CHAPTER 24

LORAN NAVIGATION

INTRODUCTION TO LORAN

2400. History and Role of Loran

The theory behind the operation of hyperbolic navigation systems was known in the late 1930s, but it took the urgency of World War II to speed development of the system into practical use. By early 1942, the British had an operating hyperbolic system in use designed to aid in long-range bomber navigation. This system, named Gee, operated on frequencies between 30 MHz and 80 MHz and employed "master" and "slave" transmitters spaced approximately 100 miles apart. The Americans were not far behind the British in development of their own system. By 1943, the U. S. Coast Guard was operating a chain of hyperbolic navigation transmitters that became **Loran-A** (The term Loran was originally an acronym for LOng RAnge Navigation). By the end of the war, the network consisted of over 70 transmitters providing coverage over approximately 30% of the earth's surface.

In the late 1940s and early 1950s, experiments in low frequency Loran produced a longer range, more accurate system. Using the 90-110 kHz band, Loran developed into a 24-hour-a-day, all-weather radionavigation system named **Loran-C**. From the late 1950s, Loran-A and Loran-C systems were operated in parallel until the mid-1970s when the U.S. Government began phasing out Loran-A. The United States continued to operate Loran-C in a number of areas around the world, including Europe, Asia, the Mediterranean Sea, and parts of the Pacific Ocean until the mid-1990s when it began closing its overseas Loran-C stations or transferring them to the governments of the host countries. This was a result of the U.S. Department of Defense adopting the Global Positioning System (GPS) as its primary radionavigation service.

From the 1990s until 2010, Loran served the 48 contiguous states within the United States, their coastal areas, Alaska, and nine of 13 provinces in Canada. North American Loran-C signals, however, were terminated in 2010 in accordance with the 2010 Department of Homeland Security Appropriations Act. The United States Coast Guard ceased transmitting Loran-C signals on 08 FEB 2010 across most of the United States. On 03 AUG 2010, US stations that operated in concert with Canadian stations, and the Canadian stations themselves, ceased transmitting. The Unites States government began dismantling former Loran-C stations until 2014 when the "Howard Coble Coast Guard and Maritime Transportation Act of 2014" was signed into law. The "Coast Guard Authorization Act of 2015" extended this provision until the Secretary of the agency overseeing the Coast Guard could justify that the Loran-C infrastructure was not needed as a backup to GPS.

As of early 2014, various countries still had operational Loran-C transmitters (or Loran-C equivalents such as the Russian Chayka system) including China, India, Japan, Northwest Europe (e.g., United Kingdom, France, Norway, Germany, and Denmark), Russia, Saudi Arabia, and South Korea. In 2014, Norway and France announced that they would shut down their transmitters on 31 December 2015. Sites in Denmark, Germany, and the U.K. subsequently decided to shut down transmitters as well though the Anthorn transmitter in Cumbria (U.K.) remains active.

In 2001, the "Volpe" report (United States Department of Transportation 2001) outlined key vulnerabilities in the reliance of GPS for critical infrastructure needs. This report (United States Department of Transportation 2001) was the first to mention the use of **Enhanced Loran** or **eLoran** as it is now called. eLoran was conceived and designed as a modern, 21st century replacement to Loran-C. eLoran was outlined as a backup navigational and timing method to a Global Navigation Satellite System (GNSS) such as GPS in instances where a GNSS system may be unavailable or untrustworthy. It was conceived as a result of the "Loran Modernization Program" and has greater accuracy than Loran-C and new features (International Loran Association 2007). The eLoran definition document, stating the design of the eLoran system, was released on 16 October 2007 (International Loran Association 2007) outlining the requirements that this new method must have and how it differs from Loran-C. As of 2016 eLoran is currently being tested at stations across the United States (UrsaNav 2015). South Korea is set to build eLoran stations in response to North Korean GPS jamming (GPS World 2016) and other countries are seeking to build eLoran infrastructure. With the cessation of signals in Northwest Europe on 31 December 2015, eLoran is no longer available for navigational use anywhere in the world. The UK continues to operate their Anthorn eLoran station for the provision of data communications and timing. eLoran signals are also transmitted from the former USCG Loran Support Unit in Wildwood, New Jersey as part of a Cooperative Research and Development Agreement (CRADA) between the DHS, USCG, UrsaNav, and Harris Corporation.

Additional information on eLoran may be found at the end of this chapter. See Section 2418.

LORAN-C DESCRIPTION

2401. Summary of Operation

The Loran-C signal is still transmitted on a continuous basis from stations in China, South Korea, and the Kingdom of Saudi Arabia. Additionally, the Chayka signal is still transmitted from stations in Russia. Modern Enhanced Loran (eLoran) is intermittently tested in the UK and US. Legacy Loran-C receivers can be used with eLoran. However, legacy receivers cannot take advantage of the Loran Data Channel, a key component of eLoran that is necessary to achieve the enhanced capabilities. All of the information presented about Loran-C is given because it is the basis of Loran-C navigation and all Loran-C navigation methods would also apply using eLoran. Some information and aids, such as Loran-C charts are not directly available or maintained by the United States government.

The Loran-C (hereafter referred to simply as Loran) system consists of **transmitting stations**, which are placed several hundred miles apart and organized into **chains**. Within a Loran chain, one station is designated as the master station and the others as **secondary stations**. Every Loran chain contains at least one master station and two secondary stations in order to provide at least two lines of position (LOP).

The master and secondary stations transmit radio pulses at precise time intervals. A Loran receiver measures the **time difference** (or time delay) **(TD)** between the vessel's receipt of the master and secondary station signal transmissions. The elapsed time is converted to distance, the locus of points having the same TD between the master and secondary forms the hyperbolic LOP. The navigator records the delayed TD values and applies them to the chart by interpolating between the printed lattice lines, manually plotting the LOPs parallel to lattice lines. The intersection of two or more of these LOPs produces a fix of the vessel's position.

There are two methods by which the navigator can convert this information into a geographic position. The first involves the use of a chart overprinted with a Loran **time delay lattice** consisting of hyperbolic TD lines spaced at convenient intervals. The navigator plots the displayed TDs by interpolating between the lattice lines printed on the chart, manually plotting the fix where lines intersect to determine latitude and longitude. In the second method, computer algorithms in the receiver's software convert the TDs to latitude and longitude for display.

As with other computerized navigation receivers, a typical Loran receiver can accept and store **waypoints**. Waypoints are sets of coordinates that describe either locations of navigational interest or points along a planned route. Waypoints may be entered by visiting the spot of interest and pressing the appropriate receiver control key, or by keying in the waypoint coordinates manually, either as a TD or latitude-longitude pair. If using waypoints to mark a planned route, the navigator can use the receiver to monitor the vessel's progress in relation to the track between each waypoint. By continuously providing parameters such as cross-track error, course over ground, speed over ground, and bearing and distance to next waypoint, the receiver continually serves as a check on the primary navigation plot.

2402. Components of the Loran System

For the marine navigator, the components of the Loran system consist of the land-based transmitting stations, the Loran **receiver** and **antenna**, and the **Loran charts**. In addition to the master and secondary transmitting stations, land-based Loran facilities also include the primary and secondary **system area monitor sites**, the **control station** and a precise time reference. The transmitters emit Loran signals at precisely timed intervals. The monitor sites and control stations continually measure and analyze the characteristics of the Loran signals received to detect any anomalies or out-of-specification conditions. Some transmitters serve only one function within a chain (i.e., either master or secondary). However, in many instances, one transmitter transmits signals for each of two adjacent chains. This practice is termed **dual rating**.

Loran receivers exhibit varying degrees of sophistication, but their signal processing is similar. The first processing stage consists of **search and acquisition**, during which the receiver searches for the signal from a particular Loran chain and establishes the approximate time reference of the master and secondaries with sufficient accuracy to permit subsequent settling and tracking.

After search and acquisition, the receiver enters the **settle** phase. In this phase, the receiver searches for and detects the front edge of the Loran pulse. After detecting the front edge of the pulse, it selects the correct cycle of the pulse to track.

Having selected the correct tracking cycle, the receiver begins the **tracking and lock** phase, in which the receiver maintains synchronization with the selected received signals. Once this phase is reached, the receiver displays either the time difference of the signals or the computed latitude and longitude.

2403. The Loran Signal

The Loran signal consists of a series of 100 kHz pulses sent first by the master station and then, in turn, by the secondary stations. Both the shape of the individual pulse and the pattern of the entire pulse sequence are shown in Figure 2403a. As compared to a carrier signal of constant amplitude, pulsed transmission allows the same signal range to be achieved with a lower average output power. Pulsed transmission also yields better signal identification properties and more precise timing of the signals.

