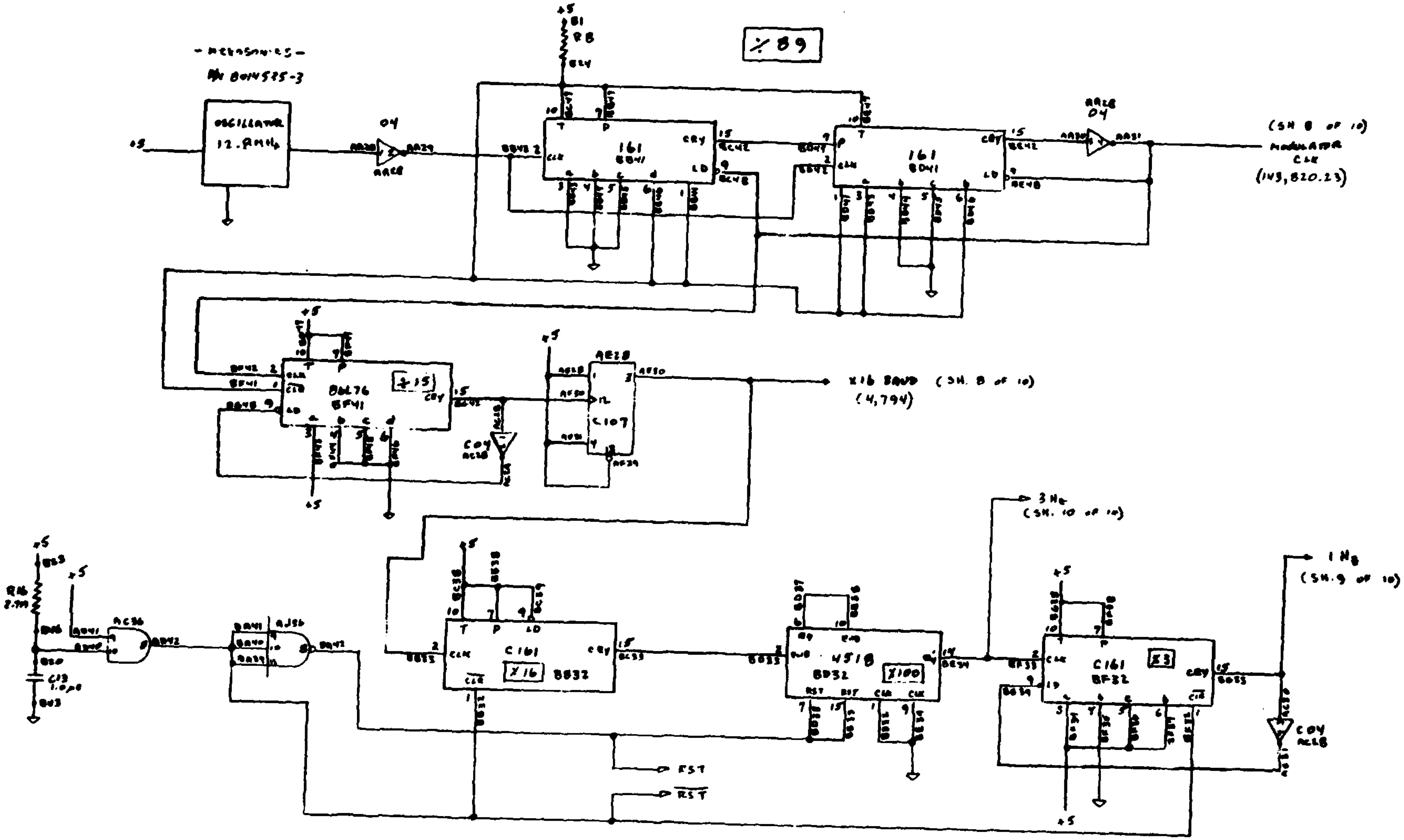


Figure 4-11. Timing Generator Schematic Diagram

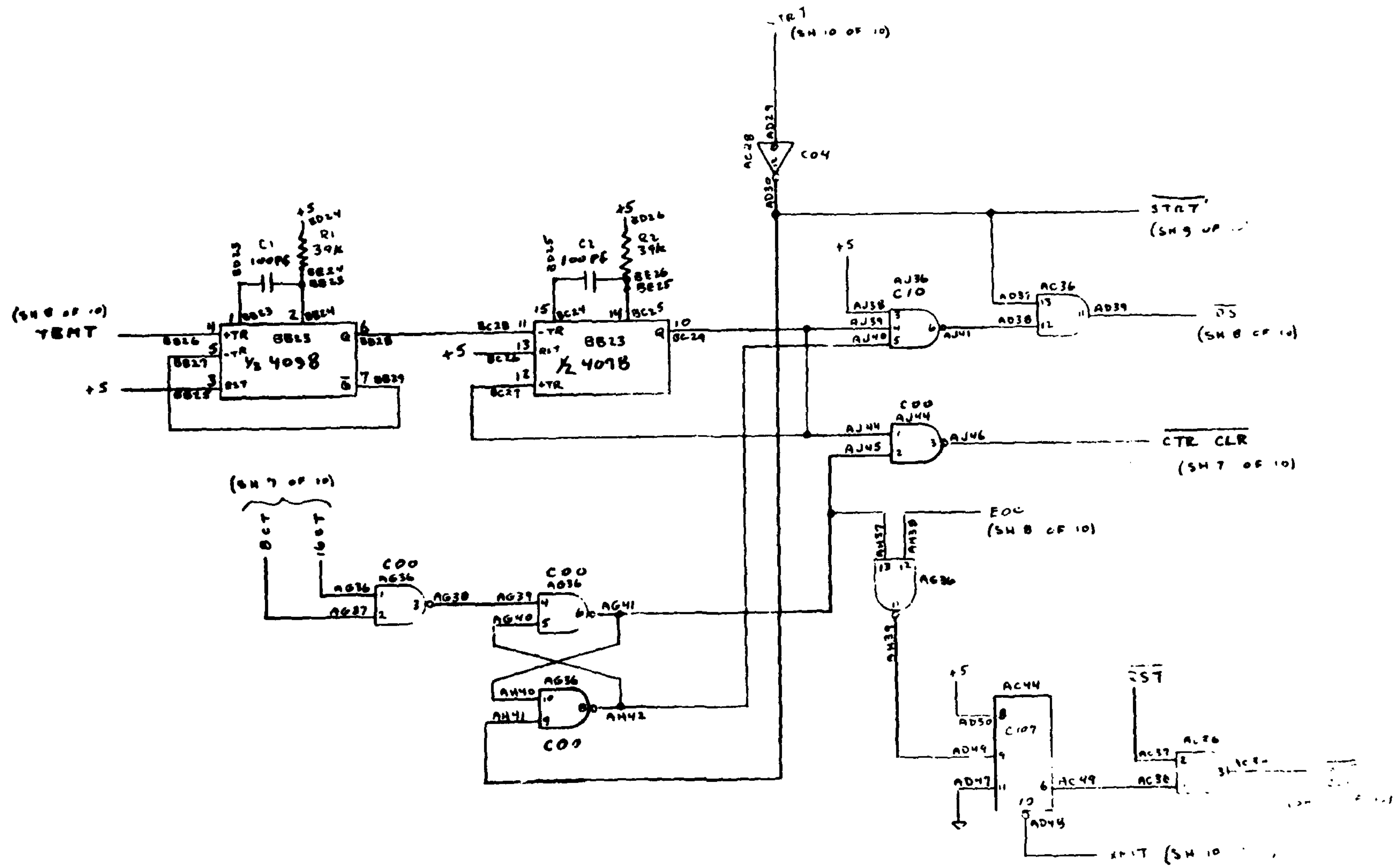


Figure 4-12. JAR/T Load Generator Schematic Diagram

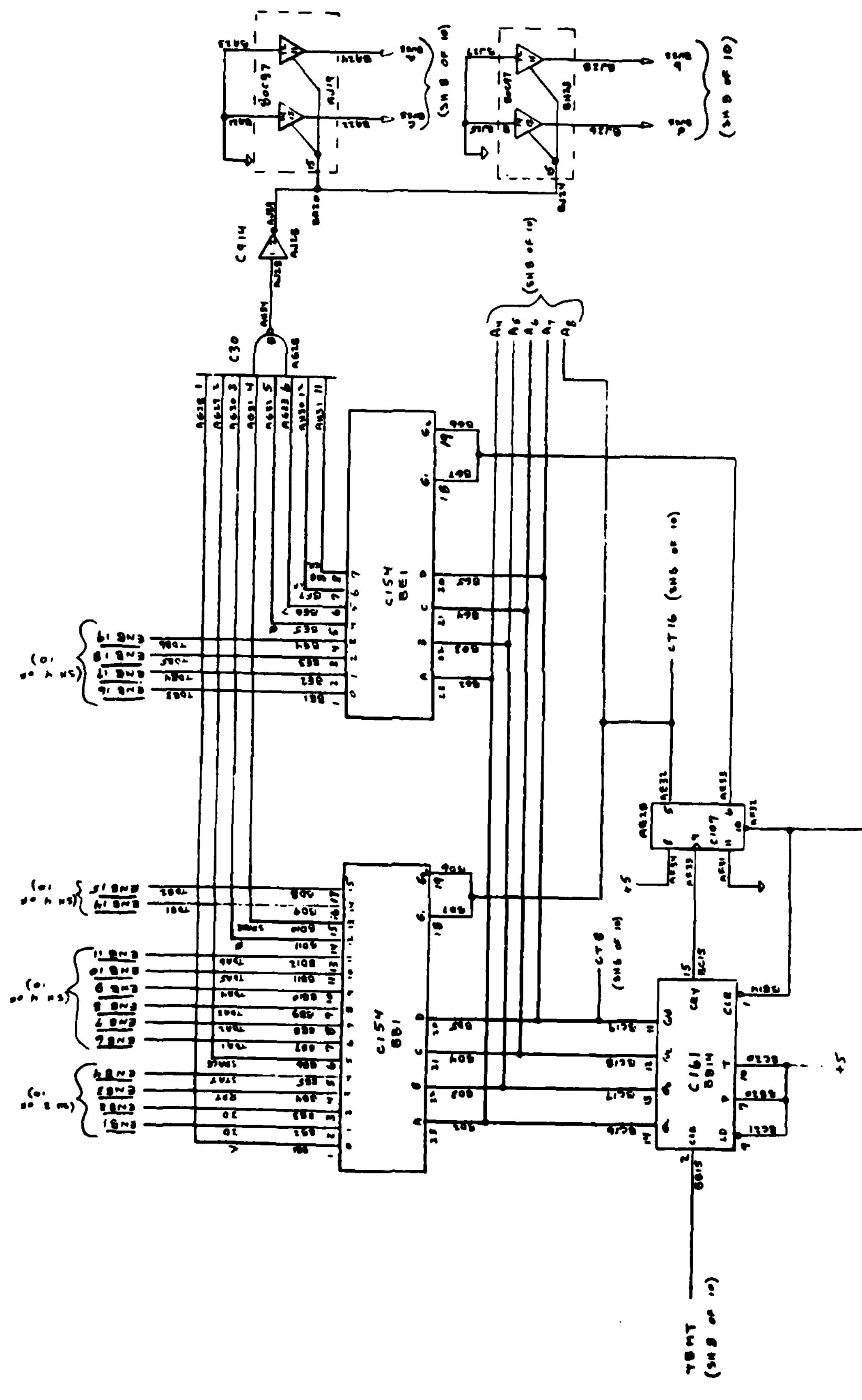


Figure 4-13. Gate Enable Schematic Diagram

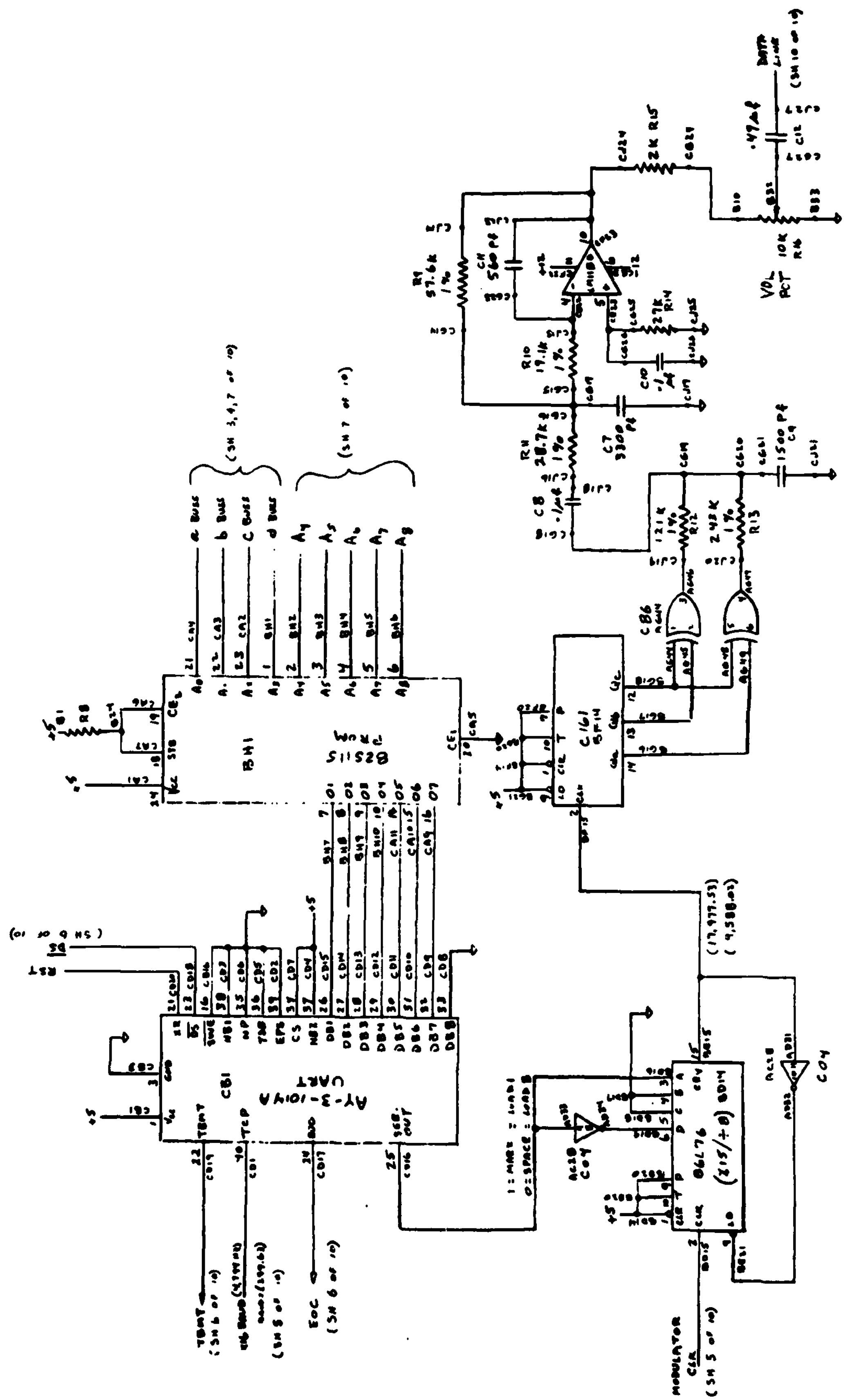


Figure 4-14. Data Link Generator Schematic Diagram

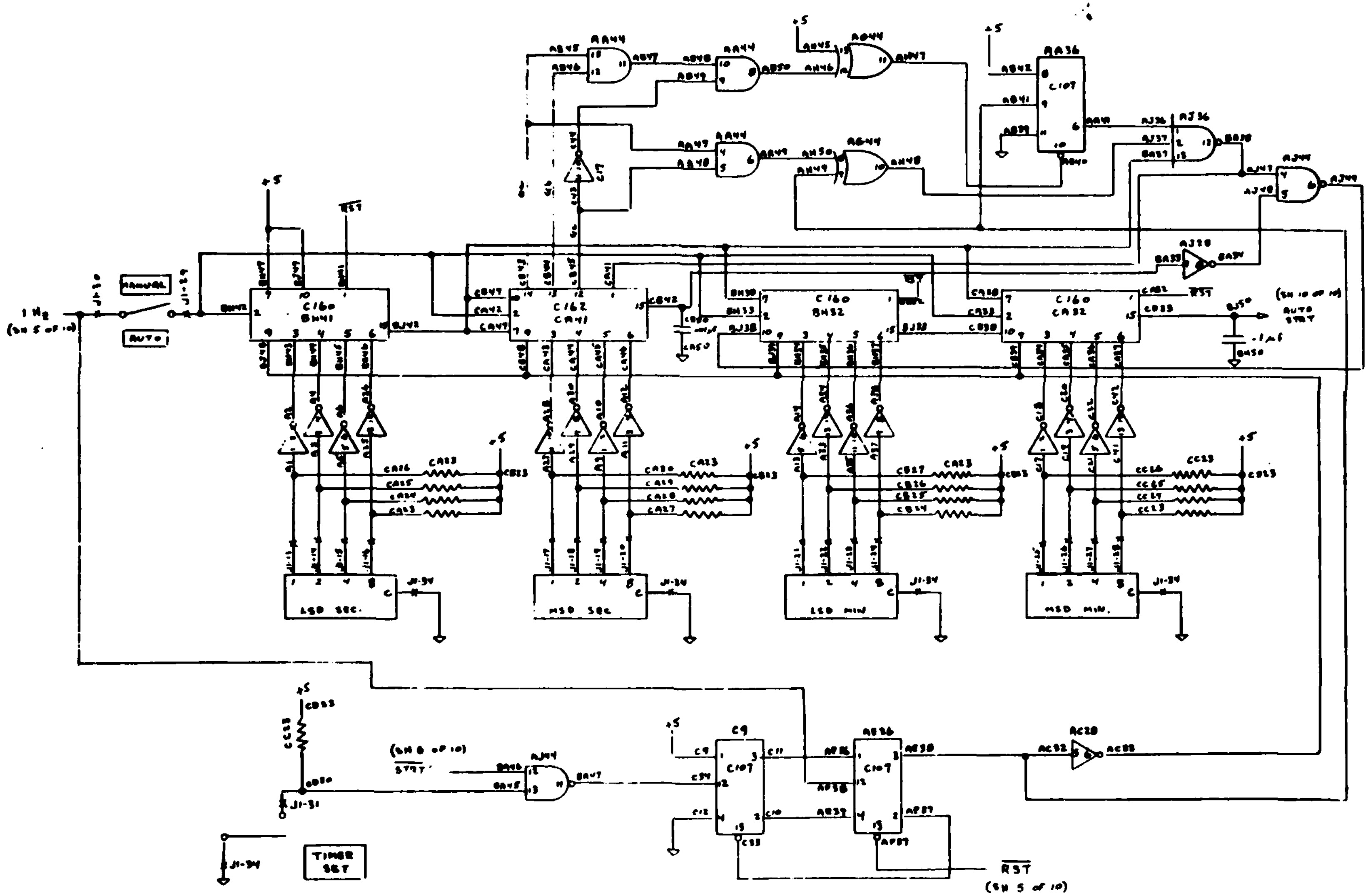


Figure 4-15. Interval Timer Schematic Diagram

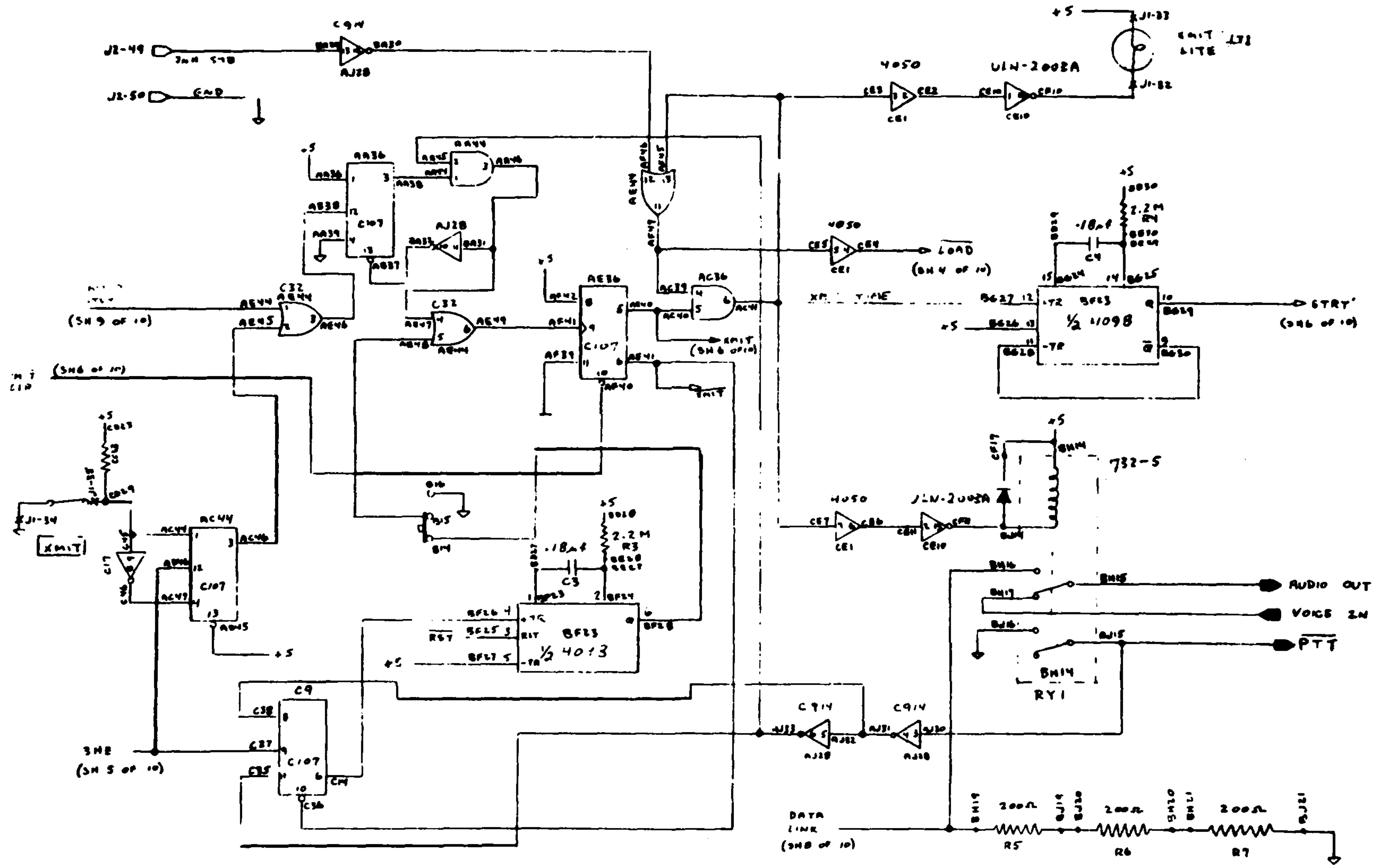


Figure 4-16. XMIT Control Schematic Diagram

Section V. DISASSEMBLY

5-1. GENERAL.

5-2. This section contains disassembly instructions for the Loran C Telemetry Unit to the extent required to remove major assemblies. For reassembly, use reverse procedure.

5-3. DISASSEMBLY PROCEDURE. (See figure 5-1.)

5-4. Use the following procedure to remove and replace the Triton VHF-FM transceiver from the LTU:

a. Disconnect all cables going to or from the transceiver.

b. Release snap fastener on each side of mounting tray, pull forward on transceiver and lift free.

c. To replace transceiver in mounting tray, slide transceiver into mounting tray, making sure two screws at rear engage plastic guide holes in rear of mounting tray. Engage snap fasteners and snap closed.

