CHAPTER 12

HYPERBOLIC SYSTEMS

INTRODUCTION TO LORAN C

1200. History

The theory behind the operation of hyperbolic radionavigation systems was known in the late 1930's, 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. By the end of the war, the network consisted of over 70 transmitters covering over 30% of the earth's surface.

In the late 1940's and early 1950's, 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. Serving both the marine and aviation communities, Loran C boasts the highest number of users of any precise radionavigation system in use. It has been designated the primary federally provided marine navigation system for the U. S. Coastal Confluence Zone (CCZ), southern Alaska, and the Great Lakes. The maritime community comprises the vast majority of Loran C users (87%), followed by civil aviation users (14%). The number of Loran users is projected to grow until well into the next century.

Notwithstanding the popularity of the system, the U. S. Department of Defense is phasing out use of Loran C in favor of the highly accurate, space-based Global Positioning System (GPS). This phase out has resulted in closing the Hawaii-based Central Pacific Loran C chain and transferring several overseas Loran C stations to host governments. The use of Loran C in the United States' radionavigation plan will undergo continuous evaluation until a final determination of the future of the system is made in 1996. At that point, a decision will be made to either continue operations or to begin to phase out the system in favor of satellite navigation. No matter what decision is reached, Loran C is expected to remain operational until at least 2015.

LORAN C DESCRIPTION

1201. Basic Theory Of Operation

The Loran C system consists of a chain of transmitting stations, each separated by several hundred miles. Within the Loran chain, one station is designated as the **master station** and the others as **secondary stations**. There must be at least two secondary stations for one master station; therefore, every Loran transmitting chain will contain at least three transmitting stations. The master and secondary stations transmit radio pulses at precise time intervals. A Loran receiver measures the **time difference (TD)** in reception at the vessel between these pulses; it then displays either this difference or a computed latitude and longitude to the operator.

The signal arrival time difference between a given master-secondary pair corresponds to the difference in distance between the receiving vessel and the two stations. The locus of points having the same time difference from a specific master-secondary pair forms a hyperbolic line of position (LOP). The intersection of two or more of these LOP's produces a fix of the vessel's position.

There are two methods by which the navigator can convert these time differences to geographic positions. The first involves the use of a chart overprinted with a Loran **time delay lattice** consisting of time delay lines spaced at convenient intervals. The navigator plots the displayed time difference by interpolating between the lattice lines printed on the chart. In the second method computer algorithms in the receiver's software convert the time delay signals to latitude and longitude for display.

Early receiver conversion algorithms were imprecise; however, modern receivers employ more precise algorithms. Their position output is usually well within the 0. 25 NM accuracy specification for Loran C. Modern receivers can also navigate by employing waypoints, directing a vessel's course between two operator-selected points. Section 1207, section 1208, and section 1209 more fully explore questions of system employment.

1202. Components Of The Loran System

The components of the Loran system consist of the land-based **transmitting stations**, the Loran **receiver** and **antenna**, and the **Loran charts**. Land-based facilities include master transmitting stations, at least two secondary transmitters for each master transmitter, control stations, monitor sites, and a time reference. The transmitters transmit the Loran signals at precise intervals in time. The control station and associated monitor sites continually measure the characteristics of the Loran signals received to detect any anomalies or any out-of-specification condition. Some transmitters serve only one function within a chain (i.e., either master or secondary); however, in several instances, one transmitter can serve as the master of one chain and secondary in another. This dual function lowers the overall costs and operating expense for the system.

Loran receivers exhibit varying degrees of sophistication; however, 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, establishing the approximate location in time of the master and secondaries with sufficient accuracy to permit subsequent settling and tracking.

After search and acquisition, the receiver enters the **settling 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 as discussed above.

1203. Description Of Operation

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. 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. Pulsed transmission results in lower power output requirements, better signal identification properties, and more precise timing of the signals. After the time delays discussed below, secondary stations transmit a series of eight pulses, each spaced 1000 µsec apart. The master and secondary stations in a chain transmit at precisely determined intervals. First, the master station transmits; then, after a specified interval, the first secondary station transmits. Then the second secondary transmits, and so on. Secondary stations are given letter designations of W, X, Y, and Z; this letter designation indicates the order in which they transmit following the master. When the master signal reaches the next secondary in sequence, this secondary station waits an interval, defined as the **secondary coding delay, (SCD)** or simply **coding delay (CD)**, and then transmits. The total elapsed time from the master transmission until the secondary emission is termed the **emissions delay (ED)**. The ED is the sum of the time for the master signal to travel to the secondary and the CD. The time required for the master to travel to the secondary is defined as the **baseline travel time (BTT)** or **baseline length (BLL)**. After the first secondary transmits, the remaining secondaries transmit in order. Each of these secondaries has its own CD/ED value. 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 designator. For example, the interval between successive transmissions of the master pulse group for the northeast US chain is 99,600 µsec. From the definition above, the GRI designator for this chain is defined as 9960. 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.

Other concepts important to the understanding of the operation of Loran 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 importance of these two concepts will become apparent during the discussion of Loran accuracy considerations below.

As discussed above, Loran C relies on time differences between two or more received signals to develop LOP's used to fix the ship's position. This section will examine in greater detail the process by which the signals are developed, transmitted, and ultimately interpreted by the navigator.

The basic theory behind the operation of a hyperbolic system is straightforward. First, the locus of points defining a constant difference in distance between a vessel and two separate stations is described by a mathematical function that, when plotted in two dimensional space, yields a hyperbola. Second, 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 to the vessel is proportional to the distance between the transmitting sites and the vessel. The following equations demonstrating this proportionality between distance and time apply:

Distance=Velocity x Time

or, using algebraic symbols

$d = c \times t$

Therefore, if the velocity (c) is constant, the distance between a vessel and 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 will better illustrate the concept. See Figure 1203a. 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. Assume further that the master station is located at coordinates (x,y) = (-200,0) and the secondary is located at (x,y) = (+200,0). Designate this secondary station as station Xray. An observer with a receiver capable of detecting electromagnetic radiation is positioned at any point A whose coordinates are defined as $x(^a)$ and $y(^a)$. 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. This methodology yields the following result for the given example:

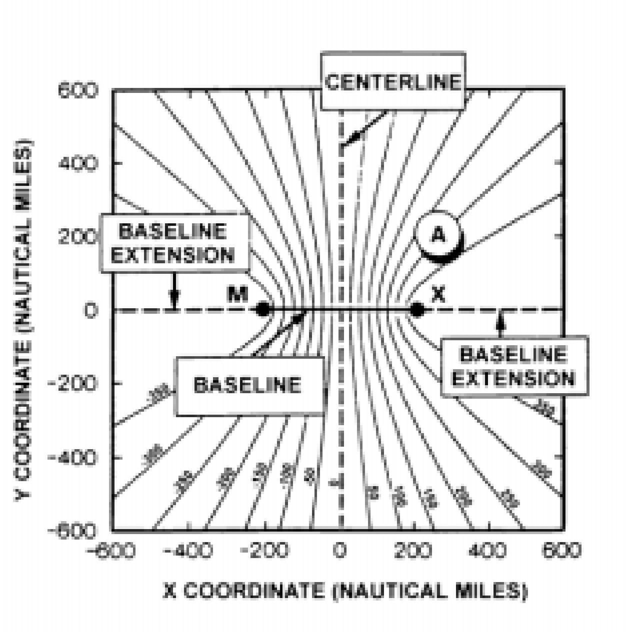


Figure 1203a. Depiction of Loran LOPs.

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

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

Finally, the difference between these distances (Z) is given by the following:

$$Z = d_{am}(-d_{as})$$

After algebraic manipulation,

$$Z = \left[(x_a + 200)^2 + y_a^2\ \ )\right]^{0.5} - \left[(x_a - 200)^2 + y_a^2\ \ \right]^{0.5}$$

With a given position of the master and secondary stations, therefore, the function describing the difference in distance is reduced to one variable; i.e., the position of the observer.

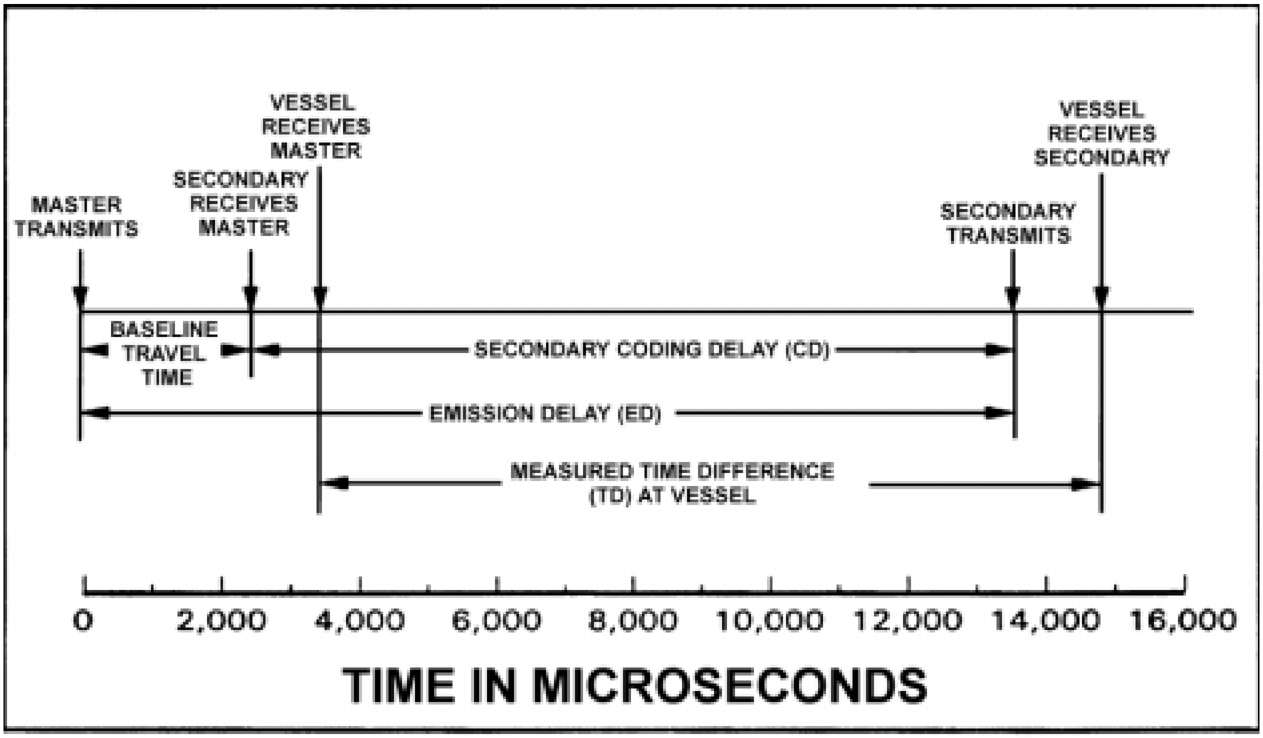


Figure 1203b. The time axis for Loran C TD for point "A."