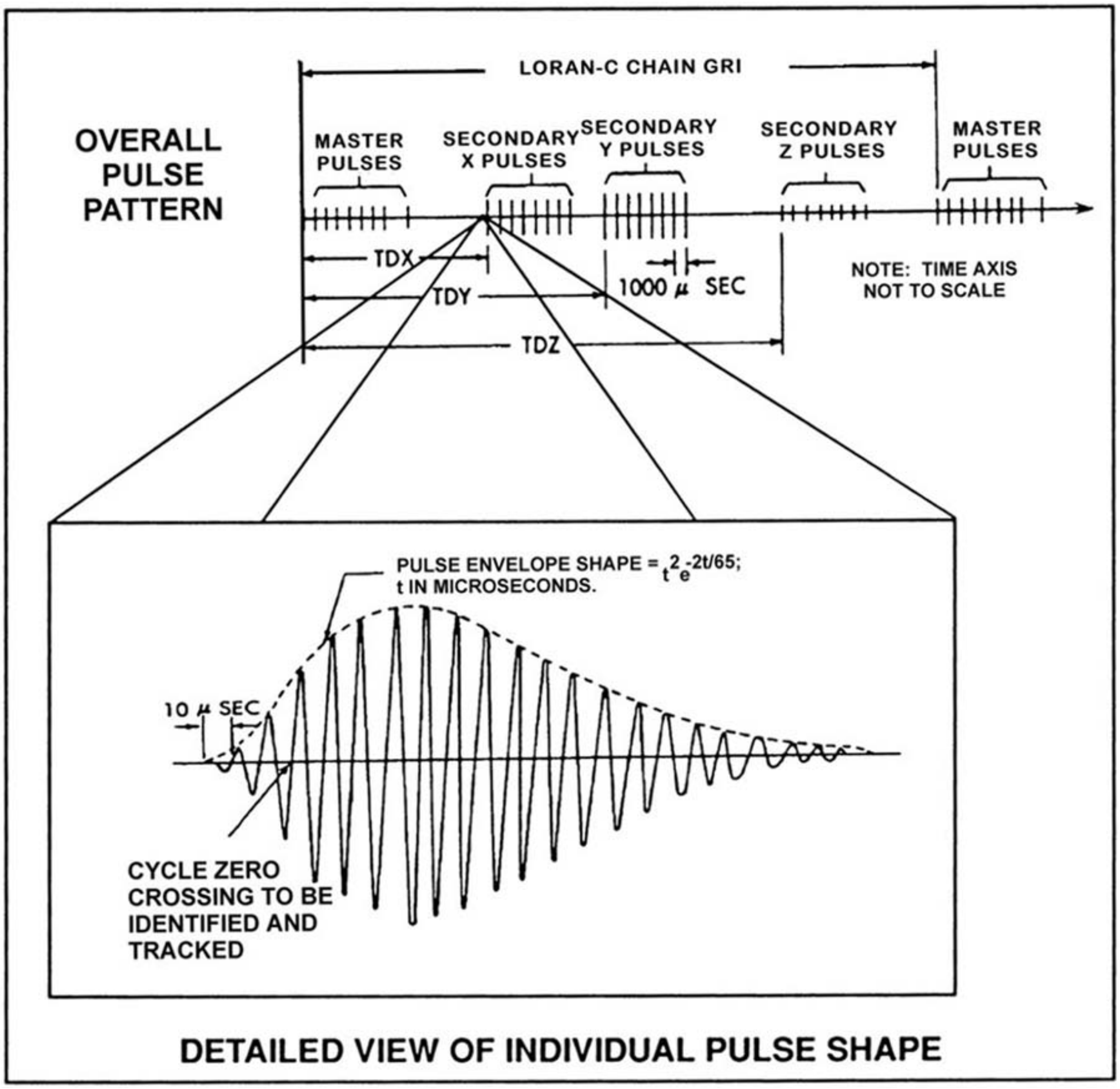

Figure 2403a. Pulse pattern and shape for Loran C transmission.

The individual sinusoidal Loran pulse exhibits a steep rise to its maximum amplitude within 65 µsec of emission and an exponential decay to zero within 200 to 300 µsec. The signal frequency is nominally defined as 100 kHz; in actuality, the signal is designed such that 99% of the radiated power is contained in a 20 kHz band centered on 100 kHz.

The Loran receiver is programmed to track the signal on the cycle corresponding to the carrier frequency's third positive crossing of the x-axis. This occurrence, termed the **standard zero crossing**, is chosen for two reasons. First, it is late enough for the pulse to have built up sufficient signal strength for the receiver to detect it. Second, it is early enough in the pulse to ensure that the receiver is detecting the transmitting station's ground wave pulse and not its sky wave pulse. Sky wave pulses are affected by atmospheric refraction and, if used unknowingly, would introduce large errors into positions determined by a Loran receiver. The pulse architecture described here reduces this major source of error.

Another important parameter of the pulse is the **envelope-to-cycle difference (ECD)**. This parameter indicates how propagation of the signal causes the pulse shape envelope (i.e., the imaginary line connecting the peak of each sinusoidal cycle) to shift in time relative to the zero crossings. The ECD is important because Loran-C receivers use the precisely shaped pulse envelope to identify the correct zero crossing. Transmitting stations are required to keep the ECD within defined limits. Many receivers display the received ECD as well.

Next, individual pulses are combined into sequences. For the master signal, a series of nine pulses is transmitted, the first eight spaced 1000 µsec apart followed by a ninth transmitted 2000 µsec after the eighth. Secondary stations

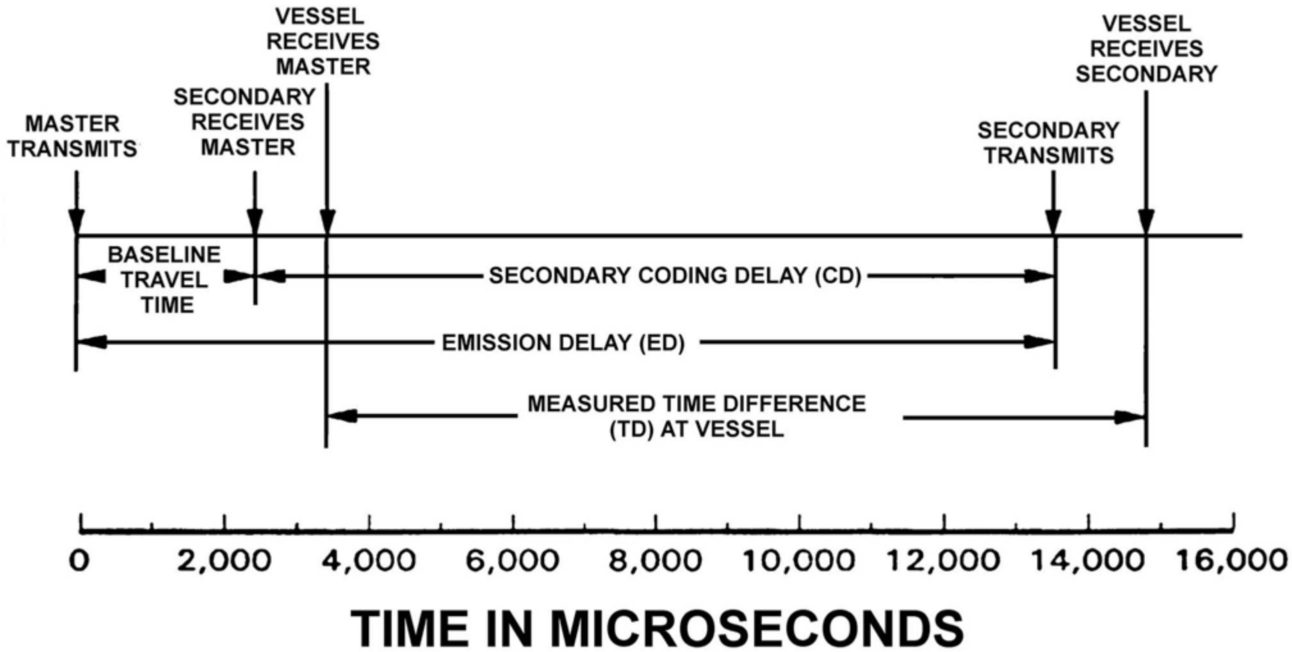

Figure 2403b. The time axis for Loran TD for point "A."

transmit a series of eight pulses, each spaced 1000 µsec apart. Secondary stations are given letter designations of V, W, X, Y, and Z; this letter designation indicates the order in which they transmit following the master. If a chain has two secondaries, they will be designated Y and Z. If a chain has three secondaries, they are X, Y and Z, and so on. Some exceptions to this general naming pattern exist (e.g., W, X and Y for some 3-secondary chains).