d. To remove mounting tray, remove transceiver, as above, remove two screws attaching top LTU cover to rear of housing, slide cover out of housing and remove three screws and nuts securing mounting tray to cover.

5-5. To remove interface from LTU, use the following procedure:

a. Remove eight screws securing rear panel to LTU housing.

b. Pull rear panel and bottom shelf containing interface assembly out to clear housing.

c. Remove four screws, spacers, nuts, lock washers and flat washers securing interface assembly to bottom shelf and remove interface assembly.

5-6. To remove 708 Loran receiver from LTU, use the following procedure:

a. Remove eight screws securing rear panel to LTU housing.

b. Pull rear panel and bottom shelf containing interface assembly out to clear housing.

c. Remove four nuts, lock washers and flat washers securing receiver to middle shelf and remove receiver.

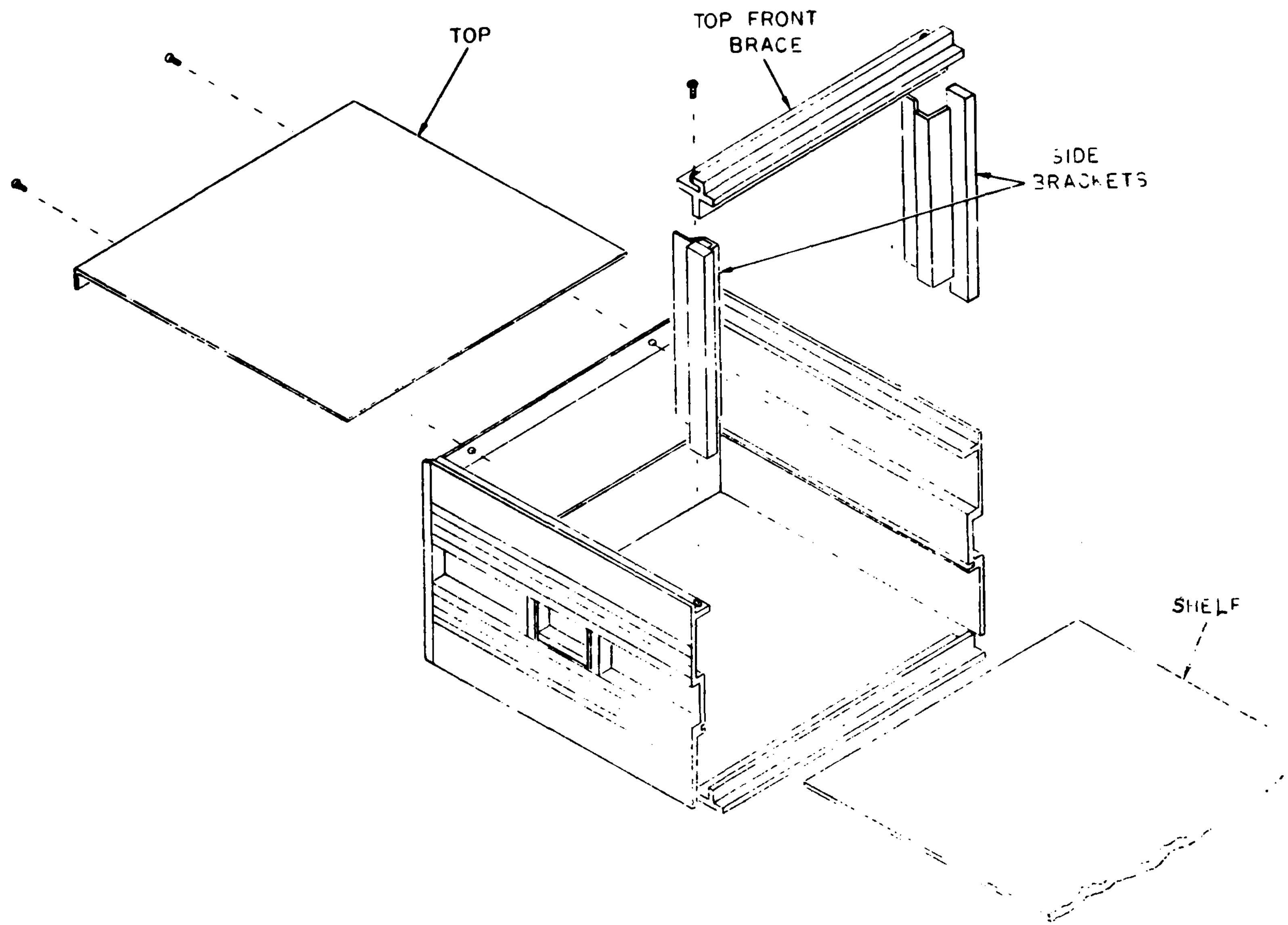


Figure 5-1. Disassembly Diagram

AD-A089 074 COAST GUARD WASHINGTON DC OFFICE OF RESEARCH AND DEV--ETC F/G 17/7
LORAN- C DISPLAY SYSTEM TEST REPORT.(U)
JUL 80 T M DROWN
UNCLASSIFIED USCG-D-47-80 NL