Figure 1203a is a conventional graphical representation of the data obtained from solving for the value (Z) using varying positions of A in the example above. The hyperbolic lines of position in the figure represent the locus of points along which the observer's simultaneous distances from the master and secondary stations are equal; he is on the centerline. For example, if the observer above were located at the point (271. 9, 200) then the distance between that observer and the secondary station (in this case, designated "X") would be 212. 5 NM. In turn, the observer's distance from the master station would be 512. 5 nautical miles. The function Z would simply be the difference of the two, or 300 NM. Refer again to Figure 1203a. The hyperbola marked by "300" represents the locus of points along which the observer is simultaneously 300 NM closer to the secondary transmitter than to the master. To fix his position, the observer must obtain a similar hyperbolic line of position generated by another master-secondary pair. Once this is done, the intersection of the two LOP's can be determined, and the observer can fix his position in the plane at a discrete position in time.

The above example was evaluated in terms of differences in distance; as discussed previously, an analogous situation exists with respect to differences in signal reception time. All that is required is the assumption that the signal propagates at constant speed. Once this assumption is made, the hyperbolic LOP's in Figure 1203a above can be re-labeled to indicate time differences instead of distances. This principle is graphically demonstrated in Figure 1203b.

Assume that electromagnetic radiation travels at the speed of light (one nautical mile traveled in 6. 18 µsec) and reconsider point A from the example above. The distance from the master station to point A was 512. 5 NM. From the relationship between distance and time defined above, 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 time delay (TD) measurement. Recall from the general discussion above that a secondary station transmits after an emissions 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 signal must then reach the receiver located with the observer at point A. Recall from above that this distance was 212. 5 NM. Therefore, the time associated with signal travel is: (6. 18 µsec/NM) × 212. 5 NM = 1,313 µsec. 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.

Recall, however, that the Loran receiver measures the time delay between reception of the master signal and the reception of the secondary signal. The quantity determined above was the total time from the transmission of the master signal to the 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 time delay observed at point A in this hypothetical example is (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 at a discrete position.

1204. Allowances For Non-Uniform Propagation Rates

The proportionality of the time and distance differences assumes a constant speed of propagation of electromagnetic radiation. To a first approximation, this is a valid assumption; however, in practice, Loran's accuracy criteria require a refinement of this approximation. The initial calculations above assumed the speed of light in a vacuum; however, the actual speed at which electromagnetic radiation propagates through the atmosphere is affected by both the medium through which it travels and the terrain over which it passes. The first of these concerns, the nature of the atmosphere through which the signal passes, gives rise to the first correction term: the **Primary Phase Factor (PF)**. This correction is transparent to the operator of a Loran system because it is incorporated into the charts and receivers used with the system, and it requires no operator action.

A **Secondary Phase Factor (SF)** accounts for the effect traveling over seawater has on the propagated signal. This correction, like the primary phase factor above, is transparent to the operator since it is incorporated into charts and system receivers.

The third and final correction required because of non-uniform speed of electromagnetic radiation is termed the **Additional Secondary Phase Factor (ASF)**. Of the three corrections mentioned in this section, this is the most important one to understand because its correct application is crucial to obtaining the most accurate results from the system. This correction is required because the SF described above assumes that the signal travels only over water when the signal travels over terrain composed of water and land. The ASF can be determined from either a mathematical model or a table constructed from empirical measurement. The latter method tends to yield more accurate results. To complicate matters further, the ASF varies seasonally.

The ASF correction is important because it is required to convert Loran time delay measurements into geographic coordinates. ASF corrections must be used with care. Some Loran charts incorporate ASF corrections while others do not. One cannot manually apply ASF correction to measured time delays when using a chart that has already been corrected. In addition, the accuracy of ASF's is much less accurate within 10 NM of the coastline. Therefore, navigators must use prudence and caution when operating with

ASF corrections in this area.

One other point must be made about ASF corrections. Some commercially available Loran receivers contain preprogrammed ASF corrections for the conversion of measured time delays into latitude and longitude printouts. The internal values for ASF corrections used by these receivers may or may not be accurate, thus leading to the possibility of navigational error. Periodically, the navigator should compare his receiver's latitude and longitude readout with either a position plotted on a chart incorporating ASF corrections for observed TD's or a position determined from manual TD correction using official ASF published values. This procedure can act as a check on his receiver's ASF correction accuracy. When the navigator wants to take full advantage of the navigational accuracy of the Loran system, he should use and plot the TD's generated by the receiver, not the converted latitude and longitude. When precision navigation is not required, converted latitude and longitude may be used.

1205. Loran Pulse Architecture

As mentioned above, Loran uses a pulsed signal rather than a continuous wave signal. This section will analyze the Loran pulse signal architecture, emphasizing design and operational considerations.

Figure 1205 represents the Loran signal. Nine of these signals are transmitted by the master station and eight are transmitted by the secondary stations every transmission cycle. The pulse exhibits a steep rise to its

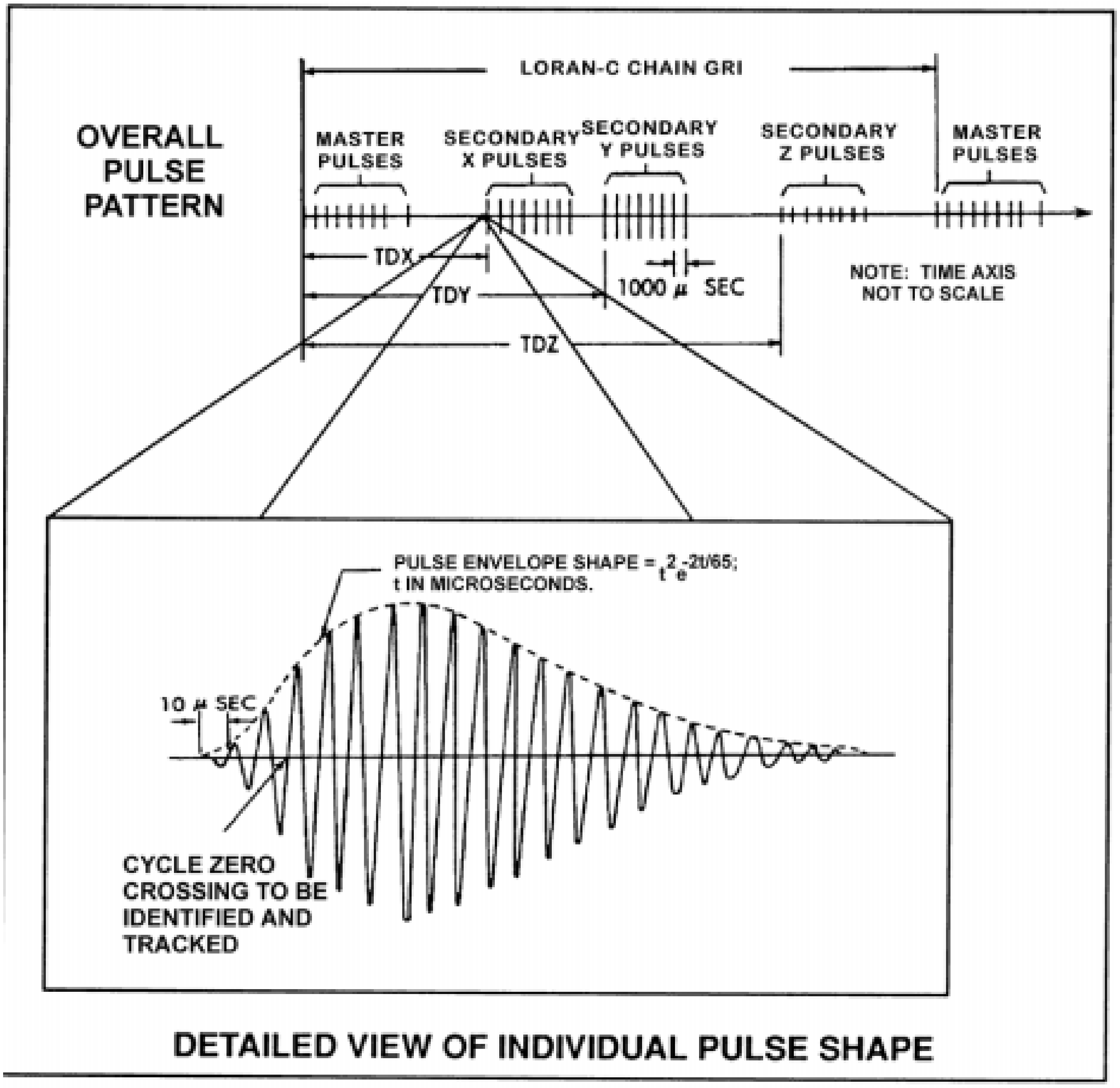


Figure 1205. Pulse pattern and shape for Loran C transmission.

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 detect the signal on the cycle corresponding to the carrier frequency's third positive crossing of the x axis. This occurrence, termed the **third positive 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. Secondly, 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 induce large errors into positions determined by the Loran system. Pulse architecture is designed to eliminate this major source of error.

Another pulse feature designed to eliminate sky wave contamination is known as **phase coding**. With phase coding, the phase of the carrier signal (i.e. , the 100 kHz signal) is changed systematically from pulse to pulse. Upon reaching the receiver, sky waves will be out of phase with the simultaneously received ground waves and, thus, they will not be recognized by the receiver. Although this phase coding offers several technical advantages, the one most important to the operator is this increase in accuracy due to the rejection of sky wave signals.