The spacing between the master signal and each of the secondary signals is governed by several parameters as illustrated in Figure 2403b. The general idea is that each of the signals must clear the entire chain coverage area before the next one is transmitted, so that no signal can be received out of order. The time required for the master signal to travel to the secondary station is defined as the average **baseline travel time (BTT)**, or **baseline length (BLL)**. To this time interval is added an additional delay defined as the **secondary coding delay (SCD)**, or simply **coding delay (CD)**. The total of these two delays is termed the **emission delay (ED)**, which is the exact time interval between the transmission of the master signal and the transmission of the secondary signal. Each secondary station has its own ED value. To ensure the proper sequence, the ED of secondary Y is longer than that of X, and the ED of Z is longer than that of Y.

Once the last secondary has transmitted, the master transmits again, and the cycle is repeated. The time to complete this cycle of transmission defines an important characteristic for the chain: the **group repetition interval (GRI)**. The group repetition interval divided by ten yields the chain's numeric designator. For example, the interval between successive transmissions of the master pulse group for the Northeast U.S. Chain (commonly referred to as "NEUS") is 99,600 µsec, just less than one tenth of a second. From the definition above, the GRI designator for this chain is defined as 9960. As mentioned previously, the GRI must be sufficiently large to allow the signals from the master and secondary stations in the chain to propagate fully throughout the region covered by the chain before the next cycle of pulses begins.

Two additional characteristics of the pulse group are **phase coding** and **blink coding**. In phase coding, the phase of the 100 kHz carrier signal is reversed from pulse to pulse in a preset pattern that repeats every two GRIs. Phase coding allows a receiver to remove skywave contamination from the groundwave signal. Loran-C signals travel away from a transmitting station in all possible directions. Groundwave is the Loran energy that travels along the surface of the earth. Skywave is Loran energy that travels up into the sky. The ionosphere reflects some of these skywaves back to the earth's surface. The skywave always arrives later than the groundwave because it travels a greater distance. The skywave of one pulse can thus contaminate the ground wave of the next pulse in the pulse group. Phase coding ensures that this skywave contamination will always "cancel out" when all the pulses of two consecutive GRIs are averaged together.

Blink coding provides integrity to the received Loran signal. When a signal from a secondary station is out of tolerance and therefore temporarily unsuitable for navigation, or **out-of-tolerance (OOT)**, the affected secondary station will blink; that is, the first two pulses of the affected secondary station are turned off and on in a repeating cycle, 3.6 seconds off and 0.4 seconds on. The receiver detects this condition and displays it to the operator. When the blink indication is received, the operator should not use the affected secondary station. If a station's signal will be temporarily shut down for maintenance, interruption notifications will be promulgated by responsible local authorities. When a secondary station is blinking, the master station will also blink its ninth pulse in a predetermined pattern that identifies the out-of-tolerance secondary or secondaries. If a master station is out of tolerance, all secondaries in the affected chain will blink. If the entire chain is OOT, then the master and all secondaries will blink.

Two other concepts important to the understanding of Loran operation are the **baseline** and **baseline extension**. The geographic line connecting a master to a particular secondary station is defined as the station pair baseline. The baseline is, in other words, that part of a great circle on which lie all the points connecting the two stations. The extension of this line beyond the stations to encompass the points along this great circle not lying between the two stations defines the baseline extension. The optimal region for hyperbolic navigation occurs in the vicinity of the baseline, while the most care must be exercised in the regions near the baseline extension. These concepts are further developed in the next few articles.

2404. Loran Theory of Operation

In Loran navigation, the locus of points having a constant difference in distance between an observer and each of two transmitter stations defines a hyperbola, which is a line of position.

Assuming a constant speed of propagation of electromagnetic radiation in the atmosphere, the time difference in the arrival of electromagnetic radiation from the two transmitter sites is proportional to the distance between each of the transmitting sites, thus creating the hyperbola on the earth's surface. The following equations demonstrate this proportionality between distance and time:

Distance = Velocity x Time

or, using algebraic symbols

d = v x t

Therefore, if the velocity (v) is constant, the distance between a vessel and each of two transmitting stations will be directly proportional to the time delay detected at the vessel between pulses of electromagnetic radiation transmitted from the two stations.

An example illustrates the concept. As shown in Figure 2404, let us assume that two Loran transmitting stations, a master and a secondary, are located along with an observer in a Cartesian coordinate system whose units are in nautical miles. We assume further that the master station, designated "M", is located at coordinates (x,y) = (-200,0) and the secondary, designated "X," is located at (x,y) = (+200,0). An observer with a receiver capable of detecting electromagnetic radiation is positioned at any point "A" whose coordinates are defined as (x_a, y_a).

Note that for mathematical convenience, these hyperbola labels have been normalized so that the hyperbola perpendicular to the baseline is labeled zero, with both negative and positive difference values. In actual practice, all Loran TDs are positive.

The Pythagorean theorem can be used to determine the distance between the observer and the master station; similarly, one can obtain the distance between the observer and the secondary station:

$$\text{distance}_{am} = [(x_a + 200)^2 + y_a^2]^{0.5}$$

$$\text{distance}_{ax} = [(x_a - 200)^2 + y_a^2]^{0.5}$$

The difference between these distances (D) is:

$$D = \text{distance}_{am} - \text{distance}_{ax}$$

Substituting,

$$D = [(x_a + 200)^2 + y_a^2]^{0.5} - [(x_a - 200)^2 + y_a^2]^{0.5}$$

With the master and secondary stations in known geographic positions, the only unknowns are the two geographic coordinates of the observer.

Each hyperbolic line of position in Figure 2404 represents the locus of points for which (D) is held constant. For example, if the observer above were located at point A (271.9, 200) then the distance between that observer and the secondary station (the point designated "X" in Figure 2404) would be 212.5 NM. In turn, the observer's distance from the master station would be 512.5 NM. The function D would simply be the difference of the two, or 300 NM. For every other point along the hyperbola passing through A, distance D has a value of 300 NM. Adjacent LOPs indicate where D is 250 NM or 350 NM.

To produce a fix, the observer must obtain a similar hyperbolic line of position generated by another master-secondary pair. Let us say another secondary station "Y" is placed at point (50,500). Mathematically, the observer will then have two equations corresponding to the M-X and M-Y TD pairs:

$$D_1 = [(x_a + 200)^2 + y_a^2]^{0.5} - [(x_a - 200)^2 + y_a^2]^{0.5}$$

$$D_2 = [(x_a + 200)^2 + y_a^2]^{0.5} - [(x_a - 50)^2 + (y_a - 500)^2]^{0.5}$$

Distances D_1 and D_2 are known because the time differences have been measured by the receiver and converted to these distances. The two remaining unknowns, x_a and y_a, may then be solved.

The above example is expressed in terms of distance in nautical miles. Because the navigator uses TDs to perform Loran hyperbolic navigation, let us rework the example for the M-X TD pair in terms of time rather than distance, adding timing details specific to Loran. Let us assume that electromagnetic radiation travels at the speed of light (one nautical mile traveled in 6.18 µsec). The distance from master station M to point A was 512.5 NM. From the relationship just defined between distance and time, it would take a signal (6.18 µsec/NM) 512.5 NM = 3,167 µsec to travel from the master station to the observer at point A. At the arrival of this signal, the observer's Loran receiver would start the TD measurement. Recall from the general discussion above that a secondary station transmits after an emission delay equal to the sum of the baseline travel time and the secondary coding delay. In this example, the master and the secondary are 400 NM apart; therefore, the baseline travel time is (6.18 µsec/NM) 400 NM = 2,472 µsec. Assuming a secondary coding delay of 11,000 µsec, the secondary station in this example would transmit (2,472 + 11,000) µsec or 13,472 µsec after the master station. The secondary signal then propagates over a distance 212.5 NM to reach point A, taking (6.18 µsec/NM) 212.5 NM = 1,313 µsec to do so. Therefore, the total time from *transmission* of the master signal to the *reception* of the secondary signal by the observer at point A is (13,472 + 1,313) µsec = 14,785 µsec.