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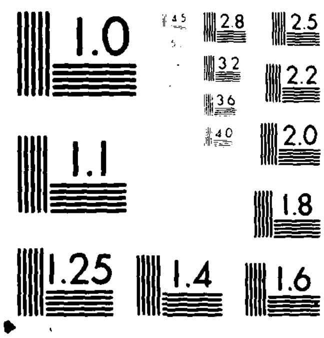

MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS 1963-A

GLOSSARY OF TERMS

A_4	An address line of the Prom (chip BH1). Corresponds to the LSB+4 of the Prom address.
A_5	An address line of the Prom (chip BH1). Corresponds to the LSB+5 of the Prom address.
A_6	An address line of the Prom (chip BH1). Corresponds to the LSB+6 of the Prom address.
A_7	An address line of the Prom (chip BH1). Corresponds to the LSB+7 of the Prom address.
A_8	An address line of the Prom (chip BH1). Corresponds to the LSB+8 of the Prom address.
a Buss	An address line of the Prom (chip BH1). Corresponds to the LSB of the Prom address.
b Buss	An address line of the Prom (chip BH1). Corresponds to the LSB+1 of the Prom address.
c Buss	An address line of the Prom (chip BH1). Corresponds to the LSB+2 of the Prom address.
d Buss	An address line of the Prom (chip BH1). Corresponds to the LSB+3 of the Prom address.
Audio Out	The Audio (voice from the microphone or the data link message) going to the VHF-FM radio telephone.
Auto Strt	The start transmission pulse from the interval time. (Auto Start)
$\overline{\text{CTR CLR}}$	The low level pulse that clears the line counter to zero. (Counter Clear)
Data Link	The modulated data, in serial form, ready for transmission.
$\overline{\text{DS}}$	The low level strobe that loads data into the UAR/T and initiates transmission. (Data Strobe)
EOC	A high logic level at the end of a character transmission. Low while transmission is in progress. (End of Character)

GLOSSARY OF TERMS - Continued

$\overline{\text{ENB X}}$	One of 24 lines that steer (enable) each line of parallel data to the Prom for ASCII conversion. ($\overline{\text{ENABLE X}}$)
INH STB	A strobe from the TDL-708 indicating that the TD data is not stable when high. (Inhibit Strobe)
$\overline{\text{LOAD}}$	The pulse used to Load the TD holding register from the TDL-708.
Modulator Clk	The basic clock frequency of 143,820.23 Hz used to modulate the digital data bits.
$\overline{\text{PTT}}$	Push To Talk, low level when microphone button is pressed.
RST	Power-On-Reset, high level pulse.
$\overline{\text{RST}}$	Power-On-Reset low level pulse.
STRT'	A high level pulse used to start the data transmission.
$\overline{\text{STRT'}}$	A low level pulse used to load the interval counter.
TBMT	Transmitter Buffer Empty Flag from the UAR/T.
TD	Time Difference, TDL-708 Time Data.
Voice In	Audio from the microphone.
XMIT	A high level signal, high for the length of the data transmission.
$\overline{\text{XMIT}}$	A low level signal, low for the length of the data transmission.
$\overline{\text{XMIT CLR}}$	A low level used to clear the transmit FLIP/FLOP AE36.
X16 BAUD	A frequency of 16 times the Baud Rate, about 4,794 Hz.
1 Hz	A frequency of one Hertz.
3 Hz	A frequency of three Hertz.
8 ct	A count of 8, from line counter
16 ct	A count of 16, from line counter

APPENDIX B

LORAN-C DISPLAY SOFTWARE FUNCTIONAL SPECIFICATION

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APPROVED

Prepared for

U. S. DEPARTMENT OF TRANSPORTATION
Transportation Systems Center
Kendall Square
Cambridge, MA 02142

Prepared by

INPUT-OUTPUT COMPUTER SERVICES, INC.
689 Concord Avenue
Cambridge, MA 02138

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1.0 GENERAL INFORMATION

1.1 Summary

With the increases in vessel traffic, in vessel size, and in the number of vessels carrying hazardous cargo in ports and waterways of the U. S., there has been a corresponding increase in the likelihood of casualty occurrence and in the possibility of injury and damage to persons, vessels, harbors, and the environment resulting from these casualties. The Coast Guard, which is responsible for the safety of the waterways, requires effective techniques for vessel traffic management which will reduce casualty probability without derogating the traffic handling capability of the harbor or waterway.

An evaluation of vessel tracking using telemetered LORAN-C time differences will be carried out in San Francisco Bay, California. The evaluation will be conducted using a computer analysis of the positions derived by LORAN-C compared to reference positions and will include a demonstration of a tracking display. The LORAN-C information will be transmitted in digital format on VHF-FM voice communications frequencies to a base station where the signal will be demodulated and the information simultaneously stored on floppy disk and displayed on a geographic display of San Francisco Bay. The data collected will be analyzed after the demonstration is completed.

1.2 Environment

The Transportation Systems Center is responsible for systems engineering under the sponsorship of the U. S. Coast Guard. The developer of the software is IOCS. The user of the software is the U. S. Coast Guard. The computer center where the program will be run is the Sensor Tracking Test System in San Francisco.

1.3 References

a) LORAN-C Display Software Statement of Work (September 14, 1977).

b) LORAN-C User Handbook (U. S. Coast Guard, Department of Transportation).

C) LORAN-C Time Difference to Latitude/Longitude Flight Module Analysis (February 22, 1972).

d) Federal Information Processing Standards Publication (Pub. 38), (February 15, 1976).

e) RT-11 System Reference Manual (DEC-11-ORUGA-C-D, DN1, DN2).

f) PDP-11/34 Processor Handbook (1976).

g) PDP-11 Peripherals Handbook.

h) Tektronix PLOT-10 Terminal Control System User Manual (070-2241-00).

i) Tektronix PLOT-10 Terminal Control System, System Manual (070-2242-00).

j) Tektronix PLOT-10 Terminal Control System Verification Routine (070-2266-00).

k) RT-11 Software Support Manual (DEC-11-ORPGA-B-D, DN1).

l) Tektronix Interactive Buffer for 4014/4015 Terminals (CM 018-0120-00).

2.0 REQUIREMENTS

2.1 Program Description

The following is a brief description of the functions that the LORAN-C Display Software (LDS) will perform. The display software will accept digital messages from up to eight vessels which have either a Coast Guard LORAN-C telemetry unit or a TDL-424, Airborne Navigator, installed on board. The digital messages contain position information which will be processed and displayed on a geographic map. These messages from each vessel will be stored for later use.

The LORAN-C display will have a number of additional features that relate to the position monitoring function such as:

- Measure range and bearing.
- Determine latitude and longitude.
- Zoom-in/zoom-out on geographic maps.
- Indicate a position by entering latitude and longitude.
- Display the stored positions of selected vessels.
- Operator annotation of the display.
- Provide an identification header for each vessel whose positions are displayed.

The software will incorporate several additional functions that will provide extra flexibility to the system:

- Send digital messages and valid operator messages to a separate data collection system.
- Provide an I/O port for a remote terminal.
- Provide a port for inputting LORAN-C time difference information to be used for differential correction.
- Provide a means by which a LORAN-C telemetry unit can be used as a benchmark for differential applications.
- Provide operator selection of all functions.
- Use step-by-step prompting techniques to lead the operator through each function.
- Provide software safeguards so that an operator cannot inadvertently modify the program.

2.2 Program Functions

2.2.1 The executive routine for LDS is OCCI. It initially receives control immediately after LDS initialization. Once it gets control it never relinquishes it until it transfers control to system shutdown. It processes all operator requests by calls to various subprograms.

2.2.2 A subprogram that generates the large map of San Francisco Harbor and adjacent areas, created by the government supplied map digitizer, will store this map on the "floppy" disk. The map will be subdivided logically into a number of submaps. LDS software will be able to display these submaps on the Tektronix 4014-1 along with target vessels and annotations when requested by the operator. Also, the latitude and longitude of any point or the range and bearing of any 2 points on a map may also be displayed.

2.2.3 Once the proper programs are in memory, the system initialization function initializes all run time data bases (such as pointers and I/O buffers) at start up time.

2.2.4 The system recovery function saves all the relevant pointers and buffers in the event of a system shut down, so that all the relevant data may be recovered for the next system start up.

2.2.5 The data base management subsystem will handle the pointers, storage buffers, and general updating of blocks of data.

2.2.6 The LORAN-C Driver and Interrupt Handler function performs the following: it manages reception of the data from the LORAN-C and TDL-424 telemetry units and handles interrupts from these units. Invalid messages are stored in an error file. Certain precautions have been taken to minimize the loss of messages in the event of a system shutdown.

2.2.7 The display driver/interrupt handler function handles transmission of data to the Tektronix 4014-1 and/or the Silent 700 and handles interrupts from these two devices.

2.2.8 The LORAN-C tracker function will utilize the LORAN-C conversion equations to track moving vessels. LDS uses software developed at TSC to convert from time delays to latitudes and longitudes.

2.2.9 The Tektronix graphic display function will display current vessel positions, past vessel positions (track history), and past vessel motion (playback), as well as a menu, table of vessels and I.D.'s, clock time, and scratch pad area for latitudes, longitudes, range and bearing, and for echoing of the selected command as well as a list of possible subcommands.

2.2.10 Time of Day function provides the real time displayed at the top of the scratch pad area.

2.2.11 The man/machine interaction encompasses any interface between the operator and the Tektronix 4014 or Silent 700. These include the operator attempting to command the LDS using the cursor, the Tektronix keyboard, or the Silent 700 keyboard, as well as the LDS response to the operator, when he issues a command.

2.2.12 The System Calibration function will enable the operator during initialization to calibrate the LORAN-C grid with the government supplied LDS map.

2.3. Program Performance

2.3.1 Accuracy

a) Mathematical

- The error in the coordinate equations themselves with exact inputs is approximately one foot. The errors introduced by quantization of LORAN-C time delay (TD) inputs to .1 of a microsecond are uniformly distributed between 0 and the gradient/10. In the San Francisco area, the gradient for the three slaves varies between 930 and 1250 feet/microsecond, hence, quantization level errors are a maximum of 125 feet, but in practice exhibit a mean error of about 50 feet. The crossing angles for the slaves range around 120 to 130 degrees. Since these quantitative level errors are a function of gradient, they are site dependent.

- Errors due to computation of range and bearing are negligible.

- Accuracy of plotted position. For map presentation usage, there are 3120 by 3120 addressable points on the CRT. A point is displayed with a possible position error of at most one half grid unit in either direction. This results in a position error of up to 0.846 feet per mile of presentation. For San Francisco Harbor, the maximum viewing area of any given presentation has been chosen as

60 miles by 60 miles. Therefore, the resolution of such a presentation would be accurate to 50.8 feet in latitude and longitude. It should be noted that this value is almost equal to the mean quantization error mentioned on the previous page.

b) Transmission

- LORAN-C Input

  Data transmitted from the LORAN-C telemetry unit have the format shown in Figure 2-1. Resolution of LORAN-C receivers is to the nearest tenth of a microsecond.

- Interdata 8/16 Output

  The output to the Interdata 8/16 (8/16E) is identical to the LORAN-C input to the PDP-11/34 (see Figure 2-1).

2.3.2 Validation

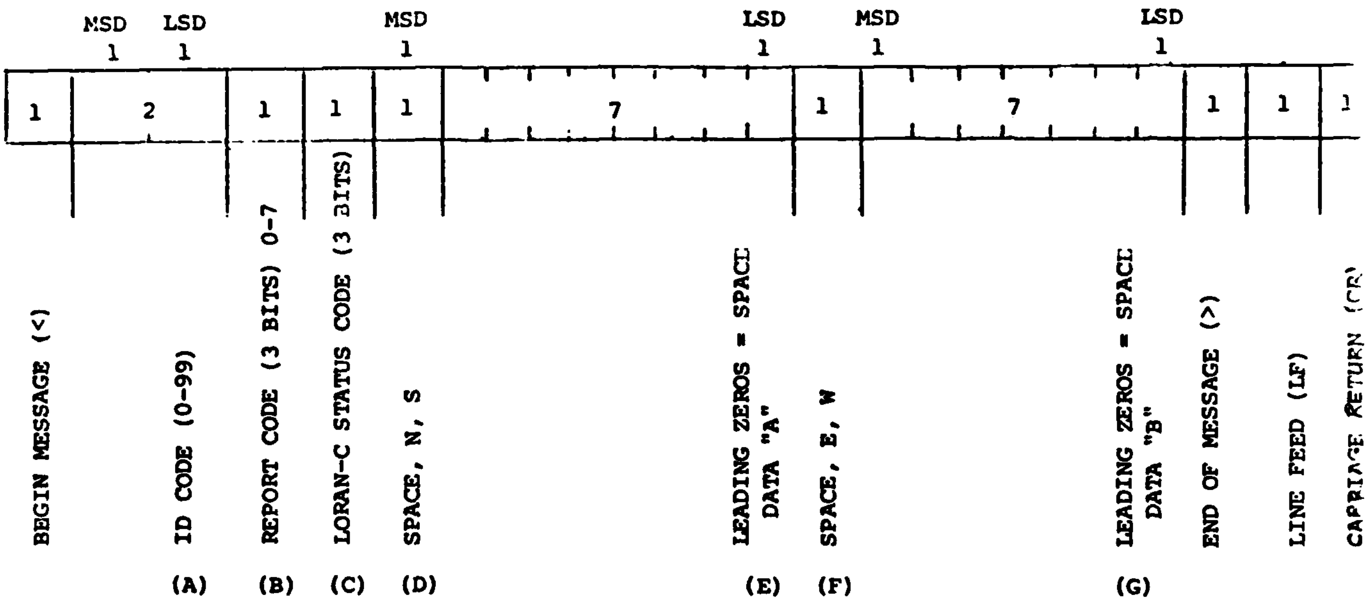
When an invalid LORAN-C message is transmitted to the PDP-11/34, an error message code is generated. Table 2-1 indicates the various error codes and errors.