The final aspect of pulse architecture that is important to the operator is **blink coding**. When a signal from a secondary station is unreliable and should not be used for navigation, the affected secondary station will blink; that is, the first two pulses of the affected secondary station are turned off for 3. 6 seconds and on for 0. 4 seconds. This blink is detected by the Loran receiver and displayed to the operator. When the blink indication is received, the operator should not use the affected secondary station.

LORAN C ACCURACY CONSIDERATIONS

1206. Position Uncertainty With Loran C

As discussed above, the TD's from a given master-secondary pair form a family of hyperbolae. Each hyperbola in this family can be considered a line of position; the vessel must be somewhere along that locus of points which form the hyperbola. A typical family of hyperbolae is shown in Figure 1206a.

Now, suppose the hyperbolic family from the master-Xray station pair shown in Figure 1203a were superimposed upon the family shown in Figure 1206a. The results would be the hyperbolic lattice shown in Figure 1206b.

Loran C LOP's for various chains and secondaries (the hyperbolic lattice formed by the families of hyperbolae for several master-secondary pairs) are printed on special nautical charts. Each of the sets of LOP's 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 only shows a limited number of LOP's to reduce clutter on the chart. Therefore, if the observed time delay falls between two

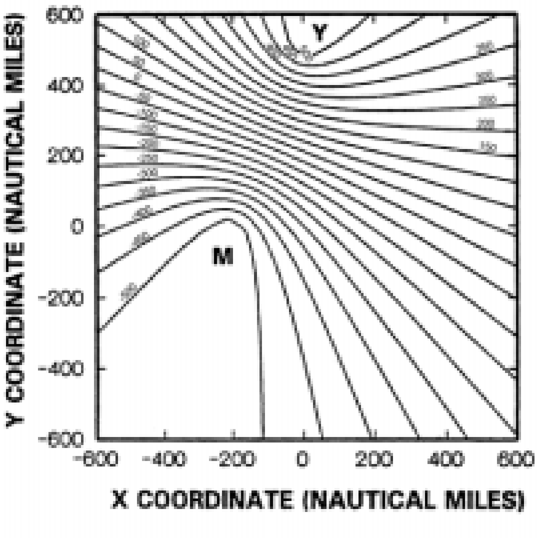


Figure 1206a. A family of hyperbolic lines generated by Loran signals.

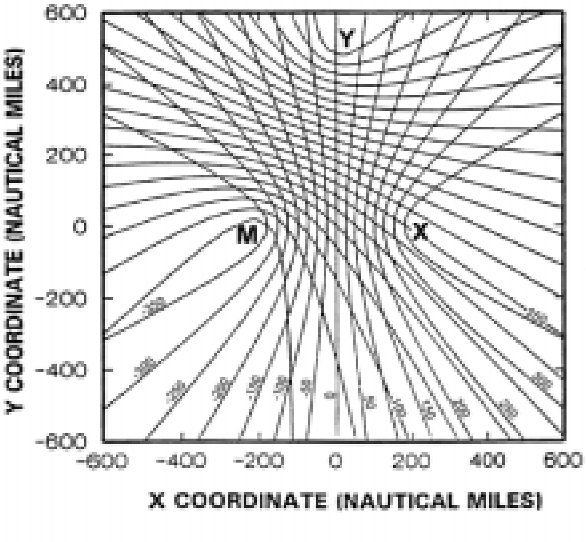


Figure 1206b. A hyperbolic lattice formed by station pairs M-X and M-Y.

charted LOP's, interpolate between them to obtain the precise LOP. After having interpolated (if necessary) between two TD measurements and plotted the resulting LOP's on the chart, the navigator marks the intersection of the LOP's and labels that intersection as his Loran fix.

A closer examination of Figure 1206b reveals two possible sources of Loran fix error. The first of these errors is a function of the LOP crossing angle. The second is a phenomenon known as fix ambiguity. Let us examine both of these in turn.

Figure 1206c 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 uncertainly as shown. As the crossing angle (i.e. , the angle of intersection of the two LOP's) 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 LOP's for which the crossing angle is as close to 90° as possible. The relationship between crossing angle and accuracy 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 sin of the crossing angle increases from 0 to 1. Therefore, the error is at a minimum when the crossing angle is 90°, and it increases thereafter as the crossing angle decreases.

Fix ambiguity can also cause the navigator to plot an erroneous position. Fix ambiguity results when one Loran LOP crosses another LOP in two separate places. Most Loran receivers have an ambiguity alarm to alert the navigator to this occurrence. Absent other information, the navigator is unsure as to which intersection marks his true position. Again, refer to Figure 1206b for an example. The -350 difference line from the master-Xray station pair crosses the -500 difference line from the master-Yankee station pair in two separate places. Absent a third LOP from either another station pair or a separate source, the navigator would not know which of these LOP intersections marked his position.

Fix ambiguity occurs in the area known as the master-secondary baseline extension, defined above in section 1203. Therefore, do not use a master-secondary pair while operating in the vicinity of that pair's baseline extension if other station pairs are available.

The large gradient of the LOP when operating in the vi-

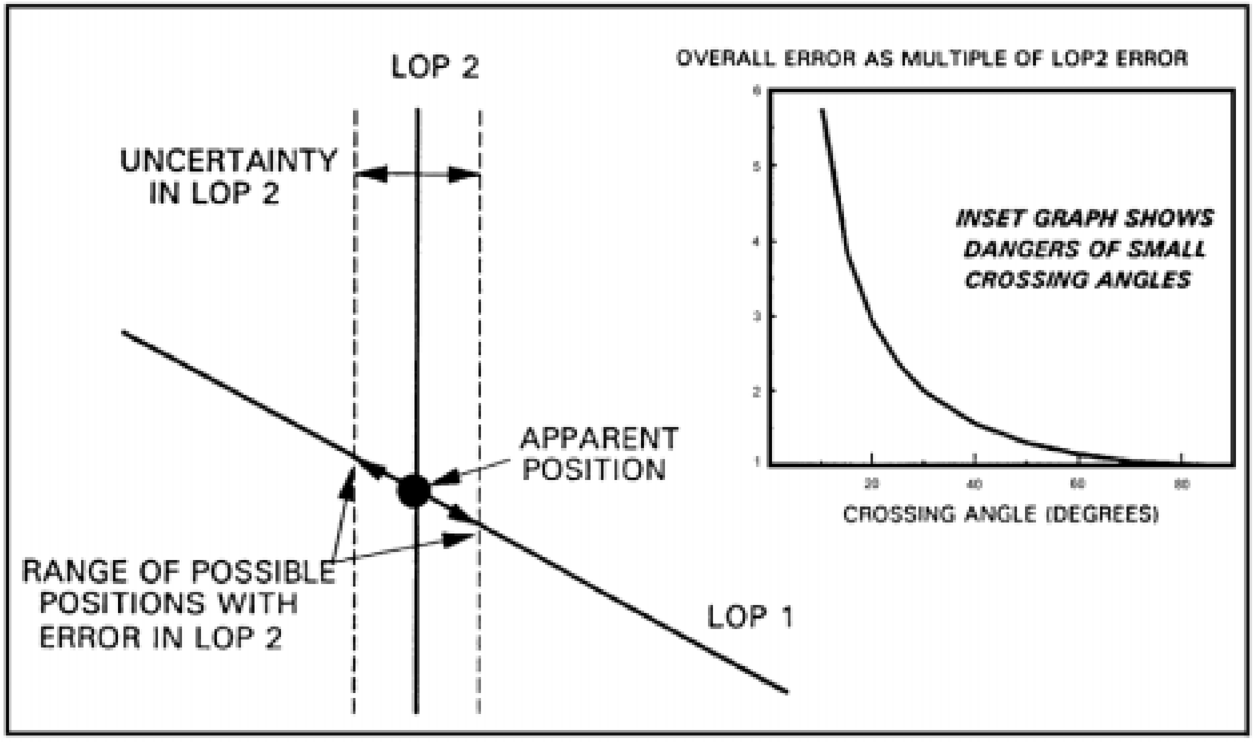


Figure 1206c. Error in Loran LOPs is magnified if the crossing angle is less than 90°.

cinity of a baseline extension is another reason to avoid using stations in the vicinity of their baseline extensions. Uncertainty error is directly proportional to the gradient of the LOP's used to determine the fix. Therefore, to minimize possible error, the gradient of the LOP's used should be as small as possible. Refer again to Figure 1206b. Note that the gradient is at a minimum along the station pair baseline and increases to its maximum value in the vicinity of the baseline extension.

The navigator, therefore, has several factors to consider in maximizing fix accuracy. Do not use a station pair when operating along it baseline extension because both the LOP gradient and crossing angle are unfavorable. In addition, fix ambiguity is more likely here.

LORAN C OPERATIONS

1207. Waypoint Navigation

A Loran receiver's major advantage is its ability to accept and store waypoints. Waypoints are sets of coordinates that describe a location of navigational interest. A navigator can enter waypoints into a receiver in one of two ways. He can either visit the area and press the appropriate receiver control key, or he can enter the waypoint coordinates manually. When manually entering the waypoint, he can express it either as a TD, a latitude and longitude, or a distance and bearing from another waypoint.

Typically, waypoints mark either points along a planned route or locations of interest. The navigator can plan his voyage as a series of waypoints, and the receiver will keep track of the vessel's progress in relation to the track between them. In keeping track of the vessel's progress, most receivers display the following parameters to the operator:

Cross Track Error (XTE): XTE is the perpendicular distance from the user's present position to the intended track between waypoints. Steering to maintain XTE near zero corrects for cross track current, cross track wind, and compass error.

Bearing (BRG): The BRG display, sometimes called the **Course to Steer** display, indicates the bearing from the vessel to the destination waypoint.

Distance to Go (DTG): The DTG display indicates the great circle distance between the vessel's present location and the destination waypoint.

Course and Speed Over Ground (COG and SOG): The COG and the SOG refer to motion over ground rather than motion relative to the water. Thus, COG and SOG reflect the combined effects of the vessel's progress through the water and the set and drift to which it is subject. The navigator may steer to maintain the COG equal to the intended track.

Loran navigation using waypoints was an important development because it showed the navigator his position *in relation to his intended destination*. Though this method of navigation is not a substitute for plotting a vessel's position on a chart to check for navigation hazards, it does give the navigator a second check on his plot.