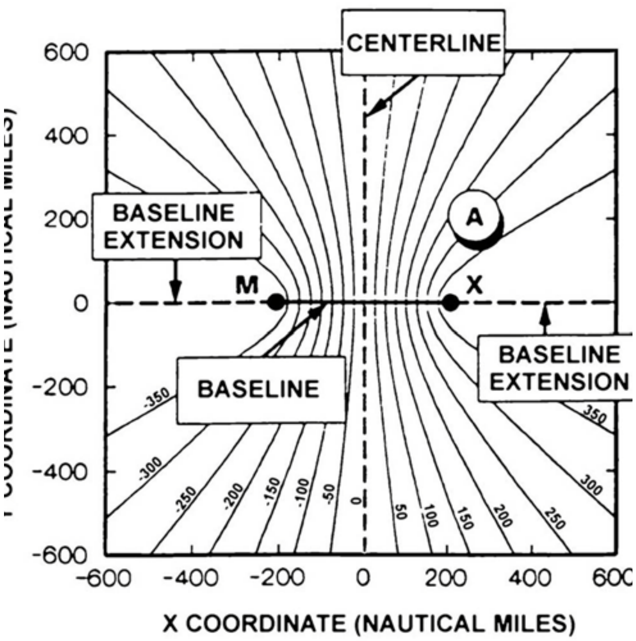

Figure 2404. Depiction of Loran LOP's.

Recall, however, that the Loran receiver measures the time delay between *reception* of the master signal and *reception* of the secondary signal. Therefore, the time quantity above must be corrected by subtracting the amount of time required for the signal to travel from the master transmitter to the observer at point A. This amount of time was 3,167 µsec. Therefore, the TD observed at point A in this hypothetical example would be (14,785 - 3,167) µsec or 11,618 µsec. Once again, this time delay is a function of the simultaneous differences in distance between the observer and the two transmitting stations, and it gives rise to a hyperbolic line of position which can be crossed with another LOP to fix the observer's position.

2405. Allowances for Non-Uniform Propagation Rates

The initial calculations above assumed the speed of light in free space; however, the actual speed at which electromagnetic radiation propagates on earth is reduced both by the atmosphere through which it travels and by the conductive surfaces—sea and land—over which it passes. The specified accuracy needed from Loran therefore requires three corrections to the propagation speed of the signal.

The reduction in propagation speed caused by the atmosphere is represented by the first correction term: the **Primary Phase Factor (PF)**. Similarly, a **Secondary Phase Factor (SF)** accounts for the reduced propagation speed caused by traveling over seawater. These two corrections are transparent to the operator because they are uniformly incorporated into all calculations represented on charts and in Loran receivers.

Because land surfaces have lower conductivity than seawater, the propagation speed of the Loran signal passing over land is further reduced as compared to the signal passing over seawater. A third and final correction, the **Additional Secondary Phase Factor (ASF)**, accounts for the delay caused by the land conductivity when converting time delays to distances and then to geographic coordinates. Depending on the mariner's location, signals from some Loran transmitters may have traveled hundreds of miles over land and must be corrected to account for this non-seawater portion of the signal path. Of the three corrections mentioned in this section, this is the most complex and the most important one to understand, and is accordingly treated in detail in Section 2410.

LORAN ACCURACY

2406. Defining Accuracy

Specifications of Loran and other radionavigation systems typically refer to three types of accuracy: **absolute, repeatable** and **relative.**

Absolute accuracy, also termed predictable or geodetic accuracy, is the accuracy of a position with respect to the geographic coordinates of the earth. For example, if the navigator plots a position based on the Loran latitude and longitude (or based on Loran TDs) the difference between the Loran position and the actual position is a measure of the system's absolute accuracy.

Repeatable accuracy is the accuracy with which the navigator can return to a position whose coordinates have been measured previously with the same navigational system. For example, suppose a navigator were to travel to a buoy and note the TDs at that position. Later, suppose the navigator, wanting to return to the buoy, returns to the previously measured TDs. The resulting position difference between the vessel and the buoy is a measure of the system's repeatable accuracy.

Relative accuracy is the accuracy with which a user can measure position relative to that of another user of the same navigation system at the same time. If one vessel were to travel to the TDs determined by another vessel, the difference in position between the two vessels would be a measure of the system's relative accuracy.

The distinction between absolute and repeatable accuracy is the most important one to understand. With the correct application of ASFs and within the **coverage area** defined for each chain, the absolute accuracy of the Loran system varies from between 0.1 and 0.25 nautical miles. However, the repeatable accuracy of the system is much better, typically between 18 and 90 meters (approximately 60 to 300 feet) depending on one's location in the coverage area. If the navigator has been to an area previously and noted the TDs corresponding to different navigational aids (e.g., a buoy marking a harbor entrance), the high repeatable accuracy of the system enables location of the buoy in adverse weather. Similarly, selected TD data for various harbor navigational aids and other locations of interest have been collected and recorded and is generally commercially available. This information provides an excellent backup navigational source to conventional harbor approach navigation.

2407. Limitations to Loran Accuracy

There are limits on the accuracy of any navigational system, and Loran is no exception. Several factors that contribute to limiting the accuracy of Loran as a navigational aid are listed in Table 2407 and are briefly discussed in this section. Even though all these factors except operator error are included in the published accuracy of Loran, the mariner's aim should be to have a working knowledge of each one and minimize any that are under their control so as to obtain the best possible accuracy.

The geometry of LOPs used in a Loran fix is of prime importance to the mariner. Because understanding of this factor is so critical to proper Loran operation, the effects of crossing angles and gradients are discussed in detail in the Section 2408. The remaining factors are briefly explained as follows.

The age of the North American (i.e. US and Canadian) Loran transmitting equipment varies from station to station. When some older types of equipment are switched from standby to active and vice versa, a slight timing shift as large as tens of nanoseconds may be seen. This is so small that it is undetectable by most marine receivers, but since all errors accumulate, it should be understood as part of the Loran "error budget."

The effects of actions to control chain timing are similar. The timing of each station in a chain is controlled based on data received at the primary system area monitor site. Signal timing errors are kept as near to zero as possible at the primary site, making the absolute accuracy of Loran generally the best in the vicinity of the primary site. Whenever, due to equipment casualty or to accomplish system maintenance, the control station shifts to the secondary system area monitor site, slight timing shifts may be introduced in parts of the coverage area.

Atmospheric noise, generally caused by lightning, reduces the **signal-to-noise ratio (SNR)** available at the receiver. This in turn degrades accuracy of the LOP. Man-made noise has a similar effect on accuracy. In rare cases, a man-made noise source whose carrier signal frequency or harmonics are near 100 kHz (such as the constant carrier control signals commonly used on high-tension power lines) may also interfere with lock-on and tracking of a Loran receiver. In general, Loran stations that are the closest to the user will have the highest SNR and will produce LOPs with the lowest errors. Geometry, however, remains a key factor in producing a good fix from combined LOPs. Therefore, the best LOPs for a fix may not all be from the very nearest stations.

The user should also be aware that the propagation speed of Loran changes with time as well. Temporal changes may be seasonal, due to snow cover or changing groundwater levels, or diurnal, due to atmospheric and surface changes from day to night. Seasonal changes may be as large as 1 μsec and diurnal changes as large as 0.2 μsec, but these vary with location and chain being used. Passing cold weather fronts may have temporary effects as well.

Disturbances on the sun's surface, most notably solar flares, disturb the earth's atmosphere as well. These Sudden Ionospheric Disturbances (SIDs) increase attenuation of radio waves and thus disturb Loran signals and reduce SNR. Such a disturbance may interfere with Loran reception for periods of hours or even longer.

Factor	Has effect on	
	Absolute Accuracy	**Repeatable Accuracy**
Crossing angles and gradients of the Loran LOPs	Yes	Yes
Stability of the transmitted signal (e.g., transmitter effect)	Yes	Yes
Loran chain control parameters (e.g., how closely actual ED is maintained to published ED, which system area monitor is being used, etc.)	Yes	Yes
Atmospheric and man-made ambient electronic noise	Yes	Yes
Factors with temporal variations in signal propagation speed (e.g., weather, seasonal effects, diurnal variations, etc.)	Yes	Yes
Sudden ionospheric disturbances	Yes	Yes
Receiver quality and sensitivity	Yes	Yes
Shipboard electric noise	Yes	Yes
Accuracy with which LOPs are printed on nautical charts	Yes	No
Accuracy of receiver's computer algorithms for coordinate conversion	Yes	No
Operator error	Yes	Yes

Table 2407. Selected Factors that Limit Loran Accuracy.

The factors above all relate to the propagated signal before it reaches the mariner. The remaining factors discussed below address the accuracy with which the mariner receives and interprets the signal.