2.3.3 Timing

a) The disk access time is 483 msecs.

b) The CRT transmit time is approximately 9600 baud.

ASCII CODE, 10 BIT-START, 7 DATA, 1 PARITY, 1 STOP



1. For messages generated by LORAN-C Telemetry Equipment
   - A. The ID Code will be assigned by thumbwheel
   - B. The Report Code will be assigned by thumbwheel
   - C. The LORAN-C Status will be assigned by 2 position switch: Position 1 - Valid TDS (000); Position 2 - Invalid TDS (111)
   - D. Use ASCII Code for space
   - E. There will only be 6 digit resolution of TDS
   - F. Use ASCII Code for space
   - G. Same as 1 (E) above

2. For message generated by TDL-424
   - C. LORAN-C Status can be one of 2 messages: 1. (111) - invalid; 2. (000) - valid
   - D. Time delays indicated by space
     Lat/Long indicated by "N" or "S"
     Invalid message for "L" or "R"
   - E. Latitude }
   - G. Longitude }

Degrees	Minutes	Hundreths of a minute

FIGURE 2-1: Digital Message Format

TABLE 2-1: Verify LORAN-C Error Codes

0	-	No error
1	-	Parity or start/stop error
2	-	No begin transmission character
3	-	Twenty four characters not transmitted
4	-	Transmission not terminated by carriage return
5	-	Invalid ID code - does not match File Table ID entries
**6	-	Invalid report code
7	-	Invalid status code
8	-	Field D not SPACE, N or S
9	-	Invalid longitude range
10	-	Field F not SPACE, E or W
11	-	Invalid latitude range
12	-	No EOM in transmitted message
13	-	No line feed in transmitted message
14	-	TD1 out of range
15	-	TD2 out of range

** Report codes to be defined later.

c) The character transmission and reception rate on the Silent 700 is 1200 baud.

d) The data is transmitted to the Interdata 8/16 at a rate of 9600 buad.

e) Since each LORAN-C telemetry unit takes approximately .8 secs. to transmit a message and since there may be as many as 8 such units, we require at least 8 secs. = 8(.8) + 1.6 secs. to pack messages from the LORAN-C telemetry unit onto the disk.

2.3.4 Flexibility

a) Modularity (Structured Approach)

The LORAN-C Display Software is being designed by utilizing a structured top down approach and by modularizing tasks as much as possible. Modularity will permit ease of modification to the LORAN-C Display Software.

b) Levels of Differential Correction

There are 3 levels of LORAN-C differential correction techniques.

- For the purposes of map calibration, there are 2 static correction factors (1 Δ correction for each time delay). These are computed by locally averaging the correction factors for a number of calibration points on the map.

- There is a short term propagation error due to such disturbances as weather conditions, which may cause the grid to shift. Consequently, the LORAN-C Display Software needs a dynamic correction for computing latitude/longitude. This will be an option which may be activated or deactivated by the operator.

- There is an equipment correction factor. Depending on the manufacturer of the LORAN-C device, there may be differences in data output from a LORAN-C unit. This correction factor may be added to compensate for these differences.

3.0 OPERATING ENVIRONMENT

3.1 Equipment Configuration (see Figure 3-1)

3.1.1 Processor

The PDP-11/34 is prewired to accept additional memory and standard peripheral device controllers including communications interfaces, mass storage controllers, etc. The PDP-11/34 computer has the following features:

- Single and double operand instructions.
- Hardware multiply and divide instructions.
- 16 bit word (2 eight bit bytes) direct addressing of 32K words or 64K bytes (K=1024).
- Parity detection on each eight bit byte.
- Word or byte processing instructions.
- Stack processing enabling ease of interrupt handling and subroutine arrangement.
- Direct memory access for peripheral devices.
- 8 general purpose registers used interchangeably for accumulators or address generation.
- Automatic priority interrupt-four line multi-level system permits grouping of interrupt lines according to response requirements.

- Vectored interrupts-fast interrupt response without device polling.
- Power fail and automatic restart-hardware detection and software protection for fluctuations in the AC power.
- Automatic bootstrap loader-automatic starts from a variety of peripheral devices.
- Self-test feature-ROM hardware automatically performs diagnostics on the CPU and memory.

3.1.2 Dual Floppy Disk (RX-11/BA)

- Data transfer at 18 microsec. per byte.
- 77 tracks, 26 sectors/track, 128 bytes/sector.
- Track seek time of 10 to 760 msec. + 20 msec. head settling time.
- 256,256 byte capacity on each of the two diskettes.

There are two major limitations to the RX-11. The average access time is 483 msec., and disk life is reduced due to the fact that there is physical contact between the heads and the disk surface. Disk failure can be expected after a million passes over any single location.

3.1.3 I/O Terminal (Tektronix 4014/1)

a) 128 ASCII keyboard characters including upper and lower case English character set and 32 control characters.

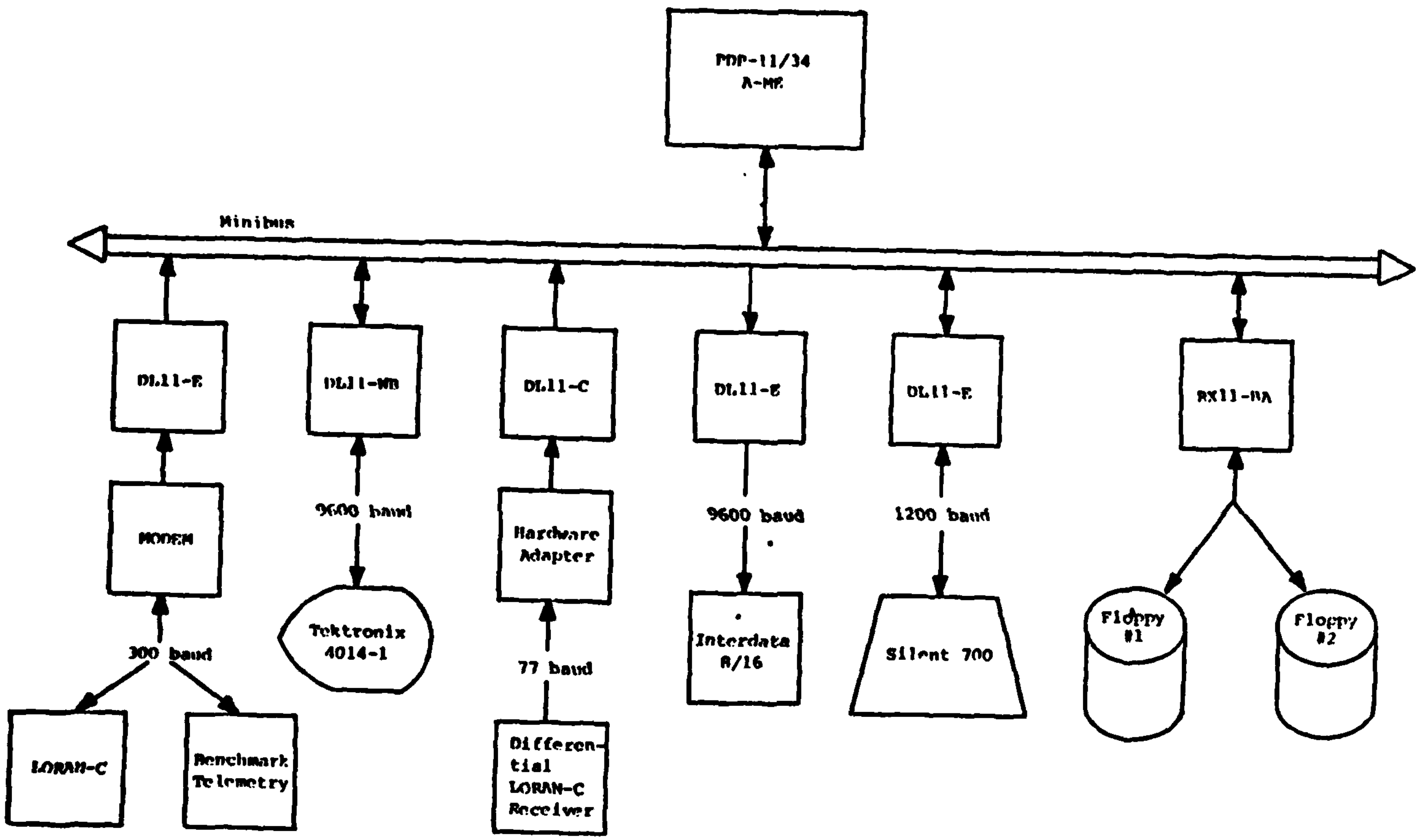


FIGURE 3-1: Hardware Diagram

b) All ASCII characters can be displayed in four sizes. The smallest yields 64 lines of 133 characters each, and the largest 35 lines of 74 characters.

c) Graphical capabilities include 4096 x 3120 addressable points on the 14.5 x 10.9 inch screen, graphical interaction by means of a joystick-controlled cross hair image, and limited refresh capability in addition to the normal storage mode of graphical display. A 3120 x 3120 area of the screen will contain the map display while the remaining 976 x 3120 area will contain the real-time clock, "scratch pad," menu instructions, and vessel ID.

d) Data is transferred from computer to terminal at 9600 baud. Alphanumerics are written to screen from the refresh buffer at 4000 characters per second, and a single graphics instruction from either computer or refresh buffer is executed at a rate of 12000 cm/sec.

e) Pertinent limitations are as follows:

(1) Images left stored on screen for more than fifteen minutes at a time, or restored on screen many times in exactly the same location, will render the involved phosphors insensitive.

(2) Although the refresh buffer holds 1024 characters, only about 480 cm of vectors or 160 characters can be refreshed without flicker.

(3) The refresh buffer cannot be randomly accessed. Change to any data currently in the buffer requires either rewritting the entire contents (at 9600 baud) or sending backspace characters to get rid of the buffer contents back to the datum to be changed and rewriting from that point. In both procedures, the refresh image is absent from the screen until the rewriting is finished.

(4) Refresh images must first be stored for them to appear on any hardcopy.

(5) The graphics cross hair cannot be displayed simultaneously with refresh images.

(6) Erasure of stored images creates a bright flash followed by about a second's delay before it is made available again.

(7) Tube life is about 1000 hours.

3.1.4 The DL-11 series of asynchronous single line interfaces handle full or half duplex communications between a wide variety of serial communication channels and a PDP-11 computer.

With such an interface, a PDP-11 computer can communicate with a local terminal such as a console teleprinter with a remote terminal via data sets and private line or public switched telephone facilities or with another local or remote PDP-11 computer.

The DL-11WB E/A interface is linked to the Tektronix 4014-1. The DL-11WB E/A interface is a combination of the DL-11W and DL-11B interfaces. Thus, it meets the interface specifications of EIA standard RS232C and CCITT Recommendation V24, and handles either local or remote (data only) communications for 8 level code devices. Also, it is a serial line interface and real time clock. It translates parallel information to serial information (required by a communication device) and translates serial information to parallel information (required by the processor).

3.1.5 The DL-11E interface meets the interface specifications of EIA and CCITT. The interface gives the user a full range of data rates and complete data set control for remote communication with either a terminal or another PDP-11 computer. There are three DL-11E's; one is interfaced to the I-8/16, one to the Silent 700, and one to the LORAN-C Modem.

3.1.6 The DL-11C is interfaced to a hardware adapter which is interfaced to the Benchmark Telemetry Unit.

3.1.7 LORAN-C Transmission to the PDP-11/34 CPU

The LORAN-C data transmission to the PDP-11/34 CPU is effected using the following hardware components.

a) A Telemetry unit having the following features:

(1) Compatible with the narrow band VHF-FM (150-160 MHZ) communications equipment currently used by the Coast Guard.

(2) Operate as a voice communications transceiver.

