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THE DESIGN, CONSTRUCTION AND TESTING
OF LORAN-C FROM A DRIFTING BUOY

by

Clayton W. Collins, Jr.
and Robert G. Walden

December 1980

TECHNICAL REPORT

*Prepared for the U.S. Department of Commerce,
National Oceanic and Atmospheric Administra-
tion, Sea Grant Office, under Grants 04-8-
M01-149 and NA 79AA-D-00102.*

WOODS HOLE, MASSACHUSETTS 02543

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Approved for Distribution:

Earl E. Hays, Chairman
Department of Ocean Engineering

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ABSTRACT

A low-windage, current-following spar buoy system containing an automatic Loran-C navigation receiver and a single sideband transmitter with associated control circuitry is described. The Loran-C unit acquires and tracks Loran-C signals and, at intervals controlled by an onboard timer, produces a digital message which modulates the transmitter. The transmitter sends this message via a radio telemetry link to a base or ship receiving station where it is decoded. The decoder displays the message contents in the form of Loran-C time differences representing two lines of position, and thus a geographic fix. The system enables the position of the buoy to be tracked as it drifts with the current and thus serves as an instrument in measuring surface and near-surface current transport. A physical description, details of electrical and mechanical design, and test results, are documented in this report. Feasibility of the system was proven, and a pre-prototype system built and tested.

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1.0 Introduction

This report describes the design, construction, and testing of a Loran-C and telemetry-equipped drifting buoy system. The design was facilitated by a significant advance in electronic technology; namely, the development of the microprocessor. This enabled several manufacturers to place on the market compact, programmed Loran-C receivers that can upon turning on the power switch, automatically acquire, synchronize, track, measure and display the differences in arrival time of signals from a master and several slave transmitting stations of the Loran-C Navigation System.

The project was motivated in early 1978 by the desire to develop such a drifting buoy system as a useful tool in the measurement of surface and near-surface current transport. Other Lagrangian techniques in the past have used dye, drift bottles, and floating buoys with or without drogues. Aircraft, surface ships, satellites and shore stations have been employed using various systems to track the position of drifting buoys. References 1 through 4 discuss some of the methods; radio direction finding, satellites, and the retransmission of Consolan, Omega, and Loran-C.

The principal advantages of the Loran-C telemetry system are that the data are immediately available to the user with no third-party processing, it offers the high resolution and accuracy of the Loran-C Navigation System, and the data is processed on the buoy prior to transmission thus avoiding any degradation in accuracy by direct retransmission of Loran-C signals.

Continued competition and development in the area of Loran-C receivers in the period 1978 to date have produced more sophisticated, versatile equipment while keeping costs to a reasonable level. All of this makes the continued application of Loran-C telemetering vehicles more attractive.

2.0 General Description

The drifting buoy contains a Loran-C receiver and a single sideband transmitter, both of which are controlled by a digital clock and unit. The Loran-C receiver measures the time delays between two slave stations and the master station and upon command produces a bi-phase audio output to modulate the transmitter. The digital message is transmitted to a base station, received by a single sideband receiver whose output is fed to a decoder. The latter processes the incoming digital word and displays it on the front panel in the form of two time delays. These time differences represent two lines of position (LOP) on a standard nautical chart overprinted with Loran-C hyperbolic lines. Intersection of two LOP fixes the position of the drifting buoy. Figure 1 is a block diagram of the buoy system.

The buoy is a current-following, low-windage structure of laid-up fiberglass ballasted in the bottom with lead. It has a watertight cover, on top of which is mounted the antenna bracket, coupler and antenna. The coupler and base of the antenna are covered by a protective fiberglass boot.

Figure 1 Block Diagram of the Buoy System

The Loran-C receiver is Model TDL-701 manufactured by Teledyne Systems of Northridge, California. The Model N820 SSB Transceiver is made by Northern Radio Company of Redmond, Washington. Both of these items are "off-the-shelf", with no modifications except that the installation of a rear output connector on the TDL-701 was requested in order to bring out the digital information and other control data. The clock and control unit was designed and built at the Woods Hole Oceanographic Institution.

The antenna that was furnished with the Loran-C receiver is also used as the transmitting antenna for the single sideband transmitter. This is accomplished by the design of an impedance network to form a duplexer, which is described later in detail. That approach eliminated the necessity of a transmit-receive relay, while preserving the proper circuit impedances in both the transmit and receive modes. Simultaneous transmission and reception can be carried out using the one antenna; thus the requirement for a separate transmitting antenna is avoided.