1208. Using Loran's High Repeatable Accuracy

In discussing Loran employment, one must develop a working definition of three types of accuracy: **absolute accuracy**, **repeatable accuracy**, and **relative accuracy**. **Absolute 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 C latitude and longitude (or based on Loran C TD's) the difference between the Loran C 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 TD's at that position. Later, suppose the navigator, wanting to return to the buoy, returns to the previously-measured TD's. 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 TD's 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 ASF's, 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 greater. If the navigator has been to an area previously and noted the TD's corresponding to different navigational aids (a buoy marking a harbor entrance, for example), the high repeatable accuracy of the system enables him to locate the buoy in under adverse weather. Similarly, selected TD data for various harbor navigational aids has been collected and recorded. These tables, if available to the navigator, provide an excellent backup navigational source to conventional harbor approach navigation. To maximize a Loran system's utility, exploit its high repeatable accuracy by using previously-determined TD measurements that locate positions critical to a vessel's safe passage. This statement raises an important question: Why use measured TD's and not a receiver's latitude and longitude output? If the navigator seeks to use the repeatable accuracy of the system, why does it matter if TD's or coordinates are used? The following section discusses this question.

1209. Time Delay Measurements And Repeatable Accuracy

The ASF conversion process is the reason for using TD’s and not Latitude/Longitude readings.

Recall that Loran receivers use ASF conversion factors to convert measured TD’s into coordinates. Recall also that the ASF corrections are a function of the terrain over which the signal must pass to reach the receiver. Therefore, the ASF corrections for one station pair are different from the ASF corrections for another station pair because the signals from the different pairs must travel over different terrain to reach the receiver. A Loran receiver does not always use the same pairs of stations to calculate a fix. Suppose a navigator marks the position of a channel buoy by recording its latitude and longitude as determine by his Loran receiver. If, on the return trip, the receiver tracks different station pairs, the latitude and longitude readings *for the exact same buoy* would be different because the new station pair would be using a different ASF correction. The same effect would occur if the navigator attempted to find the buoy with another receiver. By using previously-measured TD’s and not

						9960-W							**33W**
						LONGITUDE WEST							
LATITUDE NORTH	75° 0'	55	50	45	40	35	30	25	20	15	10	5	74° 0'
39°0'				-0.9	-1.0	-0.9	-0.9	-0.8	-0.7	-0.6	-0.6	-0.6	-0.5
55	-1.4	-1.2	-1.1	-0.9	-0.9	-0.9	-0.8	-0.7	-0.7	-0.6	-0.6	-0.6	-0.5
50	-1.3	-1.1	-1.0	-0.9	-0.8	-0.8	-0.7	-0.7	-0.6	-0.6	-0.6	-0.6	-0.5
45	-1.3	-1.0	-1.0	-0.9	-0.9	-0.7	-0.6	-0.7	-0.6	-0.6	-0.6	-0.6	-0.5
40	-1.3	-1.1	-1.0	-0.9	-0.8	-0.7	-0.6	-0.7	-0.7	-0.6	-0.6	-0.5	-0.6
35	-1.1	-1.0	-1.0	-0.9	-0.8	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
30	-1.0	-1.0	-1.0	-0.8	-0.7	-0.6	-0.7	-0.7	-0.6	-0.6	-0.6	-0.6	-0.6
25	-1.0	-1.1	-0.9	-0.8	-0.7	-0.7	-0.7	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
20	-0.9	-0.9	-0.8	-0.7	-0.7	-0.7	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
15	-0.8	-0.8	-0.8	-0.7	-0.7	-0.7	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
10	-0.6	-0.6	-0.7	-0.7	-0.7	-0.7	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
5	-0.5	-0.6	-0.7	-0.7	-0.7	-0.7	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
38°0'	-0.3	-0.6	-0.7	-0.7	-0.7	-.06	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
55	-0.4	-0.5	-0.6	-0.7	-0.7	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	
50	-0.3	-0.3	-0.6	-0.7	-0.7	-0.7	-0.7	-0.6	-0.6	-0.6	-0.6		
45	-0.3	-0.4	-0.6	-0.6	-0.6	-0.6	-0.7	-0.6	-0.6	-0.6	-0.6		
40	-0.3	-0.3	-0.4	-0.5	-0.6	-0.7	-0.7	-0.6	-0.6	-0.6			
35	-0.2	-0.3	-0.3	-0.5	-0.7	-0.6	-0.7	-0.6	-0.6				
30	-0.2	-0.2	-0.3	-0.4	-0.6	-0.6	-0.7	-0.6					
25	-0.2	-0.2	-0.3	-0.4	-0.6	-0.5	-0.7						
20	-0.2	-0.2	-0.3	-0.4	-0.6	-0.5	-0.6						
15	-0.2	-0.2	-0.3	-0.3	-0.5	-0.4	-0.6						
10	-0.2	-0.2	-0.2	-0.3	-0.4	-0.4							
5	-0.2	-0.3	-0.2	-0.3	-0.4	-0.4				Area Outside of CCZ			
37°0'	-0.2	-0.2	-0.2	-0.2	-0.4								
55	-0.2	-0.2	-0.2	-0.2	-0.3								
50	-0.2	-0.2	-0.2	-0.2	-0.2								
45	-0.2	-0.2	-0.2	-0.2									
40	-0.2	-0.2	-0.2	-0.2									
35	-0.2	-0.2	-0.2	-0.2									
30	-0.2	-0.2	-0.2	-0.1									
25	-0.2	-0.2	-0.2	-0.0									
20	-0.2	-0.2	-0.2	-0.0									
15	-0.2	-0.2	-0.1	-0.0	0.0								
10	-0.2	-0.1	-0.1	-0.0	0.0	0.1							
5	-0.1	-0.0	-0.0	-0.0	0.1	0.1							
36°0'	-0.1	-0.0	-0.0	-0.1	0.1	0.2	0.3						

Figure 1210. Excerpt from Loran C correction tables.

previously-measured latitudes and longitudes, this ASF introduced error is eliminated.

Envision the process this way. A receiver measures between measuring these TD's and displaying a latitude and longitude, the receiver accomplishes an intermediate step: applying the ASF corrections. This intermediate step is fraught with potential error. The accuracy of the corrections is a function of the stations received, the quality of the ASF correction software used, and the type of receiver employed. Measuring and using TD's eliminates this step, thus increasing the system's repeatable accuracy.

Many Loran receivers store waypoints as latitude and longitude coordinates regardless of the form in which the operator entered them into the receiver's memory. That is, the receiver applies ASF corrections prior to storing the waypoints. If, on the return visit, the same ASF's are applied to the same TD's, the latitude and longitude will also be the same. But a problem similar to the one discussed above will occur if different secondaries are used. Avoid this problem by recording all the TD's of waypoints of interest, not just the ones used by the receiver at the time. Then, when returning to the waypoint, other secondaries will be available if the previously used secondaries are not.

ASF correction tables were designed for first generation Loran receivers. The use of advanced propagation correction algorithms in modern receivers has eliminated the need for most mariners to refer to ASF Correction tables. Use these tables only when navigating on a chart whose TD LOP's have not been verified by actual measurement with a receiver whose ASF correction function has been disabled.

INFREQUENT LORAN OPERATIONS

1210. Use of ASF Correction Tables

The following is an example of the proper use of ASF Correction Tables.

Example: *Given an estimated ship's position of 39°N 74° 30'W, the ASF value for the Whiskey station pair of chain 9960.*

Solution: *Enter the Whiskey station pair table with the correct latitude and longitude. See Figure 1210. Extract a value of -0.9 µsec. This value would then be added to the observed time difference to compute the corrected time difference.*

INTRODUCTION TO OMEGA

1211. System Description

Omega is a worldwide, internationally operated radio navigation system. It operates in the Very Low Frequency (VLF) band between 10 and 14 kHz. It provides an all weather, medium-accuracy navigation service to marine navigators. The system consists of eight widely-spaced transmitters. Figure 1211 gives the location of these stations.

There is no master-secondary relationship between the Omega stations as there is between Loran C stations. The navigator is free to use any station pair that provides the most accurate line of position. Additionally, Omega measures phase differences between the two signals whereas Loran C measures time delays between signal receptions.

Common Frequencies:

10.2 kHz 11.05 kHz 11-1/3 kHz 13.6 kHz

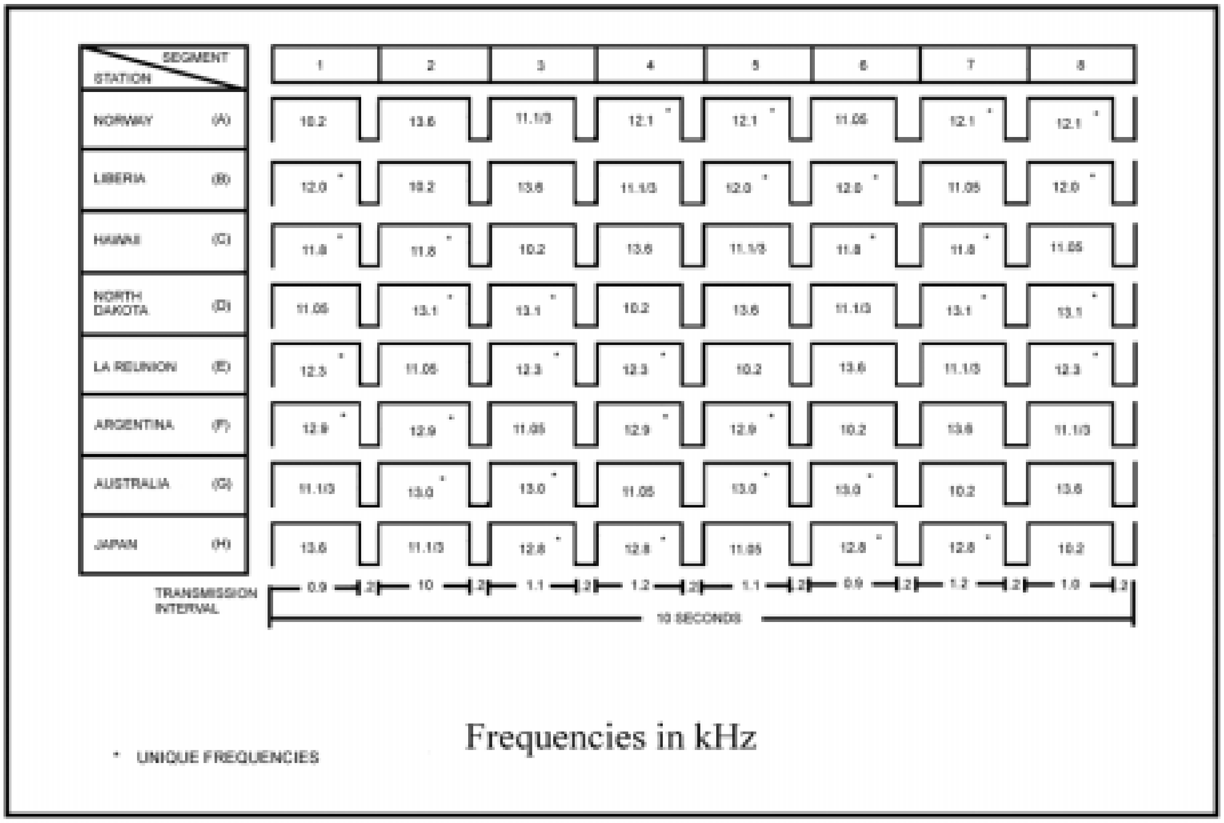
Unique Frequencies:

Station	Frequency (kHz)
A: Norway	12.1
B: Liberia	12.0
C: Hawaii	11.8
D: North Dakota	13.1
E: La Reunion	12.3
F: Argentina	12.9
G: Australia	13.0
H: Japan	12.8

Figure 1211. Omega stations and frequencies.