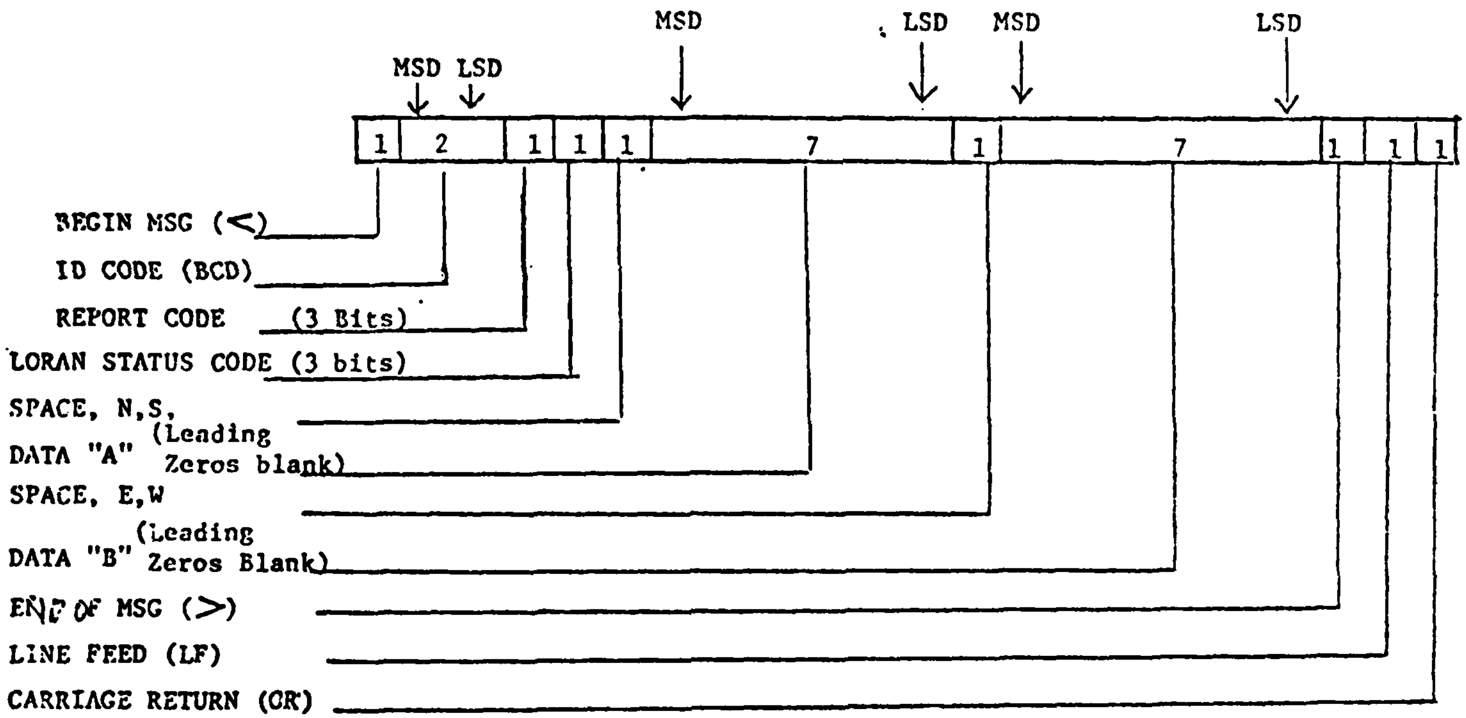
(3) Operate as a data link transmitter for transmitting an asynchronous digital message at a rate of 300 bits per second.

(4) Use ASCII format in the digital message with one start bit and one stop bit for each ASCII character.

(5) Generate a serial digital message which includes identification data, LORAN-C receiver status, and two LORAN-C time differences. The digital message will contain the same number of information bits as the digital message generated by the LORAN-C Airborne Navigator (TDL-424), including carriage return and line feed, and will be structured so that the two digital messages are identical, or as a minimum compatible, in information sequence format. Figure 3-2 shows the LORAN-C transmitted data.

(6) Inhibit data transmission automatically. when a voice transmission is made. A complete data transmission will be made immediately upon completion of each voice transmission and timing of the interval between data transmissions will begin with this data transmission.

(7) Manually inhibit data transmission.



STANDARD: BELL 202 TONES
4 cycles (1200 Hz= MARK (1)
7 1/3 cycles (2200 Hz = space 0)
BAUD LINE 300 chars/sec

FORMAT: ASCII, 10 Bit
1 start , 7 data,
1 parity, 1 stop

MSG Length: 24 chars
.8 sec

(33.3 msec/char)

FIGURE 3-2: Proposed ASCII Data Link

(8) Automatic transmission of a digital message at selected intervals over the range of two seconds to fifteen minutes.

b) Transceiver

(1) Operate in the VHF-FM maritime mobile band.

(2) Provide a minimum of five pretuned, operator selected frequencies of operation.

(3) Provide 25 watts nominal power output.

(4) Crystal controlled or frequency synthesized with channel frequencies easily changed by a technician.

c) LORAN-C Receiver

(1) Automatic lock-on and tracking of a master and two secondary stations.

(2) Operator selection of the GRI and two LORAN-C secondaries whose time differences are to be included in the digital message.

(3) Front panel display of the selected LORAN-C secondary's time differences.

d) Power Requirements

(1) 115 VAC @ 60 cycles.

(2) 12/24 VDC.

e) Other Requirements

(1) Capable of use in automobiles and in vessels twenty (20) feet in length and longer.

(2) Provide antennas for each unit capable of installation a minimum of thirty feet from the telemetry unit. Provide cable and connectors.

(3) Provide, as a minimum, maritime mobile channels 16, 21, 22, 23, and 81 as operating frequencies of the transceiver.

(4) Each unit will have a different identification code which is included as the identification data in the digital message.

f) Modem

(1) Capable of connecting to a standard communications receiver or transceiver without disrupting normal operation.

(2) Capable of providing digital input to the 11/34 DL11-WB terminal interface.

(3) Modem characteristics are:

- Bell 202 tones
- 4 cycles (1200 Hz = Mark (1))
- 7 1/3 cycles (2200 Hz = space 0)
- Baud Line 300 chars/sec

3.2 Support Software

3.2.1 Map Digitizer

The map digitizer is run on a flight service machine using a 4012 with a large tablet. The map digitizer routine treats objects on a map as the coordinates of the points that represent these objects. Maps are generated off-line and external to the LDS (LORAN-C Display Software).

3.2.2 RT-11 Operating System

The following features of the RT-11 Operating System are used throughout the operation of the LDS.

- The RT-11 I/O queueing and dequeueing logic which transmits read/write requests to the handlers and activates the LDS designated completion routines at I/O completion.

- The RT-11 clock routine which maintains the time of day clock.

- The RT-11 Teletype Handler which controls the input and output to the Tektronix 4014.

- The RT-11 Floppy Disk Handler which controls all input and output to the floppy disks.

3.3 Interfaces

3.3.1 Operator at CRT (or TTY) and CPU (PDP-11/34). For details, see Section 4.0.

a) The operator inserts an ID code with a name. With each ID code there is associated the complete name of a vessel, inserted along with the ID code.

b) The operator may display all messages within a file in sequential blocks of data on the CRT, when requested by an operator. The complete vessel name and ID code shall appear as the header for each block of data.

c) The operator has the option of selecting the maximum number of erroneous messages he wants, before a warning message is issued by the LDS. If he does not select such a number, 300 will be used.

d) The operator may request a table display. In this case, the File Table, Map Table, and the encoded data are displayed with a time stamp for the most recent message corresponding to each vessel.

e) Using the Tektronix cross hairs, the user defines the center and extent of a viewing window on top on the map currently being displayed on screen. The area lying within the new window will then be magnified to the full size of the screen map area, increasing both detail and annotation if magnification is sufficiently great. LORAN-C tracking begins automatically.

f) Using the Tektronix cross hairs, the user defines the center of a new viewing window on the map currently being displayed. The size of the new window is defined by a zoom-out factor entered at the same time. If a significantly greater area is defined, it will be displayed at reduced resolution with less annotation. Tracking begins immediately.

g) The operator may select a predefined submap by entering a number corresponding to the submap. When the maps are first digitized, submaps would be set to correspond to frequently needed windows. Once the submap has been put on screen, the tracking begins immediately.

h) A playback function allows graphical playback of the data contained in any of 8 files. Five positions per vessel selected are displayed in refresh mode progressing through time at a rate up to a hundred times real time and in the order each position was received. The earliest of the five positions is deleted with each update. The operator may freeze the playback, back it up, and resume forward playback. During frozen playback, the data block identifier for the most recent position can be displayed and a hard copy can be made. Playback requires the operator to initially enter a time frame to be viewed and a time factor that determines the speed of the playback moticn on screen.

i) The track history function allows stored display of all positions contained in the selected files and which appear within the current map window. Every nth position, where n is a parameter inserted by the operator, starting with the most recent position, shall be annotated with the block identifier consisting of a leader, report code, and time of receipt of hours and minutes.

j) The operator may add temporary annotation to the map being displayed. The position is defined with the cross hairs and the notation may include any keyboard character. This function also allows deletion of annotation.

k) The operator may delete an ID code or vessel name and purge the associated data.

l) The operator may request the range in yards and bearing in true north and magnetic north between any two points on a specified map. A dashed line will be drawn between the two points selected. It will be deleted after the command is completed.

m) The operator may input a latitude and longitude in the scratch pad area, in which case, the corresponding point will be displayed on the displayed map if within the boundaries of the visible map. The inverse of this operation shall write the latitude and longitude of an entered point in the scratch pad area.

3.3.2 Floppy Disks and CPU

a) CPU Stores LORAN-C Digital Message on Disk

The LORAN-C digital message transmitted to the CPU is received by the LORAN-C Software Handler. The Handler recieves each transmitted character, verifies parity, start and stop bits and stores the character into a buffer. When the Handler recieves the carriage return character, it activates a LORAN-C Asynchronous Routine which inspect and validates the LORAN-C data within the buffer prior to writing it to a file on the second floppy disk.

b) CPU Stores a Map on Disk Along with the Annotation

Two utility programs (one that generates the data for the nin map displays - software to be supplied by TSC - and a utility program to generate the data for the map annotation) will be exercised before the LDS is executed. These utility programs will write their respective data to seperate disk files on the first floppy disk, one file for the geographic map and one file for the map's annotation data.

3.3.3 Handlers

The LDS uses six device handlers:

- Tektronix 4014-1 input/output handler
- Floppy Disk input/output handler
- LORAN-C input handler
- Differential LORAN-C Receiver Handler-BCD
- Silent 700 input/output handler
- Interdata 8/16 handler

The reader should familiarize himself with RT-11 I/O procedures by reading Chapter Five of Reference k. All of the six handlers are character interrupt driven which means the handlers cause the CPU to be interrupted each time a character is either transmitted or received by the central processor. The general functions of each of the handlers are:

3.3.3.1 Tektronix 4014-1

The Tektronix 4014-1 handler is contained within and controled by the RT-11 Operating System. A full description of its functional operation is given in Chapter 9, section 9.4.43 (see reference k).

3.3.3.2 Floppy Disk

The Floppy Disk handler is also contained within and controlled by the RT-11 Operating System. The LDS issues read/write completion commands specifying an input/output buffer and the number of characters to transfer. The handler notifies the LDS when the transfer completes by interrupting the LDS program and executing the directed completion routine.

3.3.3.3 LORAN-C

The LORAN-C input handler services read completion requests from the LORAN-C Asynchronous Routine (LAR) of the LDS. When the LAR issues a read/completion request, it specifies an input buffer address and that a maximum of 150 characters is to be delivered to the buffer. The LORAN-C handler, however, is programmed to ignore the count of 150 characters and terminate the read with completion if any of the following two events take place:

a) It receives a transmitted carriage return character.

b) It receives a begin message character that is not the first character transmitted for the current buffer.

For (b) above, the current read is terminated with completion and the begin message character becomes the first data character for the next read buffer.

3.3.3.4 Differential LORAN-C Receiver

The Differential LORAN-C Receiver operates similarly to the LORAN-C input handler with the exception that it is in BCD format. Data is continuously transmitted and is sampled under operator control.

3.3.3.5 Silent 700

The Silent 700 input/output handler services read with completion requests from the LDS software. The LDS software indicates that it is to be notified upon reception of a complete input message, or the reception of the eightieth character of the input message. The Silent 700 handler receives input characters and places the characters into the input buffer indicated by the LDS until it receives the carriage return character or a full buffer of eighty characters.

On the output side, the Silent 700 handler is directed by write completion commands to output a designated buffer to the Silent 700 hard copy. Transfer is by character count. The LDS software is notified when the transmission is complete.

3.3.3.6 Interdata 8/16

The Interdata 8/16 handler receives write completion requests from the LDS LORAN-C Asynchronous Routine that specify a buffer address and the number of characters that are to be transmitted to the Interdata 8/16. The handler extracts each character from the buffer and transmits it to the 8/16. As each character is successfully transmitted, it generates an interrupt, which enables the handler to select the next character for transmission.

3.4 Memory Requirements

3.4.1 Software Component Sizes

LORAN-C TDL-424 Handler	~ 250 words
Interdata 8/16 Handler	~ 200 words
Benchmark Telemetry Unit Handler	~ 250 words
Silent 700 Input/Output Handler	~ 250 words
LORAN-C Asynchronous Routine	~1,000 words
System Calibration	~1,000 words
Operator Console Command Interface	~ 500 words
Annotate Map	~1,000 words
System Shutdown	~ 400 words
Display Map	~ 500 words
Insert ID with Data Block	~ 600 words
Kill	~ 500 words
List All Messages in File	~ 800 words
Number of Error Messages	~ 200 words
Playback	~1,500 words
Select Map	~ 700 words
Table	~1,000 words
Zoom	~1,000 words
Track History	~ 400 words
Position Range and Bearing	~ 250 words
Inverse Position	~ 300 words
TOTAL	~13,600 words

3.4.2 Memory Data Base Sizes

9 x 256 word LORAN-C data buffer	=	2,304	words
2 x 256 word work buffers	=	512	words
File Table 9 x 14 words	=	126	words
Map Table 9 x 10 words	=	90	words
Encode Table 9 x 12 words	=	108	words
TOTAL	=	3,140	words

3.4.3 Total Memory Requirements

RT-11 Operating System	~	2,700	words
LDS Software Components	~	13,600	words
LDS Memory Data Base	=	3,140	words
Unforseen Expansion Requirements	~	4,000	words
TOTAL MEMORY REQUIREMENTS	~	23,440	words

4.0 DESIGN CHARACTERISTICS

4.1 Data Base

4.1.1 Logical Characteristics

a) LORAN-C Data File

The LORAN-C Data File (LDF) in Figure 4-1 is one contiguous file located on the second floppy disk. The file contains a recovery record and nine subfiles. Each subfile is composed of 48 consecutive blocks where the LORAN-C messages for a particular ID are stored. The 48 blocks have a capacity for storing 1024 LORAN-C messages. Figure 4-2 shows the format of a transmitted message and its encoded counterpart. It is the encoded message that is stored in the subfile corresponding to the LORAN-C ID. Each subfile is circular. Following the write of the last block of a subfile, the first block of the subfile becomes the next logical block to be written. The LDF is accessed using a File Table (FT) index contained in memory. Format of the FT and its corresponding File Table Entry, is given Figure 4-3. The File Table is written into the Recovery Record of the LDF each time a major event such as a change of ID or NAME occurs.