3.0 The Loran-C Navigation System and Modern Loran-C Receiver Technology

An interesting history of the Loran-C hyperbolic navigation system is concisely described in the introductory pages of the Loran-C User Handbook (Reference 6). That publication points out that Loran-C is the U. S. Government sponsored navigation system for the U. S. Coastal Confluence Zone (CCZ). The U. S. East Coast Chain provides adequate coverage for Gulf Stream and Georges Bank experiments and for operations out to the vicinity of Bermuda. Fixes accurate to better than 500 meters at a range of 200 km from the transmitting stations are provided. At distances closer to the stations, in Nantucket Sound for example, fixes can be determined within 50 meters. For the rate 9960, the time difference gradient when measuring the time difference of the W secondary station (Caribou, Maine), is 1.14 miles per microsecond. This is equivalent to 28 meters per 0.1 microsecond, which is the resolution of the display of a typical Loran-C receiver. For the X secondary station (Nantucket) the gradient is 0.83 miles per microsecond, or 18.5 meters per 0.1 usec. Repeatability in this area determined by returning to a known geographical point, is 0.1 usec. in time difference readings.

The TDL-701 Loran-C Receiver is fully automatic from the moment the power switch is turned on, acquiring, locking on, tracking and displaying two time delays. A plug-in programmable read-only memory chip (PROM) contains the basic data to allow operation in the East Coast Chain. A two-position switch on the rear of the receiver allows time delay readings between the Master station (M) (Seneca, New York) and W (Caribou, Maine), and between M and Y (Carolina Beach); or between M and W and X (Nantucket), depending on the position of the switch. A rear-connector line can be used to observe synch status as the initial acquisition of signals progresses.

Versions of Loran-C receivers developed in the last two years by various manufacturers contain front-panel keyboards that enable the selection of any Group Repetition Interval (GRI) in the world, display of all secondary station time differences, signal strength, lock-on status, conversion to latitude and longitude, and course and distance calculation.

A new generation of the telemetering buoy system funded on July 1, 1980, will use a modular receiver containing only the essential portions of the electronics. For example, the front panel display is unnecessary in a

drifting buoy. Elimination of the display will effect a 40% reduction in receiver power consumption.

4.0 Radio Propagation

Loran-C ground wave coverage is illustrated in Figure 2 and in Reference 6. The ground wave is used at all times when measuring Loran-C signals, a feature characteristic of the Loran-C system. East Coast Chain coverage extends outward about 800 to 1000 miles from the coast. There are parts of the world where Loran-C is not available and where the drifting buoy system cannot be used. In areas where the signals are considered to be adequate, contamination of incoming signals by skywaves is avoided by receiver circuit design whereby the leading edges of the groundwave pulses are sampled prior to arrival of the skywave. Figure 3 shows examples of received Loran-C signals and a typical pulse. Loran-C operates on a carrier frequency of 100 kHz and at that low frequency is free from significant propagation anomalies. The ground wave is usable 24 hours a day.

For the radio telemetry link a frequency was chosen near 6.9 mHz, for which Woods Hole Oceanographic Institution is regularly licensed. The proper transmitting crystal was procured for the SSB transmitter.

A study was made of expected ground wave signal strength for the frequency band used for the telemetry link. A typical SSB transmitter is rated at approximately 100 watts peak effective power (PEP) into the base of its antenna. Assuming that tone modulation will be used rather than voice, the average power output will be one-half of the rated PEP, or 50 watts. A short vertical antenna may have an efficiency of 20%, so that the average radiated power (P_r) would be 10 watts. These parameters may vary with different transmitters and antennas, but not enough to alter the method of calculation, or the results.

Figure 4 shows the field strength calculated for 6.9 mHz using the theory and graphical methods of K. A. Norton (Reference 5). The graph is drawn using as a basis a field strength of 10 millivolts per meter at a distance of 1 statute mile from a transmitter whose P_r is 2.89 watts. At a distance of 150 miles, the field strength produced by that power can be found by rationalizing as follows:

$$\sqrt{\frac{10}{2.89}} = \frac{e}{15} \quad e = 27.9 \text{ microvolts per meter}$$

The sensitivity of modern receivers is better than 1 uv/m; therefore the receiver is not a limiting factor in the system. Atmospheric noise levels of 0.1 uv/m daytime to 6 uv/m nighttime at 6.9 mHz can be expected; therefore the signal-to-noise ratio of the signal received from the buoy transmitter at a distance of 150 miles will be about 5 to 1, more than adequate for data reception.