Receivers vary in precision, quality and sophistication. Some receivers display TDs to the nearest 0.1 µsec; others to 0.01 µsec. Internal processing also varies, whether in the analog "front end" or the digital computer algorithms that use the processed analog signal. By referencing the user manual, the mariner may gain an appreciation for the advantages and limitations of the particular model available, and may adjust operator settings to maximize performance.

The best receiver available may be hindered by a poor installation. Similarly, electronic noise produced by electric motors, other electronic equipment or even fluorescent lighting may hinder the performance of a Loran receiver if the noise source is close to the receive antenna. The mariner should consult documentation supplied with the receiver for proper installation. Generally, proper installation and placement of the of the receive antenna will mitigate these problems. In some cases, contacting the manufacturer or obtaining professional installation assistance may be appropriate.

The raw TDs obtained by the receiver must be corrected with ASFs and then translated to position. Whether the receiver performs this entire process or the mariner assists by translating TDs to position manually using a Loran overprinted chart, published accuracies take into account the small errors involved in this conversion process.

Finally, as in all endeavors, operator error when using Loran is always possible. This can be minimized with alertness, knowledge and practice.

2408. The Effects of Crossing Angles and Gradients

The hyperbolic nature of Loran requires the operator to pay special attention to the geometry of the fix, specifically to crossing angles and gradients, and to the possibility of fix ambiguity. We begin with crossing angles.

As discussed above, the TDs from any given master-secondary pair form a family of hyperbolas. Each hyperbola in this family can be considered a line of position; the vessel must be somewhere along that locus of points which forms the hyperbola. A typical family of hyperbolas is shown in Figure 2408a.

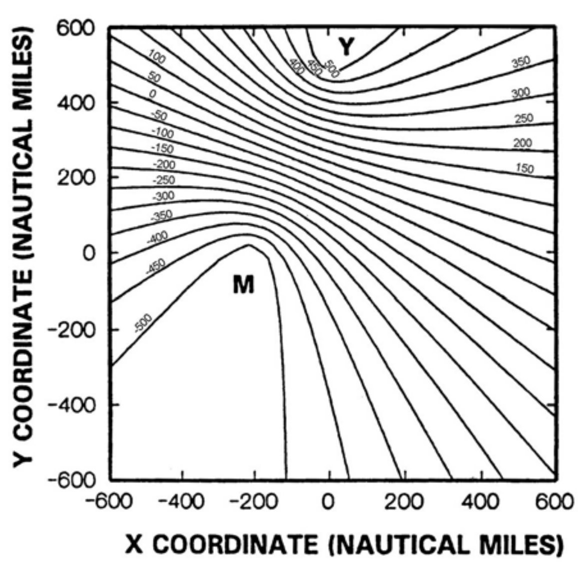

Figure 2408a. A family of hyperbolic lines generated by Loran signals.

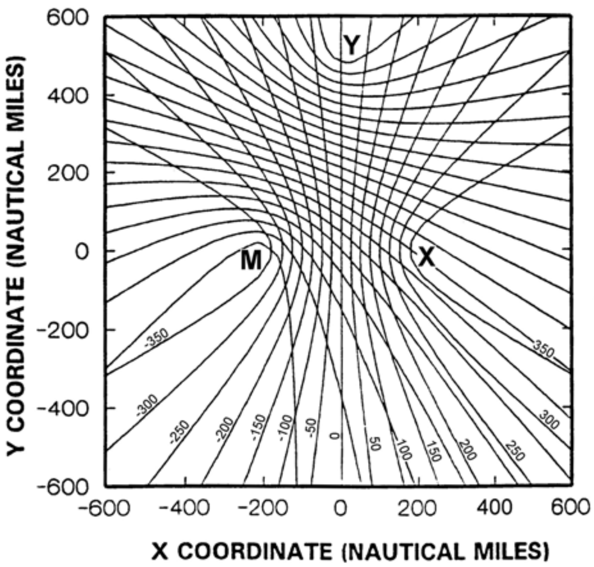

Figure 2408b. A hyperbolic lattice formed by station pairs M-X and M-Y.

Now, suppose the hyperbolic family from the Master-Xray station pair shown in Figure 2404 were superimposed upon the family shown in Figure 2408a. The results would be the hyperbolic lattice shown in Figure 2408b.

As has been noted, Loran LOPs for various chains and secondaries are printed on nautical charts. Each of the sets of LOPs is given a separate color and is denoted by a characteristic set of symbols. For example, an LOP might be designated 9960-X-25750. The designation is read as follows: the chain GRI designator is 9960, the TD is for the Master-Xray pair (M-X), and the time difference along this LOP is 25750 µsec. The chart shows only a limited number of LOPs to reduce clutter on the chart. Therefore, if the observed time delay falls between two charted LOPs, interpolation between them is required to obtain the precise LOP. After having interpolated (if necessary) between two TD measurements and plotted the resulting LOPs on the chart, the navigator marks the intersection of the LOPs and labels that intersection as the Loran fix. Note also in Figure 2408b the various angles at which the hyperbolas cross each other.

Figure 2408c shows graphically how error magnitude varies as a function of crossing angle. Assume that LOP 1 is known to contain no error, while LOP 2 has an uncertainty as shown. As the crossing angle (i.e., the angle of intersection of the two LOPs) approaches 90°, range of possible positions along LOP 1 (i.e., the position uncertainty or fix error) approaches a minimum; conversely, as the crossing angle decreases, the position uncertainty increases; the line defining the range of uncertainty grows longer. This illustration demonstrates the desirability of choosing LOPs for which the crossing angle is as close to 90° as possible.

The relationship between crossing angle and fix uncertainty can be expressed mathematically:

$$\sin(x) = \frac{\text{LOP error}}{\text{fix uncertainty}}$$

where x is the crossing angle.

Rearranging algebraically,

$$\text{fix uncertainty} = \frac{\text{LOP error}}{\sin(x)}$$

Assuming that LOP error is constant, then position uncertainty is inversely proportional to the sine of the crossing angle. As the crossing angle increases from 0° to 90°, the sine of the crossing angle increases from 0 to 1. Therefore, the error is at a minimum when the crossing angle is 90°, and increases thereafter as the crossing angle decreases.

Understanding and proper use of TD gradients are also important to the navigator. The gradient is defined as the rate of change of distance with respect to TD. Put another way, this quantity is the ratio of the spacing between adjacent Loran TDs (usually expressed in feet or meters) and the difference in microseconds between these adjacent LOPs. For example, if at a particular location two printed TD lines differ by 20 µsec and are 6 NM apart, the gradient is.

$$Gradient = \frac{6NM \quad 6076\text{ft/NM}}{20\mu\text{sec}} = 1822.8\ \text{ft}/\mu\text{sec}$$

The smaller the gradient, the smaller the distance error that results from any TD error. Thus, the best accuracy from Loran is obtained by using TDs whose gradient is the smallest possible (i.e. the hyperbolic lines are closest together). This occurs along the baseline. Gradients are much larger (i.e. hyperbolic lines are farther apart) in the vicinity of the baseline extension. Therefore, the user should select TDs having the smallest possible gradients.

Another Loran effect that can lead to navigational error in the vicinity of the baseline extension is fix ambiguity. Fix ambiguity results when one Loran LOP crosses another LOP in two separate places. Near the baseline extension, the “ends” of a hyperbola can wrap around so that they cross another LOP twice, once along the baseline, and again along the baseline extension. A third LOP would resolve the ambiguity.

Most Loran receivers are equipped with an ambiguity alarm to alert the navigator to this occurrence. However, both fix ambiguity and large gradients necessitate that the navigator avoid using a master-secondary pair when operating in the vicinity of that pair’s baseline extension.