1212. Signal Format

Each Omega station transmits on the following frequencies: 10.2 kHz, 11.05 kHz, 11.3 kHz, and 13.6 kHz. In addition to these common frequencies, each station transmits on a unique frequency given in Figure 1212. No two stations transmit the same frequency at the same time, and there is no overlap of transmissions. Each transmission segment is between 0.9 and 1.2 seconds long, with a 0.2 second interval between segments. Each station continuously repeats its transmission cycle.



SEGMENT / STATION	1	2	3	4	5	6	7	8
NORWAY (A)	10.2	13.6	11.1/3	12.1 *	12.1 *	11.05	12.1 *	12.1 *
LIBERIA (B)	12.0 *	10.2	13.6	11.1/3	12.0 *	12.0 *	11.05	12.0 *
HAWAII (C)	11.8 *	11.8 *	10.2	13.6	11.1/3	11.8 *	11.8 *	11.05
NORTH DAKOTA (D)	11.05	13.1 *	13.1 *	10.2	13.6	11.1/3	13.1 *	13.1 *
LA REUNION (E)	12.3 *	11.05	12.3 *	12.3 *	10.2	13.6	11.1/3	12.3 *
ARGENTINA (F)	12.9 *	12.9 *	11.05	12.9 *	12.9 *	10.2	13.6	11.1/3
AUSTRALIA (G)	11.1/3	13.0 *	13.0 *	11.05	13.0 *	13.0 *	10.2	13.6
JAPAN (H)	13.6	11.1/3	12.8 *	12.8 *	11.05	12.8 *	12.8 *	10.2
TRANSMISSION INTERVAL	0.9 / .2	1.0 / .2	1.1 / .2	1.2 / .2	1.1 / .2	0.9 / .2	1.2 / .2	1.0 / .2

Frequencies in kHz

* UNIQUE FREQUENCIES

Figure 1212. Transmission format.

BASIC OMEGA OPERATION

An Omega receiver determines position in either the **direct ranging mode** or the **hyperbolic mode**. Some call the direct ranging mode the **rho-rho mode**. In the direct ranging mode, the receiver measures ranges from stations by measuring phase shifts between transmitted signals and an internal reference signal. In the hyperbolic mode, the receiver measures position relative to transmitter pairs by making phase comparisons between signals coming from these pairs.

1213. Direct Ranging Mode

The Omega wavelength, at 10.2 kHz, is approximately 16 miles long. The wavelength defines the width of each Omega "lane." See Figure 1213a. This figure shows the lanes as concentric circles formed around the transmitting station. An Omega receiver measures the phase of the received signal within a known lane. This phase shift allows the receiver to determine its position's fraction distance between lanes. Knowing which lane it is in and the fractional distance between lane boundaries, the receiver can calculate an LOP. The LOP is the line of points corresponding to the fractional distance between lanes calculated by the receiver.

The schematic of Figure 1213a does not take into account that the transmitted navigation signal forming the Omega lane is not stationary. Rather, it propagates at the speed of light. To account for this moving wave, the receiver generates a reference signal at the same frequency of the Omega navigation signal. This reference signal "freezes" the Omega signal from the receiver's perspective in a manner analogous to the way a strobe light flashing at the same frequency of a rotating disk freezes the disk from an observer's perspective. Comparing these "frozen" reference and navigation signals allows the receiver to measure the phase difference between the navigation signal and the reference signal. This phase difference, in turn, is proportional to the

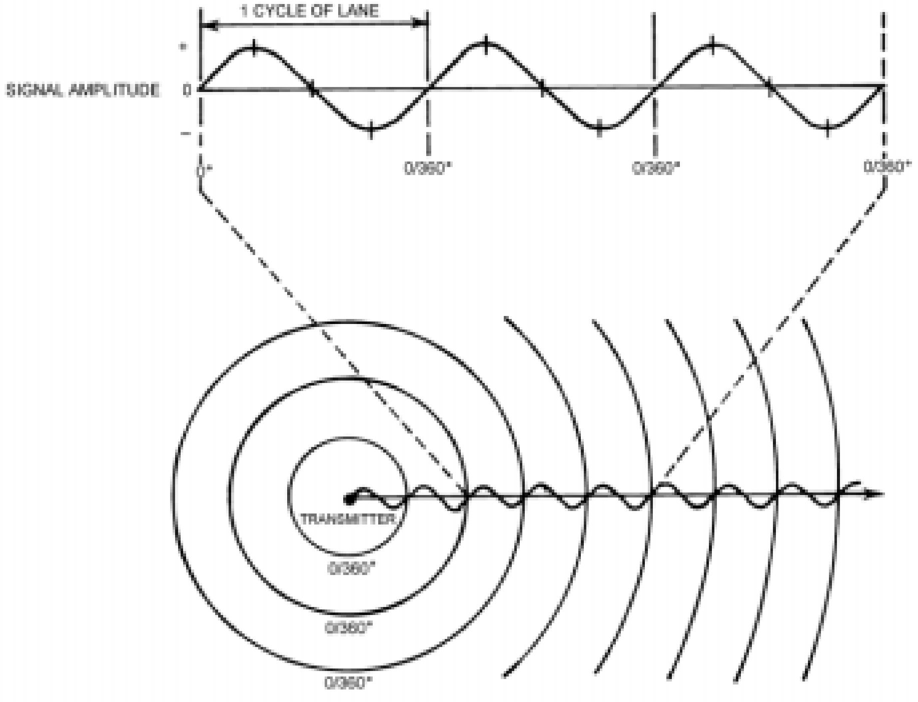


Figure 1213a. Omega lanes formed by radio waves.

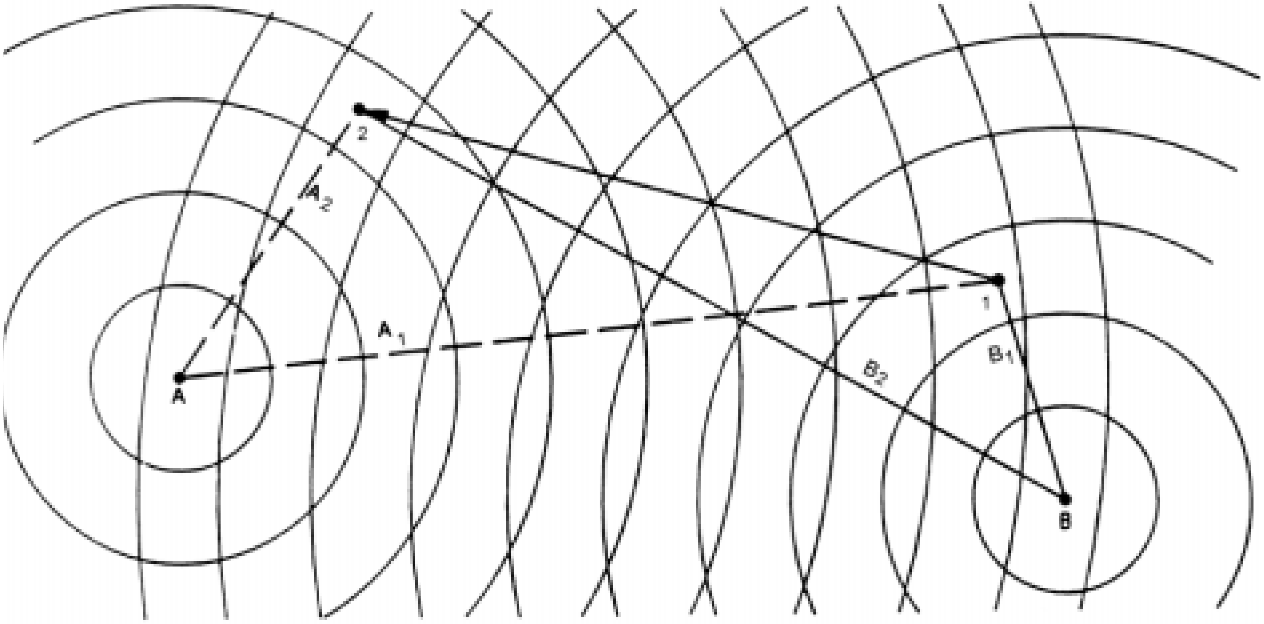


Figure 1213b. Position fixing in the direct ranging mode.

receiver's fractional distance between two Omega lanes.

See Figure 1213b for an illustration of how the direct ranging mode works. The operator initializes the Omega receiver at point 1. This initialization tells the receiver what lane it is in and the fractional distance between the lane boundaries. From this information, the receiver calculates A_1 and B_1, the distances between the receiver and stations A and B, respectively. The receiver then travels to point 2.

During the trip to point 2, the receiver keeps track of how many lanes it crosses. When it stops, it determines the fractional distance between lane boundaries at point two. From the lane counting and the phase comparison at point 2, the receiver calculates A_2 and B_2, the distances between the receiver and stations A and B, respectively.