Table 1 shows a comparison of expected field strength at several distances for two levels of radiated power.

Figure 2 - LORAN-C Groundwave Coverage: Existing and Proposed Worldwide
(from LORAN-C User Handbook)

Example of Received LORAN-C Signal
(from LORAN-C User Handbook)

Figure 3 - Typical LORAN-C Pulse
(from LORAN-C User Handbook)

Figure 4 - Graph of Field Strength vs Distance, 6.9 MHz

TABLE 1
Field Strength vs Distance

<u>Distance</u>	<u>Radiated Power</u>	
	<u>1.5 watts</u>	<u>10 watts</u>
50 miles	75 uv/m	195.3 uv/m
100 miles	32 uv/m	83 uv/m
150 miles	10.8 uv/m	27.9 uv/m
200 miles	3.6 uv/m	9.3 uv/m

5.0 Detailed Description of the System

5.1 The TDL-701 Loran-C Receiver. Figure 5 shows an overall functional block diagram of the Loran-C receiver. The antenna coupling unit (ACU) is housed within the antenna assembly and is connected to the RF Input connector on the radio frequency unit (RFU) assembly via coax cable. The digital processing unit (DPU), RFU, and power supply circuit card assemblies plug into the display assembly. Table 2 lists the technical characteristics of the receiver.

Loran-C signals received at the antenna are amplified in the antenna coupler unit and introduced into the receiver at the RF Input connector. In the RFU these signals are processed to create the three basic versions of the Loran signals that will be used in the DPU for acquisition, tracking, and obtaining time differences. The three signals, wideband, narrowband, and envelope, are then converted into format compatible for digital processing. Thus, the RFU is basically an analog device producing three unique digital equivalents of the Loran signals under processor control.

The three digitized Loran signals from the RFU are made available to the DPU, where pulse processing, under control of a microprocessor, goes through the modes required to search for, acquire, and track the Loran signals on the proper tracking point of each pulse to produce the required time differences. These modes are listed on Figure 5. Loran time differences, corresponding to hyperbolic lines of position, are sent to the display unit, where they appear on the two self-illuminating digital displays.

Various control and data functions are brought out to a special connector on the rear panel. Pin B3 is used to change TDB into a signal status display; Pin A7, when connected to ground, initiates the data message, which appears at Pin B14. The message format is shown in Figure 6.

Figure 6 Message Format

The least significant bit transmitted is the sync bit. Following this, eight bits (two BCD digits) of data identify the transmitting unit. Next, three report bits and three status bits are available for status information. Time difference A occupies the next 28 bits followed by 28 bits of time difference B. After time difference B, eight bits of identification are transmitted, identical to the first ID code. Finally the parity bit is sent, completing a total of 80 bits. The rate of transmission is 77 bits per second, with a 13 millisecond bit width.

Figure 5 - Overall Block Diagram, TDL-701 Loran-C Receiver

Receiver Technical Characteristics

Sensitivity (Nominal)	Acquisition $10\mu\text{v}$ Track $2\mu\text{v}$
Input Dynamic Range	90 dB, $10\mu\text{v}$ to 300 mv
Signal Unbalance	60 dB, at 0.1 μsec max TD error
Envelope/Cycle Discrepancy	$\pm 4\mu\text{sec}$ at -10 dB SNR
Velocity Envelope	0 to 1200 feet/sec at -10 dB SNR
Minimum SNR (Acquisition)	-10 dB

Number of Stations Tracked 3 (Master and secondaries)

Acquisition Time To Full Accuracy

<u>Chain—Rates</u>	<u>Time</u>	<u>SNR</u>
Slowest (9999)	8 min	-10 dB
Fastest (3930)	1 min	+6 dB

RF Interference Rejection	2 Manually adjusted notch filters
Single chain operation	Two chains (optional)
Data Output	Audio tone data burst containing time differences, status and receiver ID number suitable for direct radio transmission (optional)
Power	12 VDC 110 VAC 50–60 Hz (optional) 20 watts

Features

Front Panel	Two 6 digit time difference displays On/Off control switch Display Hold switch
Rear Panel	Chain select Notch filter adjust Power input Data connector Antenna input
Size	2.5 X 9 5/8 X 11 3/4 in. plus mounting bracket
Weight	4 pounds

TELEDYNE
SYSTEMS COMPANY 19601 Nordhoff Street, Northridge, California 91324 (213) 886-2211

TDL-701 Loran-C Receiver Technical Characteristics

Table 2

5.2 The Antenna Coupling Unit (ACU). The primary purpose of the ACU is to provide a high impedance match to the Loran-C antenna and a low impedance output to drive the coax cable connecting the ACU to the receiver. There is no minimum cable length insofar as circuit efficiency is concerned, but the maximum length should be no greater than 100 feet. The ACU is designed to drive this particular cable capacitance and length.

