LORAN-C, AN OVERVIEW

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Abstract

In 1974 Loran-C was selected to be the government-provided radionavigation system for the U.S. Coastal Confluence Zone and the Great Lakes. Title 14, USC 81 states that the U.S. Coast Guard may establish and maintain electronic aids to operate marine navigation required to serve the needs of the military and commerce of the United States.

Loran-C is a highly accurate positioning system. It operates at an assigned frequency of 100 kHz, and provides phase-coded pulses to develop hyperbolic time-difference lines-of-position (LOP's). In addition to providing for radionavigation, Loran-C also provides precise time and time interval to within ± 5 microseconds of UTC. The paper discusses the steps taken to plan, install, operate and maintain the Loran-C system up to the year 2000. The following topics are included in the discussion: theory of operation, timing, chain planning, group repetition interval, coding delay versus emission delay, chain calibration, chart verification, system accuracy, signal reliability, and future developments.

The opinions or assertions contained herein are the private ones of the writer and are not to be construed as official or reflecting the views of the Commandant or the Coast Guard at large.

BACKGROUND

Coast Guard operated since 1958, Loran-C has been providing highly accurate and reliable radionavigation service and Precise Time and Time Interval (PTTI) dissemination through pulsed transmissions in the 90-110 kHz band. A nominal 1200 nautical mile range, coupled with a positioning accuracy of 1/4 nautical mile, tested repeatability of up to 15 meters, and a documented availability of greater than 99.7%, has made Loran-C a reliable radionavigation system. Loran-C is a system that can be used in many land, sea, and air positioning applications.

In 1974 Loran-C was designated as the navigation system for the Great Lakes and Coastal Confluence Zone (CCZ) of the continental United States and Southwest Alaska. This zone extends fifty (50) miles from the harbor entrance or to the 100 fathom curve, whichever is further.

To provide such coverage, it was necessary to construct 12 new Loran-C stations on the East, West, and Gulf coasts and Great Lakes as well as along the Gulf of Alaska and the Bering Sea. This expansion of Loran-C service was called NIP - National Implementation Plan. This together with the Loran Improvement Program (LIP) ensured that not only was the CCZ covered, but that the coverage extended well beyond the CCZ and still maintained the high degree of accuracy and reliability originally advertised. In fact, reliability has continued to improve through equipment advancements to the point where, today, 99.9% availability and greater is enjoyed by the Loran user community.

Theory of Operation

Loran-C navigation is made possible by user equipment that measures the difference of time of arrival (TOA) in microseconds between two fixed transmitting locations. This measurement does not, however, define a unique point on the earth. It describes instead, a unique hyperbolic line-of-position or LOP. In theory, each unique time difference (TD) describes one classical hyperbolic LOP that is generated relative to the two fixed transmitting locations.

By introducing another transmitting station a different set of LOP's is created. Where an LOP of one set crosses an LOP of another set, a "fix" can be obtained. This fix is defined by the simultaneous time difference numbers of intersecting LOP's.

Theoretically, there are an infinite number of classical hyperbolic LOP's between transmitting sites and each LOP is defined by its own unique TOA difference. However, real world measurements indicate that the actual LOP's are far from classical. They're actually warped and bent in some areas, not at all like classical hyperbolic lines.

This warping and bending of the LOP's is caused by the different impedances encountered by the Loran-C transmissions as they propagate across different and varying terrains. For instance, there is virtually no warping or bending of transmissions as they travel over salt water, but across land, which is non-homogeneous, the transmissions are randomly affected, thus causing varying degrees of warpage and coverage loss.

Chain Planning

The primary purpose of a Loran-C chain is to provide the optimum coverage in a predetermined geographic area. Coverage includes not only signal strength, but also position geometry necessary to obtain the required accuracy. The primary considerations when designing a Loran-C chain are:

(1) desired signal strength
(2) background noise level
(3) system geometric constraints
(4) Group Repetition Interval (GRI) selection
(5) specific station positioning

The signal strength at a specific location in the Loran-C service area is dependent upon the transmitted power and the conductivity of the path over which the signal must propagate to reach the observer. Transmitted power is primarily a function of both antenna and antenna current; the greater the power radiated, the further away the signal can be received.

Signal attenuation is a function of the conductivity of the surface over which the signal must propagate. When the path is homogeneous in conductivity as in propagation over sea water, the signal level can be easily computed. However, when the propagation paths are mixed in conductivity as they are in land masses, Millington's Method is used to compute signal strength. The usable coverage area is limited by both the signal strength and the geometric relationship of the LOP's. To be useful to the navigator, intersecting LOP's should cross at 30 degrees or greater. This is necessary to provide a 2 drms accuracy of 1/4 nautical mile.