2409. Coverage Areas

The 0.25 NM absolute accuracy specified for Loran is valid within each chain's coverage area. This area, whose limits define the maximum range of Loran for a

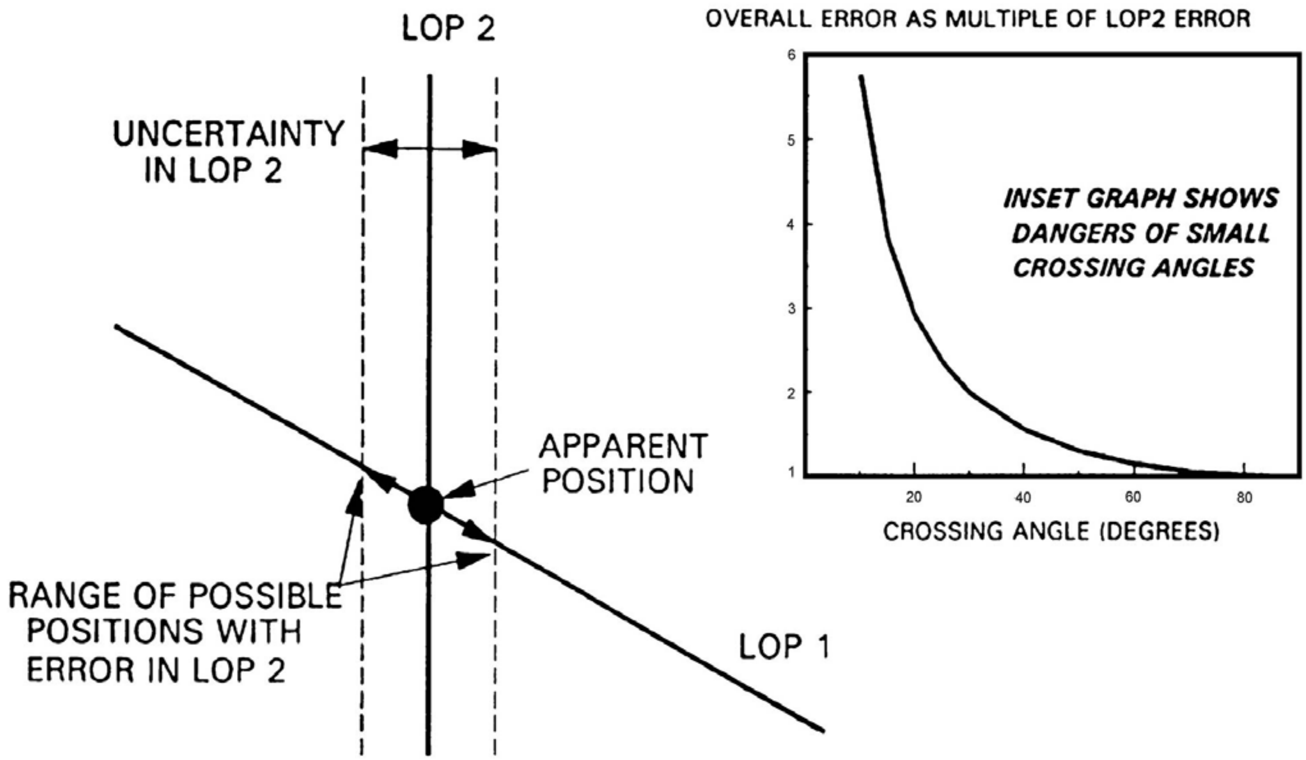

Figure 2408c. Error in Loran LOP's is magnified if the crossing angle is less than 90°.

particular chain, is the region in which both accuracy and SNR criteria are met. The National Oceanic and Atmospheric Administration (NOAA) has generally followed these coverage area limits when selecting where to print particular Loran TD lines on Loran overprinted charts.

One caveat to remember when considering coverage areas is that the 0.25 NM accuracy criteria is modified inside the coverage area in the vicinity of the coastline due to ASF effects. The following section describes this more fully.

2410. Understanding Additional Secondary Factors (ASF's)

Mathematically, calculating the reduction in propagation speed of an electromagnetic signal passing over a land surface of known conductivity is relatively straightforward. In practice, however, determining this Loran ASF correction accurately for use in the real world can be complex.

There are at least four reasons for this complexity. First, the conductivity of ground varies from region to region, so the correction to be applied is different for every signal path. Moreover, ground conductivity data may not take into account all the minor variations within each region. Second, methods used to compute ASFs vary. ASFs can be determined from either a mathematical model based on known approximate ground conductivities, or from empirical time delay measurements in various locations, or a combination of both. Methods incorporating empirical measurements tend to yield more accurate results. One receiver manufacturer may not use exactly the same correction method as another, and neither may use exactly the same method as those incorporated into time differences printed on a particular nautical chart. While such differences are minor, a user unaware of these differences may not obtain the best accuracy possible from Loran. Third, relatively large local variations in ASF variations may not be fully accounted for in the ASF models applied to the coverage area. Over the years, even empirically measured ASFs may change slightly in these areas with the addition of buildings, bridges and other structures to coastal areas. Fourth and finally, ASFs vary seasonally with changes in groundwater levels, snow pack depths and similar factors. However, ASFs are generally consistent year-on-year for a given area.

Designers of the Loran system, including Loran receiver manufacturers, have expended a great deal of effort to include ASFs in error calculations and to minimize these effects. Indeed, inaccuracies in ASF modeling are accounted for in published accuracy specifications for Loran. What then does the marine navigator need to know about ASFs beyond this? To obtain the 0.25 NM absolute accuracy advertised for Loran, the answer is clear. One must know *where* in the coverage area ASFs affect published accuracies, and one must know *when* ASFs are being incorporated, both in the receiver and on any chart in use.

With respect to *where* ASFs affect published accuracies, one must remember that local variations in the vicinity of the coastline are the most unpredictable of all ASF related effects because that is where rapid transitions from water to land occur. As a result, even though fixes determined by Loran may satisfy the 0.25 NM accuracy specification in these areas, such accuracy is not "guaranteed" for Loran within 10 NM of the coast. Users should also avoid relying solely on the lattice of Loran TDs in inshore areas.

With respect to *when* ASFs are being applied, one should realize that the default mode in most receivers combines ASFs with raw TD measurements. This is because the inclusion of ASFs is required to meet the 0.25 NM accuracy criteria. The navigator should verify which mode the receiver is in, and ensure the mode is not changed unknowingly.

The key point to remember there is that the "ASF included" and "ASF not included" modes must not be mixed. In other words, the receiver and any chart in use must handle ASFs in the same manner. If the receiver includes them, any chart in use must also include them. If operating on a chart that does not include ASFs-Loran coverage areas in another part of the world, for example-the receiver must be set to the same mode. If the navigator desires to correct ASFs manually, tables for U.S. Loran chains may be used although are not currently directly available from the U.S. Government. These documents also provide a fuller explanation of manual ASF corrections. When viewing ASF tables, remember that although the ASF correction for a single signal is always positive (indicating that the signal is always slowed and never speeded by its passage over land), the ASF correction for a time difference may be negative because two signal delays are included in the computation.

The U.S. Government does not guarantee the accuracy of ASF corrections incorporated into Loran receivers by their respective manufacturers. The prudent navigator will regularly check Loran TDs against charted LOPs when in a known position, and will compare Loran latitude and longitude readouts against other sources of position information. Ensuring the proper configuration and operation of the Loran receiver remains the navigator's responsibility.

Up to this point, our discussion has largely focused on correctly understanding and using Loran in order to obtain published accuracies. In some portions of the coverage areas, accuracy levels actually obtainable may be significantly better than these minimum published values. The following articles discuss practical techniques for maximizing the absolute, repeatable and relative accuracy of Loran.

2411. Maximizing Loran's Absolute Accuracy

Obtaining the best possible absolute accuracy from Loran rests primarily on the navigator's selection of TDs, particularly taking into account geometry, SNR and proximity to the baseline and baseline extension. As a vessel transits the coverage area, these factors gradually change and, except for SNR, are not visible on the display panel of the Loran receiver. Most receivers track an entire chain and some track multiple chains simultaneously, but the majority of installed marine receivers still use only two TDs to produce a latitude and longitude. Some receivers monitor these factors and may automatically select the best pair. The best way for the navigator, however, to monitor these factors is by referring to a Loran overprinted chart, even if not actually plotting fixes on it. The alert navigator will frequently reevaluate the selection of TDs during a transit and make adjustments as necessary.

Beyond this advice, two additional considerations may help the navigator maximize absolute accuracy. The first is the realization that Loran TD error is not evenly distributed over the coverage area. Besides the effects of transmitter station location on geometry and fix error, the locations of the primary and secondary monitor sites also have a discernible effect on TD error in the coverage area. As ASFs change daily and seasonally, the Loran control stations continually adjust the emission delay of each secondary station to keep it statistically at its nominal value as observed at the primary monitor site. What this means is that, on average, the Loran TD is more stable and more accurate in the absolute sense in the vicinity of the primary monitor site. The primary system area monitor for stations 9960-M, 9960-X and 9960-Y was placed at the entrance to New York Harbor at Sandy Hook, New Jersey for just this reason. A switch by the control station to the secondary monitor site will shift the error distribution slightly within the coverage area, reducing it near the secondary site and slightly increasing it elsewhere.

The second consideration in maximizing absolute accuracy is that most Loran receivers may be manually calibrated using a feature variously called "bias," "offset," "homeport" or a similar term. When in homeport or another known location, the known latitude and longitude (or in some cases, the difference between the current Loran display and the known values) is entered into the receiver. This forces the receiver's position error to be zero at that particular point and time.