A schematic diagram of the ACU is shown in Figure 7. In addition to matching the Loran-C antenna to the coaxial cable, the ACU functions as a two-pole filter. The first pole is comprised of L1, C10 and the combined capacitance of C1 and the antenna. The second pole consists of L2 and C6. The first pole is tuned to 86.14 kHz and the second to 114.758 kHz, thus providing a stagger-tuned type of filtering. Power for the ACU is transmitted on the center conductor of the RG-58/U coaxial cable and is decoupled from the signal by inductors in the ACU and RFU. Current drain of the ACU is 12 ma. The antenna, an 82-inch whip, is mounted permanently on the ACU casting. The nature and complexity of this active antenna coupler influenced the decision not to attempt extensive modifications to it in order to share the antenna with the transmitter, but rather to build a duplexer ahead of it. This is described in the following section.

5.3 The Duplexer and Antenna Matching Network. In order to allow the SSB transmitter to share the Loran-C antenna a choice had to be made between the use of a transmit-receive (TR) relay or some other means of carrying out the TR function. A TR relay draws a substantial amount of current to energize its coil, thus shortening battery life, and in the present design would have to be mounted remote from the transmitter and receiver, on the ACU. A separate power cable would have been needed and the relay would have been outside the buoy's water-tight compartment. As an alternative approach, a passive reactive network was devised to isolate the receiver from the transmitter while sharing the common antenna. Thus the transmitter can be keyed without disconnecting the receiver. A schematic diagram of this duplexer circuit is shown in Figure 8. The components are mounted in an aluminum enclosure the same size as the coupler and bolted to the coupler casting.

As shown in the schematic diagram, the parallel combination of the inductance L100 and the capacitance C100 form a resonant high impedance circuit at the Loran-C frequency of 100 kHz. Signals received by the antenna thus see a high impedance looking in the direction of the SSB transmitter, while the parallel circuit of L69 and C69 offer a very low impedance to 100 kHz. The Loran-C signals therefore arrive at the ACU with no significant attenuation.

When the transmitter sends data at 6.9 MHz it sees little attenuation at L100/C100 but encounters a resonant high impedance looking in the direction of L69/C69 and the ACU. Transmitted energy therefore is prevented from entering the ACU and instead is directed to the antenna where it becomes radiated power.

- NOTES: UNLESS OTHERWISE SPECIFIED
1. ALL RESISTANCE VALUES ARE IN OHMS.
 2. ALL CAPACITANCE VALUES ARE IN MICROFARADS.
 3. FOR ASSEMBLY SEE DWG 8014654-503 OR -505.
 4. ALL DIODES ARE 7126001.

REFERENCE DESIGNATION	
LAST USED	NOT USED
C11	
CR4	
L3	
Q4	
R10	

Figure 7 - ACU Schematic Diagram

L69 = 24.78 uH (51T #22 on Amidon T-94-2, $\mu = 10$)
 C69 = 7-100 pf (Arco #423)
 L100 = 17.17 mH (95T #28 AWG on Ferroxcube 846T250, $\mu = 5000$)
 C100 = 147 pf (Arco #464, 25-280 pf)

ACU:

C1 = 22 pf
 C10 = 100 pf
 L1 = 68 mH
 R1 = 15K

Antenna Z = 3- pf in series with 50 ohms

Trap ATTENUATION:

100 kHz Trap: -46 db Attenuation of 100 kHz when terminated by 50 ohms
 6.9 MHz Trap: -38 db Attenuation of 6.9 MHz when terminated by 50 ohms

Figure 8 Duplexer Schematic Diagram

In addition to the TR function, the duplexer tunes the Loran-C antenna to 6.9 MHz in the transmit mode. Since the antenna is physically less than a quarter wavelength at that frequency, the inductor L820 is inserted in series with L100/C100 and the antenna. This is of such a value that the combination of reactances tune the antenna and presents a load impedance to the transmitter that closely matches its output impedance.