1214. Hyperbolic Mode

In the direct range mode discussed above, the receiver measured the distance between it and two or more transmitting stations to determine lines of position. In the hyperbolic mode, the receiver measures the difference in phase between two transmitters.

See Figure 1214. This figure shows two transmitting stations, labeled A and B. Both of these stations transmit on the same frequency. Additionally, the stations transmit such that their waves' phase is zero at precisely the same time. Because each signal's phase is zero at each wave front, the phase difference where the wave fronts intersect is zero. Connecting the intersecting wave fronts yields a line along which the phase difference between the two signals is zero. This line forms a hyperbola called an **isophase contour**. At any point along this contour, the phase difference between the stations is zero. At any point between the isophase contours, there is a phase difference in the signals proportional to the fractional distance between the contours.

The set of isophase contours between station pairs forms a series of lanes, each corresponding to one complete cycle of phase difference. The hyperbolic mode lane width on the stations' baseline equals one-half the signal wavelength. For a 10.2 kHz signal, the baseline lane width is approximately 8 miles. Each of these 8 mile wide lanes is divided into 100 **centilanes (cels)**. The receiver measures the phase difference between stations in hundredths of a cycle. These units are termed **centicycles (cec)**.

1215. Direct Ranging And Hyperbolic Operation

Originally, the hyperbolic mode was more accurate because the direct ranging mode required a precise receiver

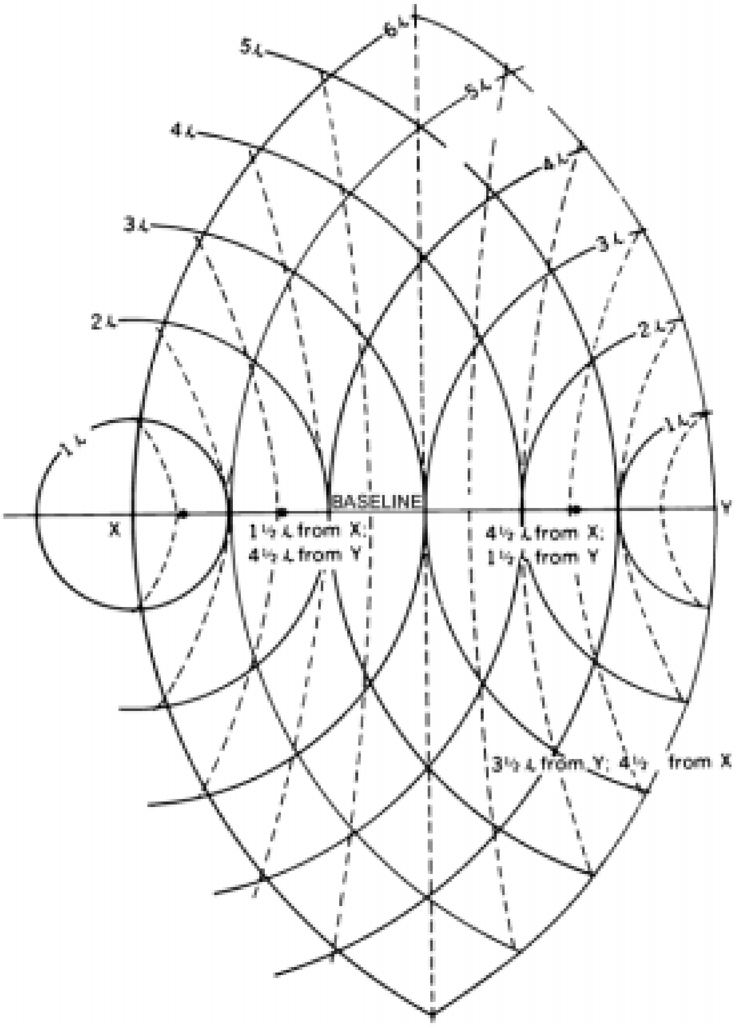


Figure 1214. Omega lanes formed by hyperbolic isophase contours.

internal oscillator to remain synchronized with the atomic oscillators used by the transmitting station. Since these oscillators would have made the receiver prohibitively expensive, the receiver carried an oscillator that was subject to clock error. In the direct ranging mode, this clock error would have been critical because this mode relies on a direct comparison between one transmitter's signal and the clock internal oscillator. In the hyperbolic mode, the receiver measures the phase difference between two transmitted signals and the receiver's internal oscillator. When the receiver subtracts one phase difference from another to calculate the difference, the clock error is mathematically eliminated. In other words, as long as the clock error remained constant between the two measurements, subtracting the two phase differences canceled out the error.

The microprocessing of modern receivers, however, allows the direct ranging mode to be used. The methodology used is similar to that used by the Global Positioning System to account for inaccuracies in GPS receiver clocks. See section 1105. The Omega receiver makes three ranging measurements and looks at the intersection of the three resulting LOP's. If there were no clock error present, the LOP's would intersect at a pinpoint. Therefore, the receiver subtracts a constant clock error from each LOP until the fix is reduced to a pinpoint. This technique allows a receiver to use the direct ranging method without a precise atomic oscillator. This technique works only if the clock error is constant for each phase difference measurement.

1216. Using Multiple Frequencies

To this point, this chapter has discussed Omega operation involving only the 10.2 kHz signal. 10.2 kHz is the primary navigation frequency because virtually all Omega receivers use this frequency. More sophisticated receivers, however, use a combination of all the available frequencies in computing a fix. Each receiver operates differently. Consult the operator's manual for a detailed discussion on how a specific receiver operates.

The above discussion on Omega operations assumed that the 10.2 kHz measurements required to calculate a fix were measured simultaneously. However, Figure 1212 shows that no two stations transmit 10.2 kHz simultaneously. Therefore, the receiver makes the 10.2 kHz phase measurements several minutes apart. In both the direct ranging and hyperbolic modes, the receiver stores the first phase difference measurement between the received signal and the receiver's internal oscillator in memory and then compares that stored value with a second phase difference measured later. The fix error caused by the slight delay between measuring station signals would be inconsequential for marine navigators because of the relative slowness of their craft. Receivers on aircraft, however, because of their craft's relatively high speed, must have a technique to advance the phase difference measured first to the time of the second phase difference measurement. This technique is called **rate aiding**.

OMEGA UNDER ICE OPERATIONS

1217. Under Ice Operation

For most military marine navigation applications, GPS has eclipsed Omega as the primary open ocean electronic navigation system. There is one area, however, in which military navigators use Omega as the primary electronic fix source: submarine operations under the polar ice cap.

Under the ice, the submarine cannot raise any antennas capable of copying GPS signals. However, VLF signals can penetrate the ice. Therefore, the submarine can deploy a **floating wire antenna (FWA)** that rises from the submerged submarine to the bottom of the ice overhead. The submarine then copies the Omega signals through the ice on the FWA.

Even though Omega is the only external electronic fix source available under the ice, its accuracy is seldom sufficient to ensure ship safety or mission accomplishment. Submarines, for example, must accurately plot the positions of thin ice regions in the event they must return to emergency surface. Omega does not position the ship with sufficient accuracy to do this. Submarines, therefore, use the inertial navigator as the primary positioning method when operating under the ice. When sufficient sounding data is available on their charts, submarine navigators supplement the inertial navigator with bottom contour navigation. Omega does, however, provide a useful backup in the under ice environment because no navigator feels comfortable navigating with only one positioning source, even if it is as accurate as the submarine inertial navigator.

VLF SIGNAL PROPAGATION

1218. Ionosphere Effects On VLF Propagation

The propagation of very-low-frequency (VLF) electromagnetic waves in the region between the lower portion of the ionosphere and the surface of the earth may be described in much the same manner as the propagation of higher frequency waves in conventional waveguides. These waves' transmission can be described by “the natural modes of propagation,” or simply “modes.” The behavior of the VLF wave may be discussed in terms of these modes of propagation.

There are three parameters that indicate how a certain mode will propagate in the earth-ionosphere waveguide: its attenuation rate, its excitation factor, and its phase velocity. The **attenuation rate** defines how fast energy is lost by the mode during its travel. The **excitation factor** measures how strongly the source generates the mode in comparison to other modes. **Phase velocity** defines the mode's speed and direction of travel. The modes are usually ordered by increasing attenuation rates, so that normally mode 1 has the lowest rate. For frequencies in the 10 kHz to 14 kHz band, the attenuation rates for the second and higher modes are so high that only the first mode is of any practical importance at very long distances. However, since mode 2 is more strongly excited than mode 1 by the type of transmitters used in the Omega system, both modes must be considered at intermediate distances.

Another consideration is that the modes have different phase velocities. Thus, as modes propagate outward from the transmitter, they move in and out of phase with one another, so that the strength of the vertical electric field of the signal displays "dips" or "nulls" at several points. These nulls gradually disappear, however, as mode 2 attenuates, so that the strength behaves in a smooth and regular manner at long distances (where mode 1 dominates).

Since the degree of modal interference is also dependent upon factors other than proximity to the transmitter, the minimum distance for reliable use is variable. For applications sensitive to spatial irregularities, such as lane resolution, the receiver should be at least 450 miles from the transmitter. Lesser separations may be adequate for daylight path propagation at 10.2 kHz. As a warning, the Omega LOPs depicted on charts are dashed within 450 nautical miles of a station.

Since the characteristics of the Omega signal are largely determined by the electromagnetic properties of the lower ionosphere and the surface of the earth, any change in these properties along a propagation path will generally affect the behavior of these signals. Of course, the changes will not all produce the same effect. Some will lead to small effects due to a relatively insensitive relationship between the signal characteristics and the corresponding properties. For Omega signals, one of the most important properties in this category is the effective height of the ionosphere. This height is about 90 kilometers (km) at night, but decreases quite rapidly to about 70 km soon after sunrise due to the ionization produced by solar radiation.

The phase velocity of mode 1 is inversely proportional to the ionosphere's height. Therefore, the daily changing ionosphere height causes a regular diurnal phase change in mode 1. The exact magnitude of this diurnal variation depends on several factors, including the geographic position of the receiver and transmitter and the orientation of the path relative to the boundary between the day and night hemispheres. This diurnal variation in phase is the major variation in the characteristics of the Omega signal at long distances.