The transmitting sites chosen with regard to the previously discussed constraint can vary up to 25-30 miles without an appreciable effect on system coverage. The final site selection becomes one that must consider both electronic and civil constraints.

Timing

Group Repetition Interval (GRI) is the interval between successive pulse groups measured at any one station in a chain. In general, the goal of GRI selection is to select a minimum GRI that causes minimum mutual interference between Loran-C GRI's in the coverage area. A consideration in the selection of a GRI is that it be as fast as possible, since increased duty cycle will provide a relative signal to noise improvement. For example, a difference between a GRI of 100,000 μsec (GRR=10CPS) and one of 50,000 μsec (GRR=20CPS) would show an apparent gain in signal to noise equal to +3db.

$$S/N = 20 \log GRR1/GRR2 + 20 \log 20/10 = +3db$$

This is equivalent to an increase in power by a factor of 2.

Factors governing the determination of minimum GRI are:

(1) pulse spacing
(2) receiver recovery time
(3) coding delays

The current Loran-C format provides for a master pulse group of nine pulses. The first eight of which are spaced 1000 μsec apart and a ninth pulse occuring 2000 μsec after the start of the eighth pulse. The secondary pulse groups are all identical in format but consist of only eight pulses spaced 1000 μsec apart; no ninth pulse. The width of the individual pulses are a nominal 300 μsec. Therefore, the elapsed time from the start of the first pulse of a group to the end of the group is 9300 μsec for the master and 7300 μsec for the secondary groups.

In addition to the time period occupied by either the master or secondary group, an additional time increment must be included to allow the receiving equipment at the Loran station sufficient time to process the group information. This additional time increment is identified as receiver recovery time. Since the absolute minimum of time of occurence between any two successive pulse groups takes place at a transmitting site, it becomes necessary to consider the minimum receiver recovery time. The recovery time varies between signals received: 4000 μsec for M to X and 3000 μsec for X to Y, Y to Z, and Z to M.

Coding Delay

The purpose of the coding delay assigned to each secondary station is to allow the stations of a chain to transmit sequentially in time and to prevent overlap of the different signal groups anywhere in the system. The Coding Delay takes into account baseline lengths in usec, distances betweeen secondaries, and the number of secondaries in the chain.

To meet the foregoing criteria it is necessary to consider the propagation time between stations, the length of the signal group (in time) and coding delay assigned to the preceeding secondary. For example, a pulse repetition period commences with the transmission of the master's group of nine pulses. The master group is then received at each secondary (W, X, Y, & Z), delayed in time by the amount of the individual baseline distances. The first secondary (Xray), upon receipt of the master group's first pulse initiates a countdown, or fixed delay, to when it will commence its transmission of pulses. This fixed delay allows for reception of all nine of the master's pulses plus recovery time needed by the secondary equipment. The signal transmitted by the first secondary must travel to the next secondary (Yankee) in the proper sequence. Yankee must process the master pulse group, the Xray pulse group and its own delay before it initiates its own transmission. This sequence is repeated throughout the chain until, finally, the master must receive the last secondary's pulse group before it can begin a new cycle of operation.

At the first secondary the minimum allowable coding delay is determined only by the length (time period) of the master pulse group and the secondary equipment recovery time. The master pulse group requires a time period of approximately 7000 μsec between the start of the first pulse and the start of the eighth pulse. The recovery time for the receiver of a master pulse group is 4000 μsec. Therefore, the minimum allowable coding delay for the first secondary becomes the elapsed time from the beginning of the first pulse to the end of the receiver recovery time or 11000 μsec.

At the second secondary, the minimum allowable coding delay is governed by the time required for the propagation, and receipt of the master and the first secondary pulse group plus the equipment recovery time.

In developing Coding Delay assignments, the computed result is rounded off to the next higher 1000 μsec increment (unless it computes to an even thousand usec value). In assigning the order of secondary functions it is well to try all possible combinations at each location since significant differences in the calculated minimum GRI may be realized.

Calibration

Once a Loran-C chain is established and initial coding delays are assigned to all of the secondaries, it becomes necessary to check or calibrate the entire chain and make minor corrections. The primary purpose of a Loran-C chain calibration is to ensure that the Emission Delay (ED) of each secondary station is set to the value published by the U.S. Coast Guard. Emission Delay is the time interval between the master station's transmission and the secondary station's transmission in the same GRI (both stations using a common time reference). This calibration technique is accomplished using a portable cesium oscillator or "Hot Clock", which is synchronized to Universal Time Coordinated (UTC). The time of each station's respective Time of Transmission (TOT) is measured against the chain's GRI when synchronized to UTC. The Hot Clock is used to provide the extremely accurate frequency for the Repetition Rate Generator and to provide the one pulse per second (1PPS) for Time of

Coincidence (TOC) determination and synchronization. This is basically a hardware implementation of the definition of Emission Delay (ED).