The inductors that make up the duplexer and antenna matching networks are wound on toroidal ferrite cores. Such inductors have the advantages of producing higher inductance values in smaller space than air-wound coils and with much fewer wire turns. In addition, the field around a toroid is confined within its windings and is not disturbed by the proximity of nearby metallic components.

A useful approximation of the inductance of a toroidal coil is given by the relationship

$$L = (0.0046 \mu N^2 h \log_{10} \frac{OD}{ID}) \text{ micro-henries}$$

where L = inductance
 μ = permeability
 N = number of turns of wire
 OD = core outer diameter in cm
 ID = inner diameter in cm
 h = height of core in cm

The permeability of an iron core is given by the manufacturer's specification listing. Core dimensions can be measured on in-stock items, or obtained from the specification sheet. The number of turns is determined arbitrarily at first by winding a single layer of a reasonably sized enameled magnet wire on a core and counting the number of turns that it will hold. All values needed to calculate the approximate inductance are then present and a trial value of L can be obtained.

An important consideration is the amount of attenuation achieved by these trap circuits. The 100 kHz trap produces approximately 43 db of attenuation at 100 kHz, and the 6.9 MHz trap about 38 db at 6.9 MHz. The value of 40 db was the target level. Figure 9 shows the antenna circuit.

Figure 9 Antenna Matching Circuit

The elements involved in the calculations of the antenna matching network are the loading coil L820, the 100 kHz trap, and the capacitance of the antenna. The capacity of the antenna is 30 pico-farads. Its reactance, Z_{ca} , at 6.9 MHz, then, is -j761 ohms, found by the equation

$$X_c = \frac{1}{2\pi fC}$$

where f = frequency in Herz
C = capacity in Farads

$$\text{Thus, } X_c = \frac{1}{(2\pi)(6.9 \times 10^6)(30 \times 10^{-12})} = 761 \text{ ohms}$$

To tune out this reactance, the combination of L100/C100 and L820, designated Z_m , is made to be the conjugate of -j761. The impedance, Z_p , of the parallel circuit L100/C100 is calculated for the frequency 6.9 MHz. This is added to Z_{ca} , and the resultant is the value of inductance required for the loading coil L820.

The parallel impedance Z_p is determined from the relationships

$$X_{L100} = 2\pi fL_{100} = 2\pi(6.9 \times 10^6)(17.17 \times 10^{-3}) = 751.9 \times 10^3 \text{ ohms}$$

$$X_{C100} = \frac{1}{2\pi fC_{100}} = \frac{1}{2\pi(6.9 \times 10^6)(150 \times 10^{-12})} = 152.2 \text{ ohms}$$

Assuming the Q of Z_p to be 120

$$\text{Then } R_{L100} = \frac{X_{L100}}{Q} = \frac{751.9 \times 10^3}{120} = 6265.8 \text{ ohms}$$

$$\text{And } Z_{L100} = R + jX_L = 6265.8 + j(751.9 \times 10^3)$$

$$\text{Now } Z_p = \frac{Z_{L100} \times Z_{C100}}{Z_{L100} + Z_{C100}} = \frac{(751926 \angle 89.5^\circ)(152.2 \angle 90^\circ)}{(6265.8 + j(751.9 \times 10^3))(0 - j152)}$$

$$Z_p = \frac{114.4 \times 10^6 \angle -0.5^\circ}{6265.8 + j 751748}$$

$$\text{Then } Z_p = \frac{114.4 \times 10^6 \angle -0.5^\circ}{752.5 \times 10^3 \angle 89.5^\circ} = 152 \angle 90^\circ$$

Therefore, the equivalent antenna circuit can be represented by Figure 10

Figure 10 Antenna Equivalent Circuit

$$Z_p + C_a = -j913 \text{ ohms}$$

X_{L820} is the conjugate of that value, or +j913 ohms, produced by an inductance of

$$L_{820} = \frac{X_{L820}}{2\pi f} = \frac{913}{(2\pi)(6.9 \times 10^6)} = 20.8 \times 10^{-6} \text{ Henries,}$$

or 20.8 microHenries

Accordingly, loading coil L820 consists of 48 turns of #20 wire on an Amidon T-94-2 core having a μ of 10. The inductance of the whole coil is 22 uH. Taps are provided for adjustment to the value needed.