The limitation of this technique is that this correction becomes less accurate with the passage of time and with increasing distance away from the point used. Most published sources indicate the technique to be of value out to a distance of 10 to 100 miles of the point where the calibration was performed. This correction does not take into account local distortions of the Loran grid due to bridges, power lines or other such man-made structures. The navigator should evaluate experimentally the effectiveness of this technique in good weather conditions before relying on it for navigation at other times. The bias should also be adjusted regularly to account for seasonal Loran variations; using the same value throughout the year is not the most effective application of this technique. Also, entering an offset into a Loran receiver alters the apparent location of waypoints stored prior to establishing this correction.

Finally, receivers vary in how this feature is implemented. Some receivers save the offset when the receiver is turned off; others zero the correction when the receiver is turned on. Some receivers replace the internal ASF value with the offset, while others add it to the internal ASF values. Refer to the owner's manual for the receiver in use.

2412. Maximizing Loran's Repeatable Accuracy

Many users consider the high repeatable accuracy of Loran its most important characteristic. To obtain the best repeatable accuracy consistently, the navigator should use measured TDs rather than latitude and longitude values supplied by the receiver.

The reason for this lies in the ASF conversion process. Recall that Loran receivers use ASFs to correct TDs. Recall also that the ASFs are a function of the terrain over which the signal must pass to reach the receiver. Therefore, the ASFs for one station pair are different from the ASFs for another station pair because the signals from the different pairs must travel over different terrain to reach the receiver.

This consideration matters because a Loran receiver may not always use the same pairs of TDs to calculate a fix. Suppose a navigator marks the position of a channel buoy by recording its latitude and longitude using the TD pair selected automatically by the Loran receiver. If, on the return trip, the receiver is using a different TD pair, the latitude and longitude readings for the exact same buoy would be slightly different because the new TD pair would be using a different ASF value. By using previously-measured TDs and not previously-measured latitudes and longitudes, this ASF-introduced error is avoided. The navigator should also record the values of all secondary TDs at the waypoint and not just the ones used by the receiver at the time. When returning to the waypoint, other TDs will be available even if the previously used TD pair is not. Recording the time and date the waypoint is stored will also help evaluate the cyclical seasonal and diurnal variations that may have since occurred.

2413. Maximizing Loran's Relative Accuracy

The classical application of relative accuracy involves two users finding the same point on the earth's surface at the same time using the same navigation system. The maximum relative Loran accuracy would be theoretically be achieved by identical receivers, configured and installed identically on identical vessels, tracking the same TDs. In practice, the two most important factors are tracking the same TDs and ensuring that ASFs are being treated consistently between the two receivers. By attending to these, the navigator should obtain relative accuracy close to the theoretical maximum.

Another application of relative accuracy is the current practice of converting old Loran TDs into latitude and longitude for use with GPS and DGPS receivers. Several commercial firms sell software applications that perform this tedious task. One key question posed by these programs is whether or not the Loran TDs include ASFs. The difficulty in answering this question depends on how the Loran TDs were obtained, and of course an understanding of ASFs. If in doubt, the navigator can perform the conversion once by specifying "with" ASFs and once "without," and then carefully choosing which is the valid one, assisted by direct observation underway if needed.

To round out the discussion of Loran, the following section briefly describes present and possible future uses for this system beyond the well-known hyperbolic navigation mode.

NON-HYPERBOLIC USES OF LORAN-C

2414. Precise Timing with Loran-C

Because Loran is fundamentally a **precise timing system**, a significant segment of the user community uses Loran for the propagation of Coordinated Universal Time (UTC). The accessibility of UTC at any desired location enables such applications as the synchronization of telephone and data networks. Because the timing of each secondary station is relative to the master, its timing accuracy derives from that of the master.

The start of each Loran station's GRI periodically coincides with the start of the UTC second. This is termed the Time of Coincidence (TOC). Because one Loran station is sufficient to provide an absolute timing reference, timing receivers do not typically rely on the hyperbolic mode or use TDs per se.

A noteworthy feature of Loran is that each transmitter station has an independent timing reference consisting of one or more Primary Reference Standards. Timing equipment at the transmitter stations constantly compares these signals and adjusts to minimize oscillator drift. The end result is a nationwide system with a large ensemble of independent timing sources. This strengthens the U.S. technology infrastructure. As another cross-check of Loran time, daily comparisons are made with UTC, as disseminated via GPS.

2415. Loran-C Time of Arrival (TOA) Mode

With the advent of the powerful digital processors and compact precise oscillators now embedded in user receivers, technical limitations that dictated Loran's hyperbolic architecture decades ago have been overcome. A receiver can now predict in real time the exact point in time a Loran station will transmit its signal, as well as the exact time the signal will be received at any assumed position.

An alternate receiver architecture that takes advantage of these capabilities uses Loran **Time of Arrival (TOA)** measurement, which are measured relative to UTC rather than to an arbitrary master station's transmission. A receiver operating in TOA mode can locate and track all Loran signals in view, prompting the descriptor “all in view” for this type of receiver. This architecture steps beyond the limitations of using only one Loran chain at a time. As a result, system availability can be improved across all the overlapping coverage areas. Coupled with advanced **Receiver Autonomous Integrity Monitor (RAIM)** algorithms, this architecture can also add an additional layer of integrity at the user level, independent of Loran blink.

2416. Loran-C in an Integrated Navigation System

An exponential worldwide increase in reliance on electronic navigation systems, most notably GPS, for positioning and timing has fueled a drive for more robust systems immune from accidental or intentional interference. Even a short outage of GPS, for example, would likely have severe safety and economic consequences for users.

In this environment, integrated navigation systems are attractive options as robust sources of position and time. The ideal **integrated navigation system** (INS) can tolerate the degradation or failure of any component system without degradation as a whole.

Loran offers several advantages to an integrated system based on GPS. Although Loran relies on radio propagation and is thus similarly vulnerable to large-scale atmospheric events such as ionospheric disturbances, at 100 kHz it occupies a very different portion of the spectrum than the 1.2 GHz to 1.6 GHz band used by GPS. Loran is a high-power system whose low frequency often uses a very large antenna for efficient propagation. Therefore, jamming Loran over a broad area is much more difficult than jamming GPS over the same area. Loran signals are present in urban and natural canyons and under foliage, where GPS signals may be partially or completely blocked. Loran's independent timing source also provides an additional degree of robustness to an integrated system. In short, the circumstances that cause failure or degradation of Loran are very different from those that cause failure or degradation of GPS. When the absolute accuracy of Loran is continually calibrated by GPS, the repeatable accuracy of Loran could ensure near-GPS performance of an integrated system in several possible navigation and timing scenarios, for periods of several hours to a few days after a total loss of GPS, depending upon the capability of the INS.

2417. Loran-C as a Data Transfer Channel

Low data rate transmission using Loran signals began in the 1960s with a system known as Clarinet Pilgrim (CP). CP was followed in the 1970s with a similar system termed “Two-Pulse Communications (TPC)”. The two primary uses of this capability were Loran chain control and backup military communications. In all cases, the data superimposed on the Loran signal were transparent to the users, who were nearly universally unaware of this dual use.

In the late 1990s, the Northwest European Loran System (NELS) implemented a pulse-position modulation scheme termed Eurofix to provide differential GPS corrections via the Loran signal to certain areas in western and northern Europe. Eurofix successfully incorporated sophisticated data communications techniques to broadcast GPS corrections in real time while allowing traditional Loran users to operate without interruption.

ENHANCED LORAN (E-LORAN)

2418. eLoran Improvements over Loran-C

As of 2016, eLoran is not available for navigational use anywhere in the world.