Data is collected first at the master, then at each secondary station and, finally, at the master again. The collection is performed at the base of the transmitting antenna. A clamp-on current transformer is installed and the signal is coupled directly to a common mode rejection filter, then to a coupler unit. The signal is then fed to an oscilloscope and the Computing Counter.

The TOC for the GRI being measured is calculated and the reference GRI is synchronized to it. A pulse, corresponding to the beginning of the reference GRI, is coupled to the Computing Counter.

Time of Transmission (TOT) readings are recorded for each pulse. Each TOT is the mean value of 100 separate samples of the time difference between the beginning of the reference GRI and the standard Zero crossover (SZC) of the pulse being measured. Then the TOT of the next pulse is measured.

The purpose of the two visits to the master station is to set a start time for the calibration and to determine the frequency offset between the master operated oscillator and the Hot Clock. The clock error rate, expressed in nanoseconds per hour (the rate at which the Hot Clock 1PPS output is shifting in time, with respect to that of the master operate oscillator) is calculated by measuring the timing offset between the two visits and dividing by the elapsed time from the first to the second measurement.

Using the Clock Error Rate and the period of the time between the first master data collection and the data collection at the secondaries, a correction to the secondary TOT's is determined and applied. The effect of this correction is to get an actual TOT which has been corrected for Hot Clock drift.

The Controlling Standard Time Difference (CSTD) offset for the baseline, as seen at the monitor site in control of the pair, is algebraically subtracted from the TOT's to correlate the measured TOT with the assigned CSTD. Then the individual pulse TOT's for each station are adjusted to the first pulse of the respective phase code groups. The mean is taken of the adjusted TOT's, yielding the final TOT for the station.

The Emission Delay of each secondary is calculated as follows:

EDs = TOTs - TOTm
The CSTD correction is determined as

COR = EDp -EDs
where EDp is the published ED for the baseline. The correction is added algebraically to the presently assigned CSTD to arrive at the value for the new CSTD.

Chart Verification

The Coast Guard is aware that the user may still find incorrect positioning information. This is caused by the varying attenuation of the signal previously mentioned that cannot be accurately predicted. However, the Coast Guard performs surveys to verify the published chart grids against actual received Loran-C signals. The Coast Guard has been verifying, and will continue to verify, the Loran-C navigation charts until satisfied that the information published is valid when compared to the actual signal received. Through the accumulation of Loran-C data, collected simultaneously with information from either Navsat, radio triangulation, or their combination, and the eventual, comparison of this data to published charts, LOP perturbations are identified and charted and a new, more accurate navigational chart is published through DMA.

Future Developments

What about Loran-C for the future? Obviously, much, if not all, of the growth of Coast Guard operated Loran-C is over. The CCZ is covered. However, certain international developments have created a need and a desire to install Loran-C chains in various locations: the Suez Canal for one, the Bay of Biscay for another. These chains are paid for and operated by other foreign governments for their own purposes. The GRI selection is normally coordinated through the U.S. Coast Guard. And the Coast Guard does provide, when asked, any technical or operational information deemed necessary or helpful.

Internally, the Coast Guard is preparing for anticipated hardware improvements, which could allow for almost complete automated Loran-C operations. Through the distribution of Hewlett-Packard 9825's and specially prepared Calculator Assisted Loran Controller (CALOC) software, much of the transmitting station monitoring functions will become automated. Further, the use of Hewlett-Packard 9845 calculators promises to allow many of the monitoring sites to be automated and remoted to the control stations, allowing a substantial decrease in the number of personnel required to monitor the transmitted signals.

The Solid-state Transmitter (AN/FPN-64), along with special Remote Operating System (ROS) hardware, promises further personnel reductions. Crews of 11 or more can be effectively reduced to 4. The Coast Guard is presently planning to replace the old AN/FPN-42 transmitters with the AN/FPN-64.

Yet all of this hardware improvement and subsequent personnel reduction is being planned and coordinated so there will be no degradation in signal or service. The established goals of 1200 nautical mile range, 1/4 mile accuracy, 15 meter repeatability, and 99.7% availability will continue to be met or exceeded well into the next decade.