Finally, the presence of a boundary between the day and night hemispheres may produce an additional variation. In the night hemisphere, both mode 1 and mode 2 are usually present. In the day hemisphere, however, only mode 1 is usually present. Hence, as the signal passes from the night to the day hemisphere, mode 2 will be converted into the daytime mode 1 at the day-night boundary. This resultant mode 1 may then interfere with the nighttime mode 1 passing unchanged into the day hemisphere. Thus, some additional variation in the characteristics may be present due to such interference.

1219. Geophysical Effects On VLF Propagation

Effects less pronounced than those associated with diurnal phase shifts are produced by various geophysical parameters including:

- Ground conductivity. Freshwater ice caps cause very high attenuation.
- Earth's magnetic field. Westerly propagation is attenuated more than easterly propagation.
- Solar activity. See the discussions of Sudden Ionospheric Disturbances and Polar Cap Absorption below.
- Latitude. The height of the ionosphere varies proportionally with latitude.

1220. Sudden Ionospheric Disturbances (SID's)

These disturbances occur when there is a very sudden and large increase in X-ray flux emitted from the sun. This occurs during either a solar flare or an "X-ray flare." An X-ray flare produces a large X-ray flux without producing a corresponding visible light emission. This effect, known as a **sudden phase anomaly (SPA)**, causes a phase advance in the VLF signal. SID effects are related to the solar zenith angle, and, consequently, occur mostly in lower latitude regions. Usually there is a phase advance over a period of 5 to 10 minutes, followed by a recovery over a period of about 30 to 60 minutes. Significant SID's could cause position errors of about 2 to 3 miles.

1221. The Polar Cap Disturbance (PCD's)

The polar cap disturbance results from the earth's magnetic field focusing particles released from the sun during a solar proton event. High-energy particles concentrate in the region of the magnetic pole, disrupting normal VLF transmission.

This effect is called the **polar cap disturbance (PCD)**. Its magnitude depends on how much of the total transmission path crosses the region near the magnetic pole. A transmission path which is entirely outside the arctic region will be unaffected by the PCD. The probability of a PCD increases during periods of high solar activity. The Omega Propagation Correction Tables make no allowances for this random phenomenon.

PCD's may persist for a week or more, but a duration of only a few days is more common. HYDROLANT/HYDROPAC messages are originated by the Defense Mapping Agency Hydrographic/Topographic Center if significant PCD's are detected.

The position error magnitude will depend upon the positioning mode in use and the effect of the PCD on each signal. If the navigator is using the hyperbolic mode and has chosen station pairs with similar transmission paths, the effect will largely be canceled out. If using the direct ranging mode, the navigator can expect a position error of up to 8 miles.

1222. Arctic Paths And Auroral Zones

The predicted propagation corrections include allowance for propagation over regions of very poor conductivity, such as Greenland and parts of Iceland. Little data are available for these areas, hence even the best estimates are uncertain. In particular, rather rapid attenuation of the signal with position occurs as one passes into the "shadow" of the Greenland ice cap.

The auroral zones surrounding the north and south geomagnetic poles affect the phase of VLF signals. Auroral effects are believed to arise from electron precipitation in the higher regions of the ionosphere. Although the visual auroral zone is generally oval in shape, the affected region near the geomagnetic poles may be circular. Thus, auroral effects occur in a circular band between 60° and 80° north and south geomagnetic latitude. This effect slows the phase velocity of the VLF signal. This effect is approximately four times as severe at night.

INFREQUENT OMEGA OPERATIONS

As the VLF signal propagates through the atmosphere, it suffers distortion from the atmospheric phenomena discussed above. Most of these phenomena can be modeled mathematically, and receiver software can automatically correct for them. After initializing the receiver with the correct position, the receiver displays the vessel's latitude and longitude, not the measured phase differences. All modern receivers have this correction capability. Therefore, a navigator with a modern receiver will seldom need to use the Propagation Correction Tables. However, if a mariner is navigating with a first generation receiver which does not automatically make propagation corrections, then he must use these Correction Tables before plotting his LOP on the chart.

1223. Manually Correcting Omega Readings

The following is an example of the correction process.

Example: *A vessel's DR position at 1200Z on January 23 is 16°N, 40°W. The navigator, operating Omega in the hyperbolic mode, chooses stations A (Norway) and C (Hawaii) to obtain an LOP. The Omega receiver readout is 720. 12. (720 full cycles + 12 centicycles). Correct this reading for plotting on the chart.*

First, examine the Omega Table Area chart to determine the area corresponding to the vessel's DR position. A DR position of 16°N 40°W corresponds to area 12. Figure 1223a shows this chart.

Next, obtain the proper Omega Propagation Correction Tables. There will be two separate volumes in this example. There will be an area 12 volume for the Norwegian station and an area 12 volume for the Hawaiian station. Inside each volume is a Page Index to Propagation Corrections. This index consists of a chartlet of area 12 subdivided into smaller areas. Figure 1223b shows the index for the Norwegian station in area 12. Again using the ship's DR position, find the section of the index corresponding to 16°N 40°W. Inspecting Figure 1223b shows that the DR position falls in section 39. That indicates that the proper correction is found on page 39 of the Correction Table. Go to page 39 of the table.

The entering arguments for the table on page 39 are date and GMT. The date is January 23 and GMT is 1200. The correction corresponding to these arguments is -0.06 cec. See Figure 1223c.

Following the same process in the Area 12 Correction volume for the Hawaiian station yields a correction of –0.67 cec.

To obtain a station pair correction, subtract the correction for the station with the higher alphabetical designator from the correction for the station with the lower designator. In this example, Hawaii's station designator (C) is higher than Norway's station designator (A). Therefore, the station pair correction is (–0.06 cec) – (–0.67 cec) = +0.61 cec.

1224. Lane Identification

The receiver's lane counter, set on departure from a known position, will indicate the present lane unless it looses its lane counting capability. In that case, the navigator can determine his lane by either dead reckoning or using the procedure described below.

Using a receiver capable of tracking multiple frequencies, compute a 3.4 kHz lane by subtracting the corrected 10.2 kHz phase reading from a corrected 13.6 kHz phase reading. Since the 3.4 kHz lane is 24 miles wide, the navigator need know his position only within 12 miles to identify the correct 3.4 kHz "coarse" lane. This "coarse" lane is formed by three 10.2 kHz "fine" lanes; all 3.4 kHz coarse lanes are bounded by 10.2 kHz lanes evenly divisible by three. Determine and plot the computed 3.4 kHz phase difference in relation to the derived 3.4 kHz coarse lane to determine the correct 10.2 kHz fine lane in which the vessel is located. Having determined the correct 10.2 kHz lane, the

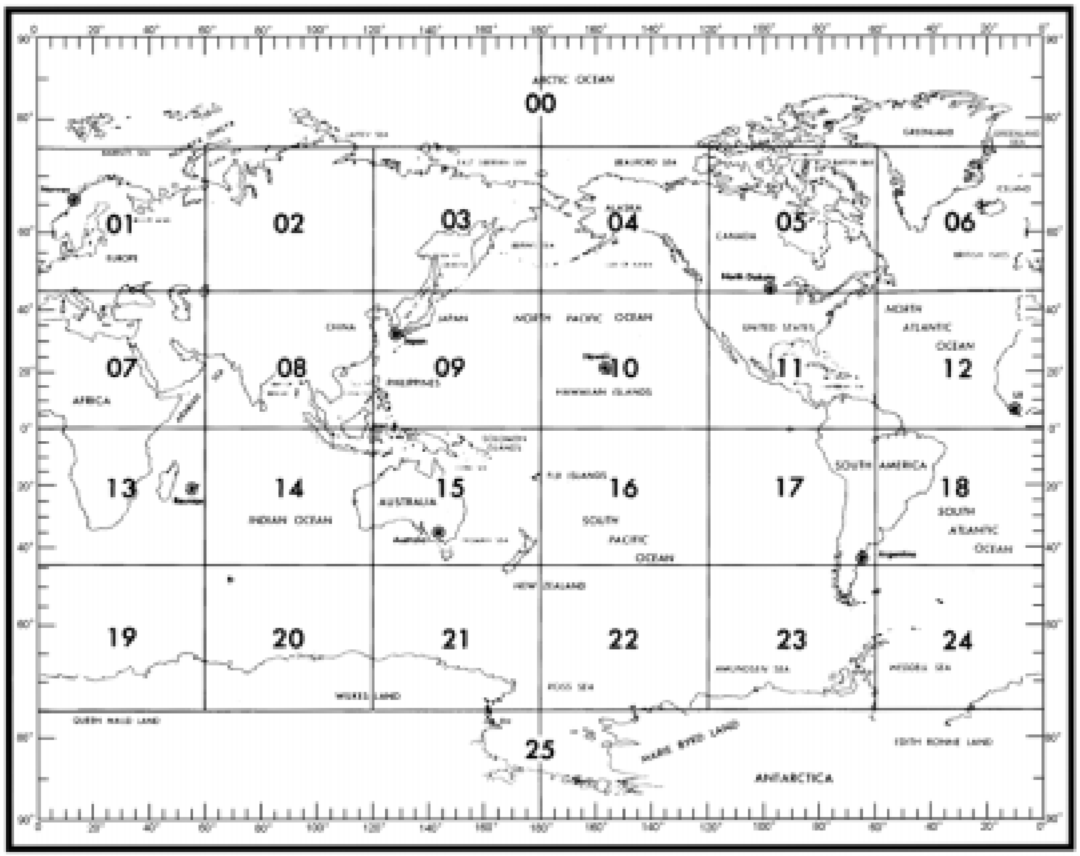
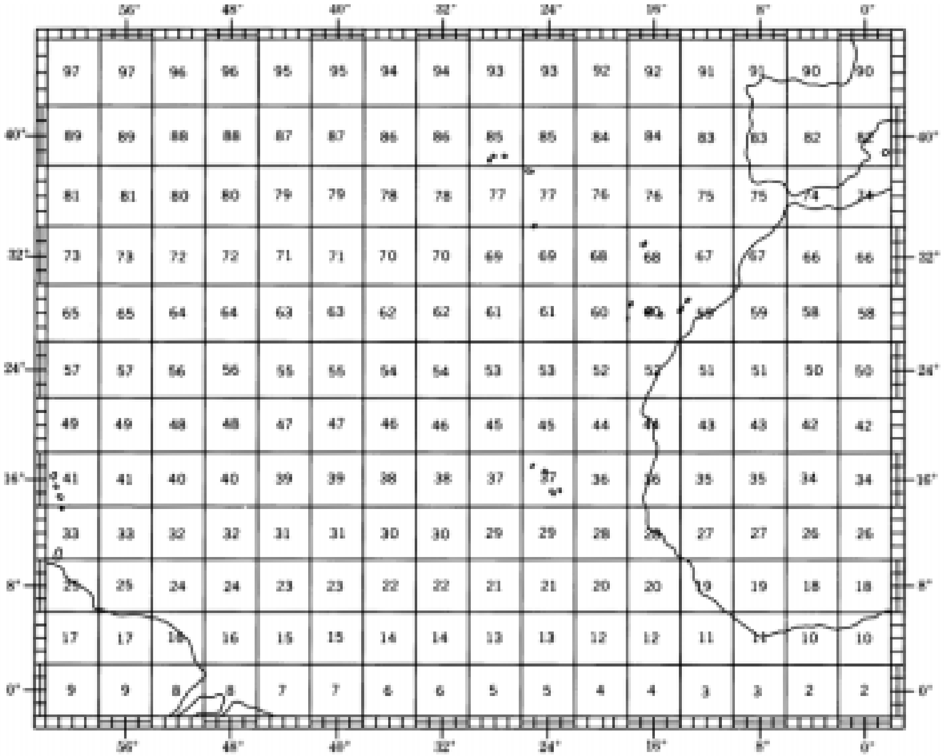