Final tuning of the antenna is accomplished by mounting the antenna on the buoy and measuring the impedance with an RF bridge. L820 is adjusted by changing the tap until $Z = R + j0$.

5.4 The Clock and Control Unit. Operation of the entire buoy system is controlled by the Clock and Control Unit, shown in functional block diagram form in Figure 11. The design object was to conserve battery power by keeping all equipment powered down except the clock and logic circuitry, until a pre-set time when a data transmission is scheduled. Intervals between transmissions can be anywhere between 10 minutes and 27 hours, depending on how the clock counters are wired. The time required to send one data message is about 1.4 seconds, during which 80 bits are transmitted as described in paragraph 5.1.

The timing cycle is determined by a free-running oscillator and seven decade counters. Selected outputs from the decade counters are sent to several flip-flops and gates where the timing logic is developed. Three buffer amplifiers take the logic outputs and apply power to the Loran-C receiver and the transmitter, operate the transmit-relay in the transmitter, and command the Loran-C receiver to send its data message.

The cycle is started by a pulse from one of the decade counters which is fed to the 5-minute lock-on flip-flop, to the TDL/N820 turn-on gate and to the power-on flip-flop; power is applied at that instant to the TDL-701 Loran-C Receiver and the N820 SSB Transmitter. Five minutes are then allowed to elapse, which is sufficient time for the receiver to automatically acquire and lock on to signals. At the end of the 5-minute lock-on period a pulse from another decade counter turns on the T-R flip-flop and the transmitter T-R relay is closed for four seconds. The same pulse turns on the command-data flip-flop. The output from this stage goes via a buffer amplifier to the transmit line in the TDL-701, whose internal logic initiates a data message. The message goes to the audio input of the transmitter to modulate it. The data message is radiated from the antenna and passes via the radio link to the base station. The number of data transmissions is controlled by the elapsed time of a reset pulse from a decade counter, that resets all counters and flip-flops. Power is removed at the same time from the receiver and the transmitter, completing one time interval.

Figure 11 - Clock and Control Unit Functional Block Diagram

The elements of timing and logic are contained in twelve COSMOS integrated circuit chips mounted with their associated circuit components on a printed wiring board.

5.4.1 Control Interface Circuit. Figure 12 shows the connections between the Clock and Control Unit and Loran-C receiver and SSB transmitter. Power to the receiver and transmitter is applied through the contacts of relay K1. Interface elements include a modulation shape control, modulation amplitude control, main power switch, Loran-C status display switch, a counter manual reset switch, manual power override switch, manual TR/Data command switch, and an external counter advance input receptacle. Driver transistor stages interface the transmitter TR, Loran-C transmit, and power turn-on functions.

5.5 The N820 Single Sideband Transceiver. The transceiver is an all-solid-state marine two-way radio. The receiver and 23 of the 24 channels are not used. The transmitter peak envelope power (PEP) into a 50 ohm matching load is 100 watts. An audio processing module provides at least 20 db of AGC range to produce a substantially constant input of audio to the modulator. The level of RF produced at the output of the power amplifier is detected and used to limit the peak envelope power output to the rated output. No transmitter adjustments are required except to adjust the local oscillator to the desired frequency. Press-to-talk and audio input connections are made through an 11-pin plug and socket at the rear of the unit. As in the case of the TDL-701 Loran-C receiver, this equipment is installed in the spar buoy without modification.

5.6 The Power Supply. The source of power for the buoy system electronics consists of two sealed, rechargeable, lead-calcium storage batteries. These are Globe Gel/Cell Type GC12200 rated at 12 volts, 20 ampere hours each. Batteries with gelled electrolyte were chosen because no spillage can occur when they are placed on their side or upside down. Attitudes other than upright occur, for example, whenever the buoy is carried horizontally on the deck of a vessel enroute to its launch site. The battery frame has space enough to accomodate about 10 batteries.