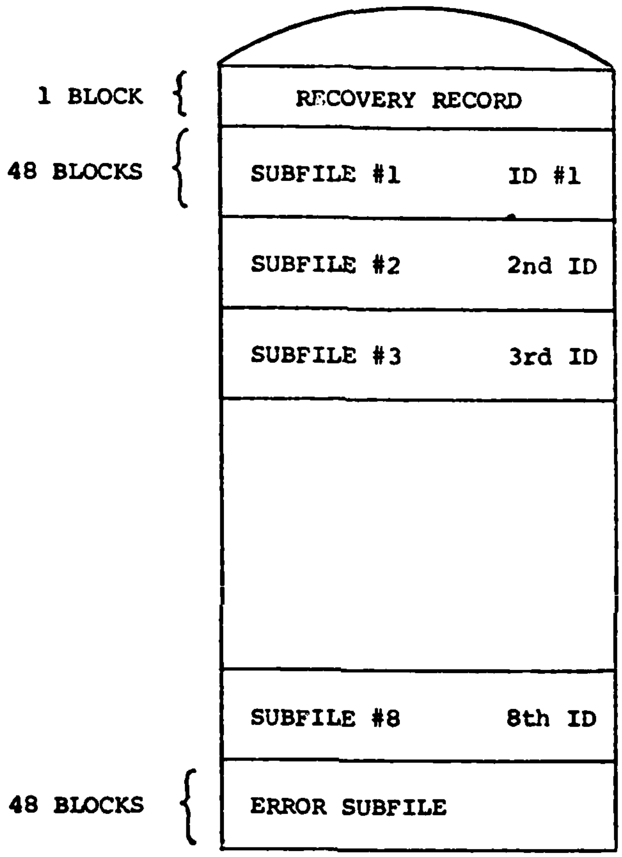


FIGURE 4-1: LORAN-C Data File (LDF)

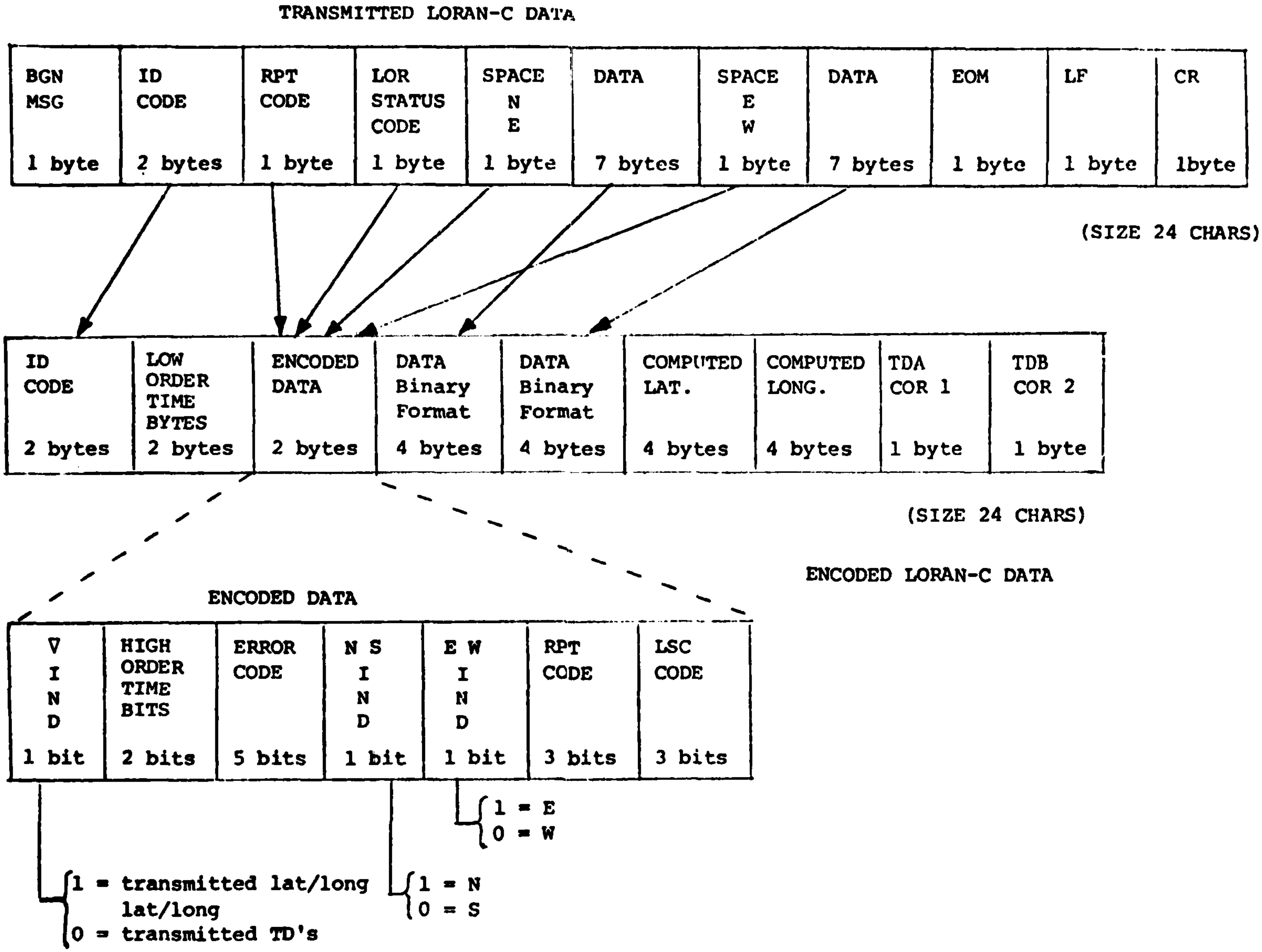


FIGURE 4-2: LORAN-C Transmitted and Encoded Data

FILE TABLE ELEMENT (FTE) 14 words

INDEX NUMERIC (1 word)	ID (1 word)	NAME (25 words)	ABS BEGIN BLOCK	CURRENT FIRST BLOCK	LAST BLOCK	CURRENT BLOCK NUMBER	BUFFER ADDRESS	OFFSET WITHIN BUFFER	NUMBER OF ENTRIES IN FILE	TD UNIT CORRECTION

FILE TABLE (F?)

1	4	NAME 4	
2	5	NAME 5	
3	3	NAME 3	
4	6	NAME 6	
5	2	NAME 2	
6	7	NAME 7	
7	1	NAME 1	
8	8	NAME 8	
9	ERR	ERROR FILE	

FIGURE 4-3: File Table and File Table Entry

b) Map File

The data for the map of the entire area to be covered by the LDS installation is stored in a contiguous direct-access file on the first floppy disk. The data is created using the map generation utility which allows the user to define submaps corresponding to frequently used viewing windows. As much geographic detail as can be accommodated on disk will be digitized.

c) Map Annotation Files

The map generation utility will also allow creation of permanent annotation which will automatically be put on screen when a map is displayed. Permanent annotation will permit line drawings as well as alphanumerics. Another file contains temporary annotation created by the operator during execution of LDS.

4.1.2 Physical Characteristics

a) Storage Requirements

First Floppy:	RT-11 System	51,200	bytes
	LDS Software	50,000	
	Annotation Files	+ 5,000	
		106,200	bytes
	Total Available Space	256,256	bytes
		- 106,200	
	Available for Map	150,056	bytes
		(~37,000 points)	
Second Floppy:	LORAN-C Data Files (9 files at 48 blocks each)	221,184	bytes
	Recovery Record	512	
		221,696	bytes
	Total Available Space	256,256	bytes
		- 221,696	
	Unused	34,560	bytes

b) Access Method

The LORAN-C Data File is accessed using the RT-11 Fortran subroutines; open, direct-access read/write, and close.

The map and annotation files are accessed using the PLOT-10 subroutines for open, read/write and close.

4.2 Operating Procedures

4.2.1 System Initialization

Prior to the first initialization of the LDS, the following utility programs are executed:

UTLLDF - which creates the LORAN-C Data File (LDF) and writes the FT to the recovery record;

UTLMPG - which generates the map and writes the MT to the LDF recovery record.

UTLANO - which creates the permanent annotation for the map.

The data for map and the corresponding annotation are written onto the first floppy disk.

When the recovery record is written to the LDF, along with the FT and MT, the initialization/ recovery indicator is written to indicate a calibration of the LDS is to be executed when the system is first initialized.

The LDS initialization first opens the LDF and reads the recovery record, the FT, MT, and initialization/recovery indicator into memory. Upon noting that the initialization/recovery indicator indicates a calibration, the LDS requests that the operator enter the following information:

a) Input Magnetic North variation

b) LORAN-C Input Parameters

c) Map Segment static correction factors

d) Establish base readings for Differential/Benchmark

Once the operator enters the required information, LDS enters its normal initialization phase. During the normal phase, the initialization/recovery indicator is altered to indicate the system is in normal operation. The recovery record containing the FT,MT, calibration information and initialization indicator is written back to the disk. An initial double buffered read is issued to the LORAN-C Handler activating LORAN-C input. A read is started for the alternate console device to enable input on that device. The system now reports that initialization is complete and awaits operator commands.

4.2.2 System Shutdown

During LDS system shutdown, the outstanding reads to the LORAN-C Handler are cancelled. The read to the alternate console device is deactivated and the initialization/recovery indicator is changed to a normal shutdown indication. The recovery record is written back to disk. Now if the system is reinitialized, the system will perform a normal initialization.

4.2.3 Recovery Initialization

Should the LDS system fail between the period of an initialization and before a system shutdown, when the system is next initialized, the initialization/recovery indicator will indicate the system failed during the operation of the system. If this is the case, the LDS initialization will enter recovery mode. In recovery mode, the FT pointers to the nine data files, specifically the current first block, and the current block number pointers, are repositioned. The repositioning is accomplished by reading each record of each file and sequencing on the ID and time stamp information. Once the repositioning has taken place, normal initialization procedures are followed.

4.3 Inputs

4.3.1 LORAN-C

Once the LORAN-C reads are started during initialization, the LDS LORAN-C Handler receives data a character at a time, interrupting the processor long enough to put each into a buffer. Eventually the LORAN-C completion routine transmits the completed message to the other computer, validates and encodes the message for use by the rest of the LDS and writes it to disk. Every character the 11/34 receives shall be transmitted to the I-8/16 in the sequence in which it arrives.

4.3.2 Operator Commands

The operator may enter any command on the system console (Tektronix 4014) or the alternate console each time an appropriate prompt is displayed on either. Commands operate asynchronously on both terminals with the limitations that graphics display commands can only be displayed onto the Tektronix terminal and that both terminals cannot simultaneously execute the same function. All command functions from both terminals can be dynamically terminated using the kill command.

4.3.3 Time of Day

The operator, through the Operator Command Interface, may reset the clock.

4.3.4 Error Diagnostics

Error diagnostic messages for erroneous operator interface instructions shall be displayed on the terminal that the request was generated on.

4.4 Program Logic

4.4.1 Logical Flow

The system can logically be thought of as two independently operating processes with the nine data base subfiles as their common interface (see Figure 4-4). The

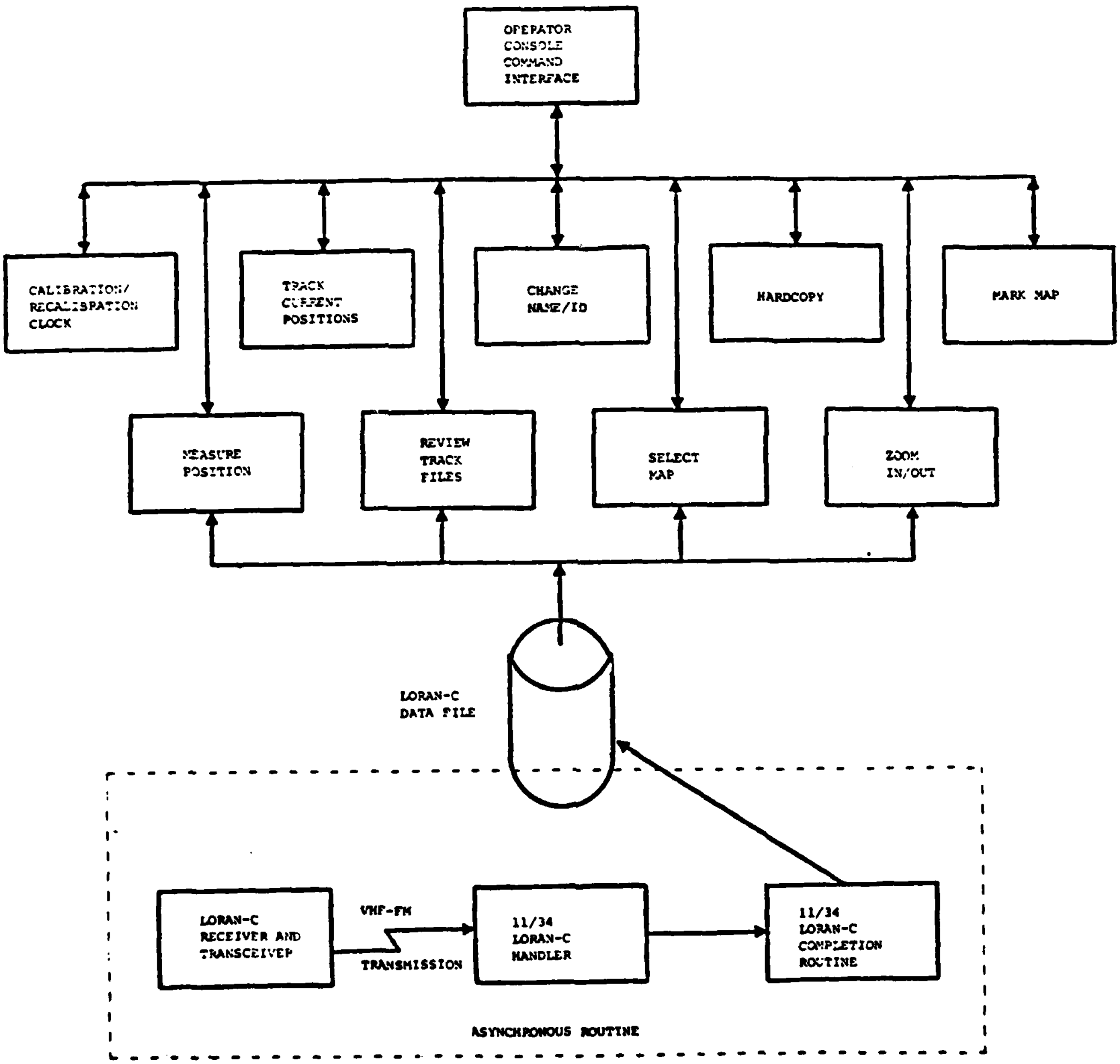


__FIGURE 4-4:__ LDS Logical Flow

is accumulated in disk files by the asynchronous routines, and the operator works on those files through the command interface.