Figure 1223a. Omega table areas.



97	97	96	96	95	95	94	94	93	93	92	92	91	91	90	90
89	89	88	88	87	87	86	86	85	85	84	84	83	83	82	82
81	81	80	80	79	79	78	78	77	77	76	76	75	75	74	74
73	73	72	72	71	71	70	70	69	69	68	68	67	67	66	66
65	65	64	64	63	63	62	62	61	61	60	60	59	59	58	58
57	57	56	56	55	55	54	54	53	53	52	52	51	51	50	50
49	49	48	48	47	47	46	46	45	45	44	44	43	43	42	42
41	41	40	40	39	39	38	38	37	37	36	36	35	35	34	34
33	33	32	32	31	31	30	30	29	29	28	28	27	27	26	26
25	25	24	24	23	23	22	22	21	21	20	20	19	19	18	18
17	17	16	16	15	15	14	14	13	13	12	12	11	11	10	10
9	9	8	8	7	7	6	6	5	5	4	4	3	3	2	2

Figure 1223b. Page index to propagation correction.

10.2 KHZ OMEGA PROPAGATION CORRECTIONS IN UNITS OF CECS

LOCATION 16.0 N 40.0 W
STATION A NORWAY

DATE											GMT													
	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1-15 JAN	-68	-68	-68	-68	-68	-68	-68	-68	-65	2	8	-9	-8	-6	-6	-8	-12	-19	-28	-41	-55	-63	-66	-67	-68
16-31 JAN	-68	-68	-68	-68	-68	-68	-68	-68	-60	6	6	-10	-6	-3	-3	-5	-9	-16	-25	-37	-52	-62	-65	-67	-68
1-14 FEB	-68	-68	-68	-68	-68	-68	-68	-66	-47	12	2	-7	-1	1	1	-1	-5	-11	-21	-33	-49	-61	-65	-67	-68
15-29 FEB	-68	-68	-68	-68	-68	-68	-67	-57	-32	12	-1	-2	2	4	4	2	-2	-7	-16	-28	-45	-59	-64	-67	-68
1-15 MAR	-67	-67	-68	-68	-68	-68	-61	-46	-19	9	-1	2	4	6	6	6	2	-3	-11	-23	-41	-57	-63	-66	-67
16-31 MAR	-67	-67	-68	-68	-68	-63	-54	-37	-9	8	0	3	6	7	8	7	5	1	-7	-18	-36	-55	-62	-66	-67
1-15 APR	-67	-67	-68	-68	-63	-54	-44	-27	0	5	2	5	7	9	9	9	7	4	-2	-12	-30	-52	-60	-65	-67
16-30 APR	-66	-67	-67	-65	-56	-49	-38	-21	6	4	3	6	8	10	10	10	8	6	1	-7	-25	-48	-58	-64	-66
1-15 MAY	-65	-66	-65	-61	-53	-44	-32	-15	7	4	4	7	9	11	11	10	9	7	3	-3	-18	-42	-54	-62	-65
16-31 MAY	-64	-65	-65	-62	-51	-43	-29	-13	7	4	5	8	10	11	12	11	10	7	4	0	-13	-36	-51	-59	-64
1-15 JUN	-62	-63	-64	-61	-51	-41	-28	-11	7	4	5	8	10	12	12	11	10	8	5	1	-8	-30	-49	-57	-62
16-30 JUN	-61	-63	-63	-61	-50	-41	-28	-11	7	4	5	8	10	12	12	11	10	8	5	2	-6	-27	-48	-56	-61
1-15 JUL	-61	-63	-64	-61	-55	-41	-30	-13	7	5	5	8	10	11	12	11	10	8	5	2	-6	-28	-48	-56	-61
16-31 JUL	-63	-65	-65	-62	-54	-44	-31	-15	6	5	4	7	10	11	12	11	10	8	5	1	-9	-32	-50	-58	-63
1-15 AUG	-65	-66	-65	-59	-52	-47	-35	-17	5	5	4	7	9	11	11	11	9	7	4	-2	-15	-39	-53	-61	-65
16-31 AUG	-66	-67	-67	-65	-56	-49	-38	-23	4	5	3	6	8	10	10	10	8	6	2	-6	-22	-46	-57	-63	-66
1-15 SEP	-67	-67	-68	-67	-64	-55	-44	-26	5	5	2	5	7	9	9	9	7	3	-3	-14	-33	-53	-61	-65	-67
16-30 SEP	-67	-67	-68	-68	-67	-61	-47	-32	2	5	1	4	6	8	8	7	5	-1	-9	-20	-40	-57	-63	-66	-67
1-15 OCT	-67	-67	-68	-68	-68	-66	-56	-38	0	5	-2	3	5	6	6	4	0	-7	-16	-29	-48	-60	-64	-66	-67
16-31 OCT	-67	-67	-68	-68	-68	-68	-64	-49	-7	7	-5	1	3	4	3	0	-4	-12	-21	-36	-53	-61	-65	-67	-67
1-15 NOV	-67	-67	-67	-68	-68	-68	-68	-60	-23	12	-6	-4	-1	0	0	-3	-9	-17	-27	-41	-56	-62	-65	-67	-67
16-30 NOV	-67	-67	-67	-68	-68	-68	-68	-66	-42	13	-2	-8	-4	-3	-3	-6	-11	-20	-29	-43	-57	-63	-66	-67	-67
1-15 DEC	-67	-67	-67	-68	-68	-68	-68	-68	-60	13	5	-10	-7	-6	-6	-9	-14	-21	-31	-44	-57	-63	-66	-67	-67
16-31 DEC	-67	-67	-67	-68	-68	-68	-68	-68	-64	8	7	-10	-9	-7	-7	-9	-14	-21	-30	-43	-56	-63	-66	-67	-67

Figure 1223c. Omega Propogation Correction Tables for 10.2 kHz, Station A, at 16°N, 40° W.

navigator can reset his receiver to the proper lane count.

Example: *A vessel's 200700Z Jan DR position is 51° 26'N, 167°32'W. The receiver has lost the lane count but the 0700Z phase readings for pair A-C are 0.19 centicycles for 10.2 kHz and 0.99 centicycles for 13.6 kHz. Determine the correct 10.2 kHz fine lane. See Figure 1224.*

To solve the problem, first plot the vessel's DR position. Use Omega plotting sheet 7609. Then determine the 10.2 kHz lanes evenly divisible by three between which the DR position plots. Inspecting the DR position on chart 7609 shows that the position falls between lanes A-C 1017 and A-C 1020. These lanes mark the boundary of the 3.4 kHz coarse lane. Then, determine the propagation correction for both the 10.2 kHz and 13.6 kHz signals from the Propagation Correction Tables for both frequencies, and apply these corrections to the measured phase difference to obtain the corrected phase difference.

Inspecting the tables yields the following results:

Correction for Station A (13.6 kHz) = – 1.42 cec
Correction for Station C (13.6 kHz) = – 0.89 cec
Correction for Station A (10.2 kHz) = – 0.54 cec
Correction for Station C (10.2 kHz) = – 0.45 cec
Corrected 13.6 kHz reading = 0.99 cec + (– 1.42 cec) – (– 0.89 cec) = 0.46 cec.
Corrected 10.2 kHz reading = 0.19 cec + (– 0.54 cec) – (– 0.45 cec) = 0.10 cec
Corrected 3.4 kHz derived reading = 0.46 cec – 0.10 cec = 0.36 cec.

Therefore, the vessel's position lies 36% of the way from lane A-C 1017 to lane A-C 1020. Use this information to determine that the correct 10.2 kHz fine lane is lane A-C 1018. Combining the proper lane with the 10.2 kHz corrected reading yields the correct Omega LOP: A-C 1018.10.

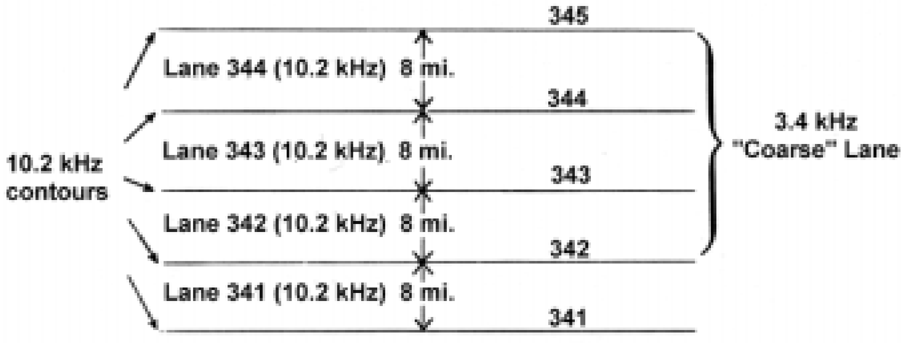


Figure 1224. The coarse lane.