5.6.1 The Power Budget. The power budget is shown in Figure 13 based on a operating schedule of one data transmission each hour, at which time the data message is sent five times. The power budget, then may be calculated as follows:

$$\begin{array}{rcl} 0.01 \text{ Amps} \times 54 \text{ mins} & = & 0.54 \\ 1.7 \text{ Amps} \times 6 \text{ mins} & = & 10.2 \\ 6.5 \text{ Amps} \times .3 \text{ mins} & = & \underline{1.995} \\ & & 12.735 \text{ Amps/min} \end{array}$$

$$\frac{12.735}{60} = 0.2122 \text{ Amps average continuous current}$$

$$.2122 \text{ Amps for 24 hours} = 5.09 \text{ AH per day}$$

$$\frac{40 \text{ AH}}{5.09} \text{ (battery capacity)} = 7.86, \text{ or approximately 8 days on two 20 AH batteries}$$

Figure 12 - Control Unit Interconnection and Interface Diagram

Figure 13 The Power Budget

5.7 The TDL-471C Data Link Decoder. The TDL-471C decoder performs the demodulation, decoding, display, and transfer of the received data link message. The unit uses low-power COSMOS circuitry mounted on five printed circuit boards and packaged into a portable instrument suitable either for base station, shipboard, or aircraft operation. The front panel consists of 18 incandescent seven-segment displays arranged to read out two digits for ID, seven for TDA, seven for TDB, and one digit each for status and report.

The decoder gets its input from a standard communications radio receiver set to the upper sideband mode. The receiver main tuning control is adjusted so that its audio output consists of the bi-phased FSK frequencies of 1800 and 2200 Hz. The decoder then processes and displays the message.

Upon receiving the first message all of the displays are automatically turned on and the message displayed. The displays are updated for each new message received. Figure 14 represents the front and rear panel of the TDL-471C.

Characteristics of the decoder are listed in Table 3.

6.0 Buoy Design

6.1 Spar Buoy. A spar buoy was designed and constructed to contain batteries and ballast at the bottom and electronic assemblies and antenna at the top end. The diameter of the upper section is $16\frac{1}{2}$ inches to accommodate the Loran-C and single sideband transmitter without any mechanical modifications. This section is attached to a $10\frac{1}{2}$ inch diameter lower section.

The buoy is 10 feet long constructed of layed-up fibreglass matting and cloth. The total weight, ballasted with 200 pounds of lead is 430 pounds.

TDL-471C FRONT PANEL

TDL-471C REAR PANEL

TI02549

Figure 14 - TDL-471C Data Link Decoder

PHYSICAL CHARACTERISTICS

Weight	2.9 lbs
Volume	166 in. ³
Size	2.5" x 7" x 9.5"

ELECTRICAL CHARACTERISTICS

Primary Power	+12V at 1.7 amps (max) 120 ma in reset condition
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Input Audio Signal

Bandwidth	300 - 3000 Hz
Amplitude	100 mv to 2V
Impedance	1000
Data Rate	77 bits/second
Data Format	Bi-phased FSK 1800 Hz Data = "one" 2200 Hz data = "zero"

OPERATIONAL FEATURES

Two independent time different displays

TD readout resolution: .01 μ sec.

Signal integrity checks

- 79 bit count
- Leading ID equals trailing ID
- Odd parity
- gap detection
- noise rejection

Reset capability

Display dim

Table 3

The batteries and electronics are attached to internal racks which can be withdrawn from the tube for servicing or charging. The base of the antenna with its matching network is attached to the top plate of the spar. The matching network is protected by a fibreglass hood around the base of the antenna.

The waterline depth, center of buoyancy and center of gravity, are all shown in the drawing (Figure 15).

7.0 System Tests

Several significant tests were necessary at various stages in the evolution of the system. Their success or failure would determine whether or not the project ought to proceed to the following phase.

7.1 Evaluation of the TDL-701 Loran-C Receiver. A period was allotted for the evaluation of the Loran-C receiver to see if: (1) It could automatically synchronize itself to Loran-C radio signals and thereby operate unattended; (2) The receiver sensitivity was sufficient to produce a high degree of reliable operation; (3) Data accuracy and repeatability were in fact great enough to hold data scatter to a minimum; (4) Operation was reliable using a short antenna suitable for buoy installation; (5) The equipment was provided with usable digital output circuitry; and (6) The power requirement was modest enough to allow two months or more mission endurance without servicing.

The receiver was turned on and off about 50 times in order to observe its lock-on capability. Operation was both fixed (top floor of buildings in downtown Woods Hole and the Quissett campus) and mobile (installed in an automobile), using the 8-foot antenna provided by the manufacturer as part of the system. A control unit was built and used to actuate a signal-status display in the receiver and to trigger the digital output message which was observed on an oscilloscope.