4.4.2 The following sections give brief narrative descriptions of the major system operations.

4.4.2.1 Initialization

The Initialization software module is loaded with the initial loading of the LDS system. The Initialization software will be overlayed by the processing LDS system once the system is initialized. Initialization first opens the LORAN-C Data File and reads the Recovery Record into memory. The Recovery Record contains the File Table, the Map Table, Site Calibration Information and Initialization/Recovery indicator.

Initialization examines the Initialization/Recovery indicator to determine which of these initialization modes to perform:

(a) Calibration - this type of initialization is only performed when the LORAN-C Data File is first created or recreated. In this mode, Initialization requests that the operator key in certain information to complete table descriptions; such as map file names, etc., and particular site calibration information.

(b) Recovery Initialization - repositions the LORAN-C Data File current first block, and current block number pointers within the FT for each of the nine subfiles.

(c) Normal Initialization - Each of the two previous initializations, namely Calibration and Recovery Initialization, both complete their respective initializations by executing normal initialization. Normal Initialization sets the Initialization/Recovery indicator to a system active status and initiates the first read to the LORAN-C Handler and the alternate console device. Initialization now types out the initialization complete message and transfers control to the Operator Console Command Interface Module.

4.4.2.2 LORAN-C Asynchronous Routine

The LORAN-C asynchronous routine is activated by the LORAN-C Handler each time the Handler receives the transmission of a carriage return. The LORAN-C Handler is initially activated by the LDS initialization module. When the asynchronous routine receives control, it immediately requests another read from the LORAN-C Handler. Thus, the asynchronous routine self-perpetuates itself, insuring a read request is always outstanding within the LORAN-C Handler. The reads are only deactivated at System Shutdown.

A queued buffering system of great flexibility will be adapted for use by the asynchronous routine. The system incorporates a message buffer capable of storing eight messages, a 2-element "listhead," LORAVL, pointing to the first and last element still available for use in the message buffer, and a listhead, LOREAD, for each function to be applied to the message buffer: reading a message into the buffer from the LORAN-C telemetry and the TDL-424, transmitting the messages to the other computer, and encoding and storing each message on disk. The queued buffering system would allow all these functions to operate asynchronously. Initially, however, the four operations will be performed serially: a buffer element is "dequeued" from the LORAVL listhead and queued into the LOREAD listhead. LOREAD indicates the first and last elements in the buffer containing messages just read and outstanding. For this applications, reads are issued in pairs: when the first read is completed, it is queued in the XMIT listhead to indicate it is to be transmitted to the other computer. The message is encoded for writing to the floppy disk, another element is dequeued from LORAVL and queued into LOREAD. The second read is issued. If the first read has been dequeued from the XMIT listhead, the first message is dequeued from there and restored to the list of available elements in LORAVL. Note that in the message buffer, pointers are also stored to point to the next message in the group, with a pointer of zero signifying the last message in the group. For now, there will always be two messages in the group. Figure 4-5 is a snapshot of three listheads and the buffer at a random point in time.

LORAVL	LOREAD	XMIT
5	3	2
1	4	2

buffer address	pointers	
1	0	
2	0	
3	4	message
4	0	message
5	6	
6	7	
7	8	
8	1	

A pair of messages has just been read into buffer elements 3 and 4. The message in 3 is about to be queued for transmission to the auxilliary computer. Buffer element 2, meanwhile, has already been transmitted to the auxiliary computer and the element address is about to be restored to available status in LORAVL. Three will now be queued in XMIT replacing the two and transmission of the message in 3 awaited.

<u>FIGURE 4-5</u>: Queued Buffering

The LORAN-C input data is next encoded into a compact form to minimize the amount of disk space to store the information. The data is encoded into a memory buffer which is maintained in memory to permit fast access of the most current information for each of the eight target vessels.

The encoded data is next packed into the 256 word disk buffer that corresponds to the ID of the LORAN-C transmitted data. NOTE: If the transmitted data was found to be in error during the verification phase, the memory encode buffer used, as well as the 256 word disk buffer, are the buffers associated with the error subfile of the LORAN-C Data File.

When the encoded data is moved to the disk data buffer, the current offset pointer within the File Table Element (FTE) determines where the data will be placed into the buffer. As much data as will fit into the buffer will be packed into the buffer. Any data left over will be written into the beginning locations of the buffer after the previous buffer has been written to disk.

Each time an encoded data element is placed into the 256 word disk buffer, the entire contents of the buffer are written to disk using the current block pointers within the appropriate FTE. This is done to insure that if a system crash occurs, that only a limited number of LORAN-C transmitted messages will be lost to the system.

TABLE 4-1: Validity Checking

VALIDITY CHECKING PERFORMED ON LORAN-C TRANSMITTED MESSAGE:

1. Each message starts with a BGN and ends with a CR and is composed of 24 transmitted characters.

2. Each transmitted character has a start and stop bit and the correct odd parity. (This is checked by the LORAN-C Handler.)

3. ID Code must match a File Table Entry Code.

4. Only the base three bits of the Report Code are used (range 0 to 7).

5. Only the Base three bits of the LORAN Status will be used for LORAN-C transmitted messages. For TDL-424 transmitted messages only values for LORAN-C status are 000 for valid and any other value is invalid. Currently, the only status codes to be transmitted are 0 and 7.

6. The field preceeding the 1st time difference or latitude must be a space, N, or S character. (For northern latitude LDS will only accept N.)

7. If 6 above was a space, this field must contain a time difference whose magnitude is checked. Any other value is a latitude which undergoes a magnitude check.

8. The field preceeding the second time difference or longitude must be a space, E or W character. (For western longitudes LDS will accept only W.)

(Continued)

TABLE 4-1 (Continued)

9. If 8 above was a space, this field must contain a difference whose magnitude is checked. Any other value is a longitude which undergoes a magnitude check.

10. The next two characters must be EOM and LF.

4.4.2.3 Display Map Subroutine

Any LDS function requiring the display of a geographic area and its associated annotation will call this subroutine. The area to be displayed, the "window," is selected by the operator according to the procedures for selecting a submap, zooming in, or zooming out.

4.4.2.4 Track LORAN-C Positions Subroutine

Whenever LORAN-C positions are to be displayed in refreshable mode superimposed over a map, this subroutine will be called. Each position is represented by an appropriate identifying symbol which moves about the map according to current LORAN-C telemetry, when operating in tracking mode, or according to position histories when operating in playback mode.

APPENDIX C

2 DRMS CIRCLE CALCULATIONS

The position determined by the intersection of two Loran-C lines of position (LOP) is subject to error. This error is presumed to be random in occurence and therefore normally disbributed about a mean value for the position. The errors are caused by the shifting of the LOP's with time and can be expressed as a function of the deviation of the LOP's about their individual mean values. Accepted expressions of position error are derived from the standard deviations of the Loran-C LOP's about their mean values.

The 2 drms circle is one accepted expression of position error. The circle is constructed about a mean position value using a radius equal to two times the root mean square of transformed values of the standard deviations of any two LOP's. The basic expression is as follows:

$$2\ \text{drms} = 2(\sigma x^2 + \sigma y^2)^{1/2}$$

σ_x = Major Axis of Error Ellipse

σ_y = Minor Axis of Error Ellipse

The 2 drms circle defines the area in which between 95.4% and 98.2% of the individual position plots will fall when the same two LOP's are used repeatedly.[1]

In general, the area of actual position error is an ellipse. The only time the area of position error could be a circle is when the magnitudes of the standard deviations of two LOP's are equal. The error ellipse can be bounded by a parallelogram constructed of straight line segments which represent both the mean value of each LOP and the error caused by one standard deviation from each mean. Figure C-1 illustrates this general case. It can be seen that the two LOP's do not align themselves with the major and minor axes of the ellipse. In order to construct the 2 drms circle, values must be derived for the length of the axes. This is done through transformation using the expressions of Figure C-1.[2]

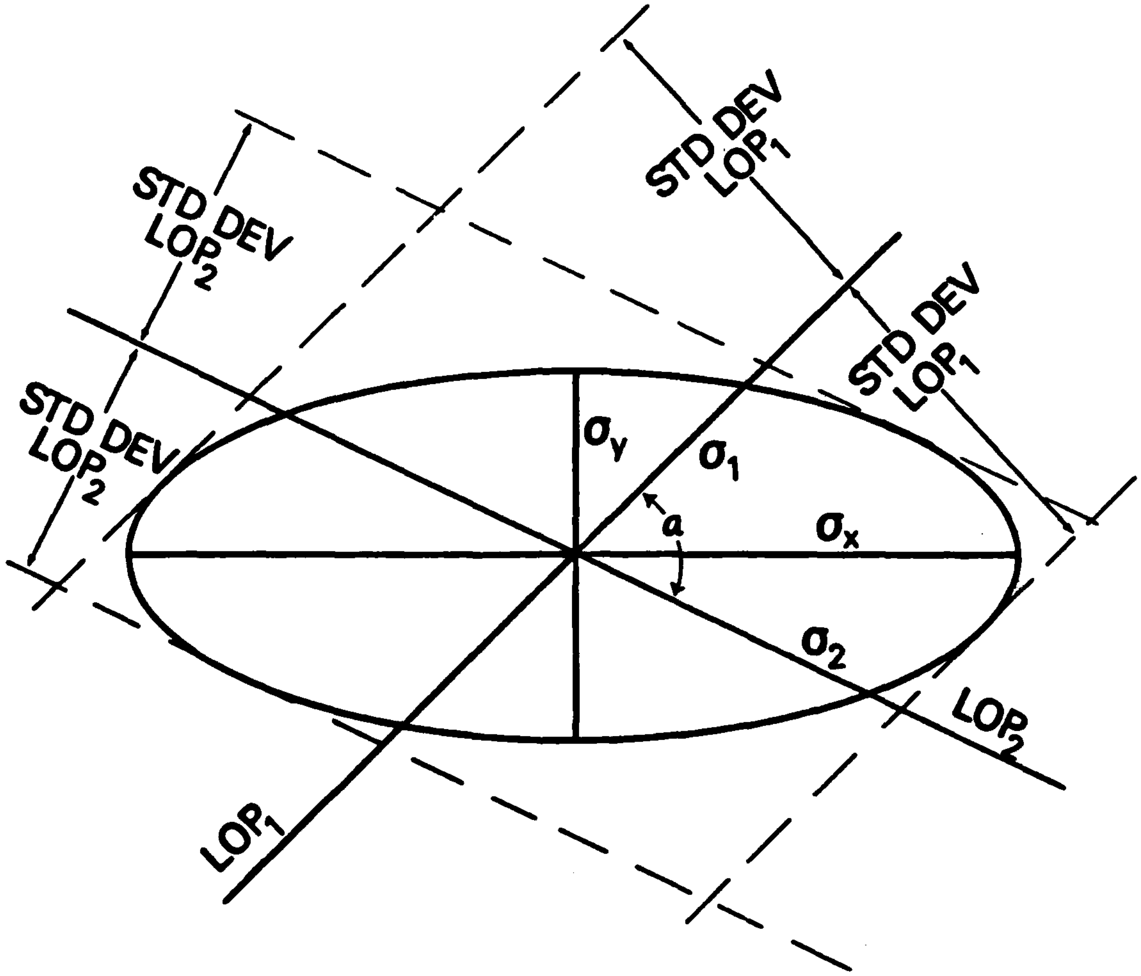
In all calculations, the following assumpitions are made:

(1) All errrors are normally distributed about a mean value.

(2) The LOP's are straight lines in the area of the position.

(3) The area around the position is a flat, two dimensional surface. Altitude is not to be considered.

FIGURE C-1
ERROR TRANSFORMATION



STD DEV$_{1,2}$ = $\sigma_{1,2}$

$$\sigma_x = \left[2 \frac{1}{\mathrm{SIN}^2 a}\left(\sigma_1^2 + \sigma_2^2 + \sqrt{(\sigma_1^2+\sigma_2^2)^2 - 4\sigma_1^2\sigma_2^2\,\mathrm{SIN}^2 a}\right)\right]^{1/2}$$

$$\sigma_y = \left[2 \frac{1}{\mathrm{SIN}^2 a}\left(\sigma_1^2 + \sigma_2^2 - \sqrt{(\sigma_1^2+\sigma_2^2)^2 - 4\sigma_1^2\sigma_2^2\,\mathrm{SIN}^2 a}\right)\right]^{1/2}$$

a = LOP CROSSING ANGLE

(4) The errors associated with one LOP are independent of the errors association with the other LOP.