While eLoran is currently only broadcast in North America from the former USCG Loran Support Unit transmitting site in Wildwood, New Jersey, the system specifications have been developed and tested. The information presented here comes from various sources involved in the development of eLoran and gives an overview to the enhanced capabilities that eLoran will provide.

eLoran was designed such that new capabilities were added to increase system performance while retaining all of the previous hyperbolic navigation characteristics of Loran-C (Helwig, Offermans, Stout, & Schue, 2011). Any Loran-C receiver can be used with an eLoran transmitting station although Loran-C receivers cannot take advantage of the new capabilities built into eLoran.

eLoran was designed to have improved accuracy, availability, continuity, and integrity over Loran-C (FAA, 2004). eLoran will be a stratum-1 source of UTC time within 50ns such that clocks can be calibrated using eLoran (Helwig, 2011). When fully deployed, it would be the most accurate broadcast source of UTC time independent of a Global Navigation Satellite System (GNSS) such as GPS.

eLoran will be more accurate than Loran-C with a designed position accuracy within 8-20 meters provided the receiver is set up properly and any additional secondary factor corrections are applied (International Loran Association 2007) (Helwig, 2011). eLoran will be able to achieve an increased accuracy over Loran-C because the transmitted signal has tighter tolerances between the GRIs, pulses, and zero-crossings which result in less error in the transmitted signal (International Loran Association 2007) (Helwig, 2011). eLoran also contains a data channel which transmits messages indicating error corrections and precise timing information (International Loran Association 2007) (Helwig, 2011). eLoran's increased position and timing accuracy over Loran-C will allow it to meet modern Maritime Harbor Entrance and Approach (HEA) and Aviation En Route and Non-Precision Approach (RNA) requirements (International Loran Association 2007) (Helwig, 2011).

eLoran also includes one or more Loran Data Channels (LDC), which use various means of modulation to transmit messages (Schue et al., 2000). Current LDC modulation schemes include either the 3-state Eurofix approach or the 9th pulse modulation approach, or both (Helwig, 2011). These messages are very short in nature because the LDC has a low data throughput (slow rate of message transmission). The LDC continuously transmits a series of messages when the system broadcasts (Schue et al., 2000) (Helwig, 2011).

Each pulse position modulation technique accomplishes transmission of a full message within 3s, though the internal structure of each message is slightly different. Alternative modulation techniques provide higher data rates (Schue et al., 2000). The Eurofix approach independently modulates each one of the last six pulses of the GRI by ±1μs. Many possible configurations (combinations of -1μs, 0, or +1μs shifted pulse) of the last six pulses can be created using this modulation technique; 128 are used for encoding messages. Each sixth-pulse modulation represents seven bits of information. Every message is 210 bits long, containing 30 seven-bit parts. One complete message takes 30 GRIs to receive and a new message begins broadcasting every 30 GRIs. A full message would take a maximum of 3s (assuming a GRI of 9999) to receive using the Eurofix method (Offermans, Helwig, Van Willigen, 1996) (Offermans, Helwig, Van Willigen, 1997).

The 9th pulse modulation technique adds an extra pulse approximately 1000μs after the 8th pulse of the Master station (which is also 1000μs before the final pulse in the master station) and an extra (9th) pulse in the secondary station approximately 1000μs after the 8th secondary pulse (making the modulated 9th pulse the final pulse in the secondary GRI). 32 possible states (states 0 through state 31) are defined by moving the position of this pulse in each GRI. The zero-state is defined when this pulse occurs exactly 1000μs after the 8th pulse. The 31 remaining symbols are positioned in the GRI using the formula: D_x μ=1.25mod[x,8]+50.625floor(x/8) where "x" is the possible state (0,31) and Dx is the pulse's time-offset from the zero-state position in the GRI. A receiver would obtain the offset distance of the 9th pulse and use the inverse of the above formula to determine message state. Each GRI can carry 5-bits of information and each 9th pulse modulated message is 120-bits long; so an entire message is transmitted over 24 GRIs. A full message would take a maximum of 2.4s (assuming a GRI of 9999) to receive using the 9th pulse modulation method (Peterson, Dykstra, Lown & Shmihluk 2006).

A standard eLoran receiver should have the capability of reading messages from the LDC encoded with any type of standardized LDC technique. The message types will be standardized and repeat at regular intervals. When operational. eLoran will be capable of transmitting the following message types and additional message types may be defined in the future (The Radio Technical Commission for Maritime Services 2008) (International Loran Association 2007) (Dykstra & Peterson, 2006) (Helwig, 2011):

- ASF corrections.
- Almanac information containing station specific information such as: station position, station name and station status (replacing Loran blink codes).
- UTC Time of Day expressed as number of seconds since the Loran epoch of 0h0m0s-01 JAN 1958. The number of seconds from the Loran epoch to the time of transmission of the message can be calculated as: $T = 24(GRI)(MEC)+ED$ where MEC is the Message-Epoch-Count which is the number of 24-GRI intervals since the Loran epoch.
- Various Government-Use only messages.

The source of timing for the transmission of eLoran pulses is independent of monitor sites and control centers; the eLoran signals are synchronized to an identifiable, independent UTC source at each site (Helwig, 2011). All time of transmissions for both the master and secondary stations are determined using the independent clocks at each station synchronized to UTC so that a user can obtain/calculate timing information from the strongest signal available instead of just needing the master station fix (The Radio Technical Commission for Maritime Services 2008). The synchronization of all stations with an independent UTC time source allows for greater position accuracy.

eLoran pulses are synchronized independent of any GNSS system using a clock at each transmitter site (Offermans, et al. 2013). One can obtain current UTC time by reading the time of day message from the LDC. Another method of calculating the UTC time involves knowing the receiver's position and ASF corrections (Offermans, Johannessen, Schue, Hirchauer & Powers, 2013). An eLoran receiver measures the time of arrival (the time when a pulse is received). Knowing the receiver's position along with some ASF corrections, one can obtain a synchronized UTC time of transmission (Offermans, et al. 2013) (Helwig, 2011). Since each eLoran transmission is locked to UTC time and each transmitter is an independent source of UTC time, then UTC time may be obtained accurately from any eLoran transmitting station fix.

2419. eLoran Definition Document

The Enhanced Loran (eLoran) Definition Document was developed in 2006 at the United States Coast Guard Navigation Center by an international team of authors and was published by the ILA in 2007.

The document provides an overview, background and introduction to eLoran along with a detailed description of the eLoran system (eLoran signal, transmitting stations, control centers, monitoring & reference stations and user equipment. The document includes a description of the maritime application for eLoran along with a broader overall service provision for the system. See the following ling for access to the document:

Figure 2419. Enhance Loran Definition Document (2007). https://rntfnd.org/wp-content/uploads/eLoran-Definition-Document-0-1-Released.pdf

2420. References

Dykstra, K., Peterson, B., (2006). Loran data channel: Progress to date and future plans. *35th Annual Convention and Technical Symposium of the International Loran Association*. Groton, CT.

Helwig, A., Offermans, G., Stout C., & Schue, C., (2011). eLoran system definition and signal specification tutorial. *40th International Loran Association Conference*. Busan.

International Loran Association (ILA), 2007. *Enhanced Loran (eLoran) Definition*.

Offermans, G., Helwig, A., & Van Willigen, D., (1996). The Eurofix datalink concept: Reliable data transmission using Loran-C. *Proceedings of the 25th Annual Technical Meeting of the International Loran Association*, San Diego, CA.

Offermans, G., Helwig, A., & Van Willigen, D., (1997). Eurofix DGPS Service through the Sylt Loran-C transmitter: Static and dynamic test results. *Proceedings of the 26th Annual Technical Meeting of the International Loran Association*, Ottawa, Canada.

Offermans, G., Johannessen, E., Schue, C., Hirschauer, J., & Powers., E., (2013). UTC synchronization and stratum-1 frequency recovery using eLoran: The alternate basket for your eggs. *45th Annual Precise Time and Time Interval Systems and Applications Meeting. The Institute of Navigation*. Bellevue, WA.

Peterson, B., Dykstra, K., Lown, D., & Shmilhluk, K., (2006, vers 1.3). Loran Data Channel Communications Using 9th Pulse Modulation.

Schue, C., Peterson, B., et al, (2000). Enhanced Loran-C Data Channel Project, *German Institute of Navigation (DGON) Symposium and Technical Conference*, Bonn, Germany.

Schue, C., Peterson, B, Celano, T., (2004). Low Cost Digitally Enhanced Loran for Tactical Applications (LC DELTA), *Thirty-third Annual International Loran Association Technical Symposium*.

Schue, C. A. III, (2008). The next generation LF transmitter and its impact on Loran, eLoran, and tactical (e)Loran systems, *Royal Institute of Navigation NAV08 conference and Thirty-seventh Annual International Loran Association Technical Symposium*.

The Radio Technical Commission for Maritime Services, (2008). *Specification of the eLoran System Preliminary, Tentative and Unofficial*. Unofficial Specification.

United States Coast Guard, (2012). *Loran-C General Information*. http://www.navcen.uscg.gov/?pageName=loranMain (accessed 09 15, 2016).

United States Department of Transportation, (2001). *Vulnerability assessment of the transportation infrastructure relying on the global positioning system*. Government Report.

UrsaNav. (2015). *eLoran Points of Light*. Q&A Paper.

UrsaNav. *Loran-C.* http://www.ursanav.com/solutions/technology/loran-c/ (accessed September15, 2016).