The receiver was operated along the shore in good over-water signal conditions and in various locations where one or more signals were marginally received over land paths, and from a standstill to speeds up to 40 miles per hour. Accumulation of time difference readings (fixes) logged during this part of the evaluation showed the accuracy to be well within the scale of available charts. Further, the repeatability agreed with the theoretical value of 0.1 to 0.2 usec or a radius of 30 meters or less, this being confirmed in the mobile mode by returning to the same physical spot several times and logging the displayed time difference readings. Observations of the tracking ability of the receiver in a moving vehicle showed that it would not lose synchronization when subjected to various magnitudes of speed and acceleration. The receiver always operated properly along the shore, but some locations inland caused it to show a weak-signal status reading, a situation that was expected.

Figure 15 - Spar Buoy

At all times, except in a poor signal area, the receiver, from an initial turn-on of power, automatically acquired and tracked the signals, a test of its ability to operate unattended.

The conclusion was that the existence on the market of fully automatic Loran-C receivers having on-board microprocessors make them a good candidate for use with a radio-telemetry link on moored or drifting buoys.

Another test was made with the receiver installed in a 12 foot discus buoy which was then towed from the Woods Hole Oceanographic Institution wharf to Nobska Point and back. Time delay readings were observed when passing abeam of various navigation buoys and the results logged. The charted track of this excursion showed the Loran-C receiver to have some trouble acquiring the Cape Race, Newfoundland slave signal at first but thereafter to maintain track for the whole distance. The chart is a 5000:1 scale with computerized Loran-C lines overlaid to increase the plotting resolution. Figure 16 shows this track. A further significant test showed that the Loran-C receiving antenna can be disconnected for as long as 15 seconds without degrading measurement accuracy. This amount of time allows the antenna to be used for data transmission and then be reconnected to the Loran-C receiver.

7.2 Modulating of the Transmitter. An interface R-C shaping network is connected between the Loran-C receiver data output line and the transmitter audio input. Tests showed that this shaping network, together with the audio bandpass characteristics of the transmitter audio input circuit, enabled the Loran-C data to fully modulate the transmitter and produce a clean bi-phased FSK signal containing 1800 Hz and 2200 Hz at its output.

7.3 Antenna Coupler and Duplexer. Tests of the simultaneous use of the 8-foot whip antenna for receiving and transmitting were vitally important. When construction of the duplexer was finished, a preliminary test was made prior to sending transmitted energy into it. With the Loran-C receiver tracking, a 50 ohm load was connected across the transmitter input jack in the duplexer to see if there would be any degradation of Loran-C operation. Next, the transmitter was connected and modulated by the receiver using a dummy transmitter load. Finally, the whole system, less the control unit but including the antenna, was installed on the 12-foot discus test buoy and exercised. In all of these tests it was determined that the system would (1) provide a Loran-C receiver output to modulate the telemetry transmitter, (2) utilize the Loran-C antenna for simultaneous reception of Loran-C signals and transmission of telemetry, and (3) operate from a small buoy with the antenna base only a foot or two above the sea surface.

7.4 Overall System Test. The complete system was installed in the specially designed spar buoy, turned on, the timing set, and the buoy set adrift in Vineyard Sound off Nobska Point on an easting tide. It was accompanied closely by the R/V ASTERIAS. At each data

Figure 16 - Buoy Track- Preliminary Test

transmission, preset to 15-minute intervals, Loran-C readings were recorded at the base station in the laboratory and compared with simultaneous readings taken on the ASTERIAS' Loran-C receiver. Figure 17 shows the track traced in this test. Although in two consecutive instances there was an obvious discrepancy between the two Loran-C readings, the overall results showed almost exact agreement and satisfactory results.

8.0 Conclusion

Loran-C is an established long range navigational system permitting accurate fixes at any time. Present day Loran-C receivers are accurate and reliable, using state-of-the-art electronic devices. The receivers operate automatically to acquire and track signals which are then processed and displayed as navigational information. Advantage of these basic features was taken in the design of the telemetering Loran-C spar buoy system.

Development of on-board microprocessors in Loran-C receivers enable the transformation of time difference measurements into digital form suitable for directly modulating a radio telemetry transmitter. The report shows that this data can be telemetered from a buoy without disturbing the measurement accuracy of the Loran-C receiver. A common, short antenna close to the sea surface can be used by the receiver and the transmitter.

The system will operate unattended in a "hands off" mode. The power budget is modest enough to achieve a mission endurance of two months or more.

The system is a good candidate for use in drifting buoys, and for monitoring the position of surface moorings.

Figure 18 - Spar Buoy, Photograph

Figure 19 - Spar Buoy, Photograph

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