In calculating the 2 drms value for Section 5.2, the gradient values calculated by the Transportation Systems Center were used:

(1) M-X Gradient = 936 feet/microsecond 116° T

(2) M-Y Gradient = 1100 feet/microsecond 356° T

The published standard deviation is one tenth of a microsecond or 93.6 feet and 110.0 feet respectively. The LOP crossing angle is the same as the angle between the two LOP gradients, [2] which is 120°. In evaluating the transformation expressions in Figure C-1, the following values were assigned to the variables:

(1) σ_{m-x} = 93.6 feet

(2) σ_{m-y} = 110.0 feet

(3) Sin x = .866

The resulting ellipse axes values are:

(1) σ_x = 145.4 ft = 48.46 yds

(2) σ_y = 81.8 ft = 27.27 yds

Using these values to calculate the radius of the 2 drms circle yields:

(1) 2 drms radius = 333.7 ft or 111 yds

REFERENCES

(1) R. J. Kalagher, "Measures of error in LORAN and their Relationship to Geometrical Dilution of Precision, 1973

(2) U. S. Coast Guard Loran-C Engineering Course Notebook, 1976

APPENDIX D

COMMUNICATIONS LINK ANALYSIS

An analysis of the communications link was performed by the Transportation Systems Center. The analysis was based on the following conditions:

a. Conventional VHF-FM marine band transceiving equipment was used

b. Transmitter power one watt

c. Ship antenna height 30 feet

d. Shore antenna height 400 feet

e. Maximum range 20 nautical miles

f. Transmitted bit stream was represented by FSK modulation using frequency shifts from 1200 Hz to 2200 Hz at a 300 bit per second rate, in accordance with the Bell 202 standard.

The analysis was carried out in three steps:

a. Determine available signal level

b. Calculate receiver signal to noise ratio

c. Evaluate FSK error performance

To determine available signal level, a line of sight condition was verified. Using the expression:

$$d = (2ht)^{1/2} + (2hr)^{1/2}$$

d = distance in statute miles
ht = transmit antenna height (ft)
hr = receiver antenna height (ft)

It was calculated that, under the stated operating conditions, a line of sight condition existed out to 36.0 statute miles or 31.3 nautical miles. Therefore, the 20 nautical mile operating range was within the limits of the line of sight condition.

Signal level was calculated using the expression for surface wave propagation.

$$A = \frac{(hr.\ ht)\ gt.\ gt}{d^4}$$

gr = receiver antenna gain
gt = transmit antenna gain
A = signal attenuation
d = distance

For gr = gt = 0dB, A equals 121.6 dB at 20 nautical miles power level at a receiver (P_r) 20 nautical miles from a one watt transmitter would be:

$$P_r = 30dB + (-121.6)\ dBm$$
$$P_r = -91.6dBm$$

The signal to noise ratio is developed by first calculating the noise power in the receiver. The components of the noise expression are antenna noise and internal receiver noise. This noise can be expressed in terms of equivalent temperature, in degrees Kelvin.

$$T_s = T_a + T_r$$

T_s = total noise temperature
T_a = antenna noise temperature
T_r = receiver noise temeprature

Nominal values of T_a and T_r were selected. A typical receiver will have a noise figure of 5dB which is equivalent to a temperature of 627 degrees Kelvin. The antenna temperature was selected as 2000 degrees Kelvin. A T_s of 2627 degrees Kelvin is equivalent to a noise power density of -164.4 dBm/Hz. For a receiver with a 25kHz bandwidth the noise power will be -120.4 dBm and a signal-to-noise ration of 28.6 dB. Considering that an FM discriminator has a nominal threshold level of 12dB, the expected signal level at the receiver would be 16.6 dB above the receiver threshold.

The receiver can be considered to be an ideal FM demodulator because the calculated signal-to-noise ratio is so high. Under these conditions, it can be assumed that the signal-to-noise ratio of the signal out of the FM demodulator is at least equal to 28dB. It can also be assumed tht the input to the FSK modem is at least 28dB.

An evaluation of the FSK modem error performance was made using the following expression:

$$P_e = 1/2 \exp(-S/2N)$$

P_e = probability of bit error
S/N = Signal to noise ratio at FSK modem input

For a S/N = 28dB, the probability of a bit error is very small. Almost no errors will be seen. In fact, the S/N ratio can decrease to 13.3 dB before the probable bit error rate approaches that of existing wire line teletype links, i.e. $P_e = 1X10^{-5}$, or one bit error in $1X10^5$ bits of information.

DATA REDUCTION AND ANALYSIS

Two elements of raw data were collected and stored. They were: (1) the radar range and bearing of the test vessel and (2) the Loran-C time differences. Each element was time annotated upon receipt at the data collect system. Radar information was received once every three seconds and Loran-C information was received once every fifteen seconds.

The first step in data reduction was to calculate a radar position that corresponded in time with each loran position. This was done under the premise that the vessel traveled in a straight line between radar position updates. Using this assumption, a radar position, corresponding in time to a loran position, could be interpolated using a radar data point that was received immediately before the receipt of a loran data point and a radar data point that was received immediately after. See Figure E-1. In some cases, a radar data point and a loran data point were received in the same second. In these cases, the radar data point was used directly.

The loran data points were converted to lat/long using the LDS coordinate conversion routine, Sect 4.2, and then converted to range and bearing from the radar antenna. Range and bearing conversion was calculated assuming a flat earth surface over the 2000 to 3000 yard ranges in which the test data was taken. The net effect of the conversions was to place both the loran data points and the radar data points in a common polar coordinate system.

Using each cooresponding radar data point as a reference, the position difference of the loran data point was calculated and expressed in cartesian coordinate terms as DX and DY. The baseline radar information was referenced to true north. This reference was maintained throughout the data reduction. Therefore, the expression of the position difference between corresponding loran and radar points becomes arranged so that DY corresponds to error north and DX corresponds to error east. Each quantity is expressed in yards.

Sources of error in the data reduction have been identified as follows:

(1) Timing: A 1/40 second timing lag was identified between the receipt of data points and their time annotation.

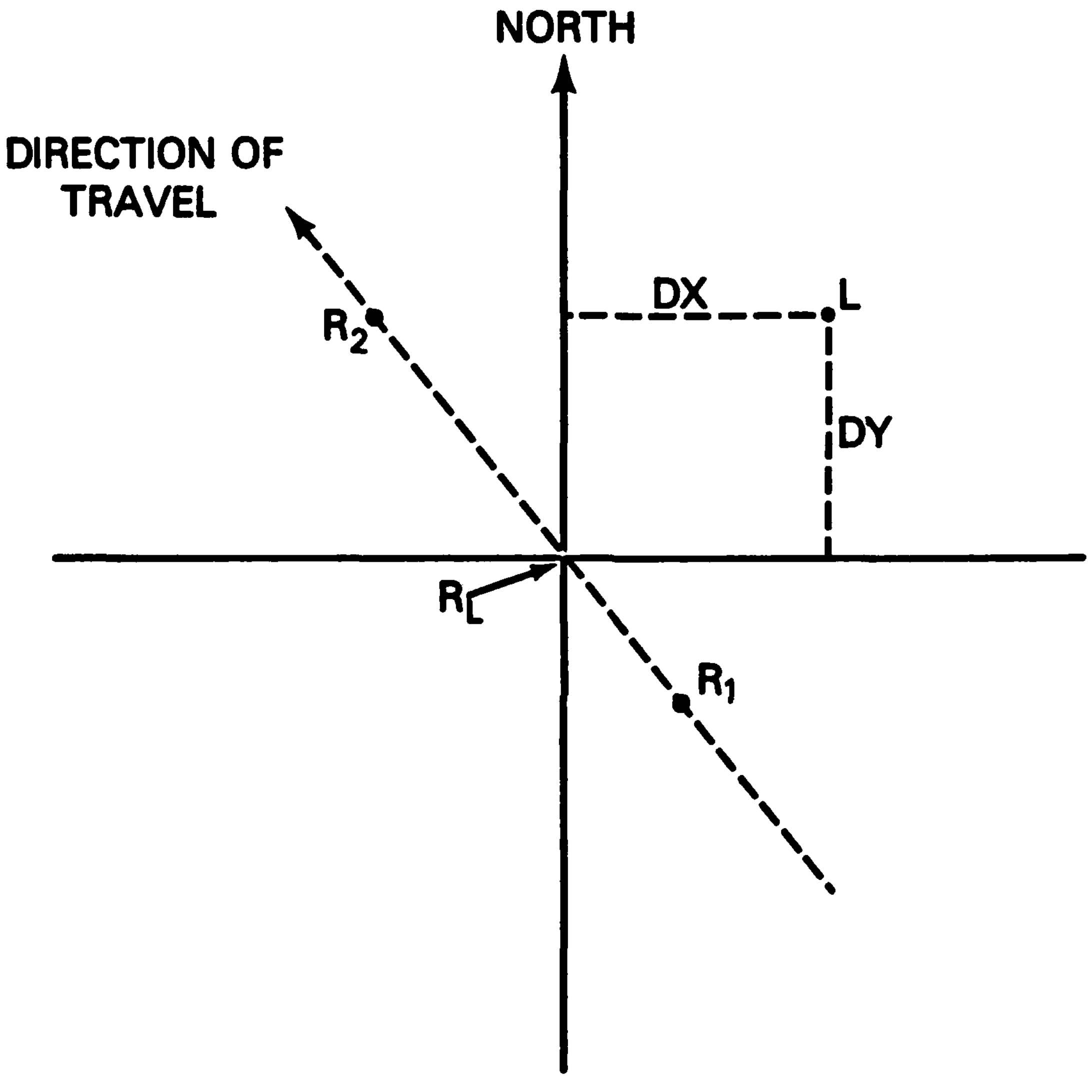
(2) Time difference to lat/long conversion routine: converges to one foot for ideal loran time difference inputs.

(3) Radar Range: +/-30 Feet.

(4) Radar Bearing: not stated for ranges up to 9000 yards.
+/0.15 degrees for ranges beyond 9000 yards

(5) Lat/Long to Polar and Cartesian coordinate conversion: not determined.

FIGURE E-1
RADAR DATA POINT INTERPOLATION



R_1, R_2 — Received Radar Data Point

L — Received Loran Data Point

R_L — Interpolated Radar Position

DX, DY — Distance in Yards Between Interpolated Radar Position and Received Loran Position

The data was analyzed to determine the distribution of loran positions around the radar positions. This was accomplished through a statistical analysis of the DX and DY values for each test run. The mean value of both DX and DY for each day of testing was used to derive a mean error vector. This vector expressed the average offset (BIAS) of each data group. The area of error was defined by one standard deviation of DX and DY. This expression of error leads to the 2 drms calculations outlined in Appendix C.

The following tables list the data points used in the analysis and show the statistical distribution calculated from the data. All data points were quantized to 10 yard resolution. Three test runs were analyzed with a total of 2088 data points.

TABLE E-1

M/V GRIZZLY DAY 5

627 DATA POINTS

DX Values (Yards): MEAN VALUE = 181.56 YD, STD DEV = 82.01 YD

Value	Freq.	Value	Freq.	Value	Freq.
10	2	160	23	310	8
20	6	170	31	320	9
30	3	180	35	330	7
40	10	190	34	340	7
50	8	200	35	350	8
60	9	210	27	360	1
70	8	220	24	370	2
80	18	230	17	380	5
90	22	240	23	390	3
100	27	250	11	400	1
110	21	260	12	410	1
120	25	270	14	420	1
130	34	280	13	430	2
140	38	290	9	440	1
150	24	300	8		

DY Values (Yards): MEAN VALUE = 157.93 YD, STD DEV = 46.09 YD

Value	Freq.	Value	Freq.	Value	Freq.
10	1	100	29	200	39
30	3	110	36	210	30
40	2	120	41	220	24
50	3	130	42	230	18
60	6	140	45	240	10
70	7	150	55	250	6
80	10	160	53	260	5
90	17	170	51	270	5
		180	50	280	1
		190	38		

MEAN ERROR VECTOR = $(DX^2 + DY^2)^{1/2}$
= 240.64 Yards

AZIMUTH = ARCTAN DX/DY
= 48.98 DEGREES
2 drms = 188.14 Yards

TABLE E-2

M/V GRIZZLY DAY 6

678 DATA POINTS

DX Values (Yards): MEAN VALUE = 161.12 YD, STD DEV = 89.01 YD

Value	Freq.	Value	Freq.	Value	Freq.
230	22	300	7	380	1
240	11	310	8	390	3
250	19	320	4	400	1
260	12	330	4	410	2
270	7	340	7	420	2
280	8	350	6	450	1
290	8	360	6	460	2
300	7	370	3		

DY Values (Yards): MEAN VALUE = 155.40 YD, STD DEV = 46.38 YD

Value	Freq.	Value	Freq.	Value	Freq.
10	1	110	37	210	40
20	1	120	39	220	24
40	1	130	47	230	10
50	2	140	57	240	9
60	9	150	54	250	6
70	14	160	70	260	7
80	20	170	52	270	5
90	21	180	44	280	1
100	29	190	42	310	1

MEAN ERROR VECTOR = $(DX^2 + DY^2)^{1/2}$
= 223.85 Yards
AZIMUTH = ARCTAN DX/DY
= 46.04 Degrees
2 drms = 200.74 Yards

TABLE E-3

M/V GRIZZLY DAY 7

783 DATA POINTS

DX Values (Yards): MEAN VALUE = 186.65 YD, STD DEV = 89.32 YD

Value	Freq.	Value	Freq.	Value	Freq.
10	14	150	35	300	7
20	7	160	33	310	10
30	7	170	35	320	13
40	9	180	39	330	9
50	7	190	39	340	12
60	11	200	36	350	9
70	15	210	29	360	9
80	23	220	24	370	7
90	21	230	27	380	7
100	26	240	19	390	3
110	34	250	30	400	4
120	25	260	15	410	4
130	33	270	13	420	3
140	41	280	19	430	1

DY Values (Yards): MEAN VALUE = 157.20 YD, STD DEV = 43.82 YD

Value	Freq.	Value	Freq.	Value	Freq.
40	2	120	47	210	40
50	3	130	71	220	30
60	5	140	72	230	25
70	12	150	67	240	10
80	11	160	70	250	7
90	18	170	56	260	6
100	37	180	55	270	3
110	47	190	52	290	2
		200	35		

MEAN ERROR VECTOR = $(DX^2 + DY^2)^{1/2}$
= 244.03 Yards
AZIMUTH = ARCTAN DX/DY
= 49.9 Degrees
2 drms = 198.99 Yards

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