LORAN—THE NEW RADIO NAVIGATOR.

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Introduction.

What Loran is and what it does.—Loran is a system of position finding on the sea or in the air, by reception of radio signals from transmitting stations of known position. The name is a term derived by combining the first two letters of LOng, the first two letters of RAnge and the first letter of Navigation. It was developed by the Radiation Laboratory of the Massachusetts Institute of Technology, the U.S. Coast Guard, and the U.S. Navy as a wartime radio aid to navigation. It is now no longer confidential and is available for the use of the maritime world. As its name implies, the system aims to furnish reliable positions to navigators at greater distances from the transmitting stations than is possible by other methods of radio navigation. Unlike radar, which uses very high frequencies of hundreds of millions of cycles, Loran operates on a frequency of about 2000 kilocycles. This is the region of the radio spectrum just above the commercial broadcast band. The extremely short waves of radar travel along nearly equivalent optical paths and are therefore limited in their range by the curvature of the earth. The longer waves of Loran, on the other hand, travel not only over the surface of the earth, but travel skyward and encounter the electrically ionized region of the upper atmosphere, which is called the ionosphere, and may be reflected back hundreds of miles from the sending antenna (see fig. 1). This is what makes the long range of Loran possible. With present techniques, the limit of distance is about 1,400 nautical miles by night and about half of this by day.

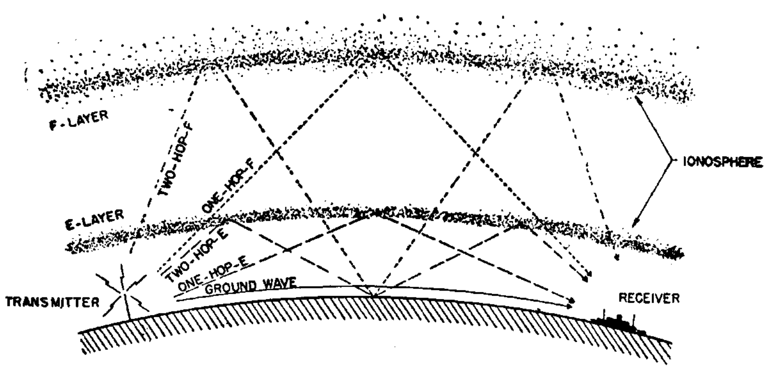


Fig. 1
Ground wave and sky wave paths.

Loran principle.—Loran operates on the following principles :—

(1) Radio signals consisting of short pulses are broadcast from a pair of special shore-based transmitting stations.

(2) These signals are received aboard ship on a specially designed radio receiver.

(3) The difference in time of arrival of the signals from the two stations is measured on a special indicator.

(4) This measured time difference is utilized to determine directly from special tables or charts a line of position on the earth's surface.

(5) Two or more lines of position, determined from two or more pairs of transmitting stations, are crossed to obtain a Loran fix.

Thus, Loran is entirely different from radio direction finding, for it measures time of arrival of radio waves, rather than direction of arrival. Loran therefore, may use simple straight wire antennas, rather than loops or complicated directional antenna arrangements.

Principles of operation (transmission).

Pulsing.—A Loran transmitter broadcasts short power bursts or pulses of radio energy into space in all directions. Each pulse lasts about 40 microseconds (40 millionths of a second). The pulses recur at regular intervals, but the transmitter is inactive for a relatively long period (for example 40.000 microseconds) between recurring pulses, as shown in figure 2. The short pulses of radio energy provide precise index marks for use in time measurements.

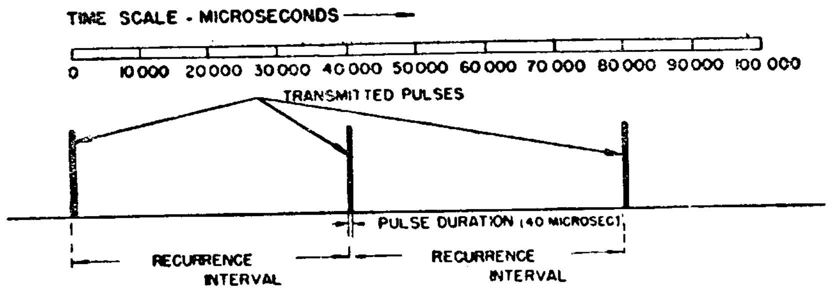


Fig. 2

Graphic representation of Loran pulses showing recurrence interval and pulse duration.

The radio pulses travel out from the transmitter, at a rapid but constant and known velocity of 162,000 nautical miles per second, or 983 feet per microsecond. Therefore distance can be measured in radio wave travel time as readily as in miles or feet, provided suitable measuring methods are used.

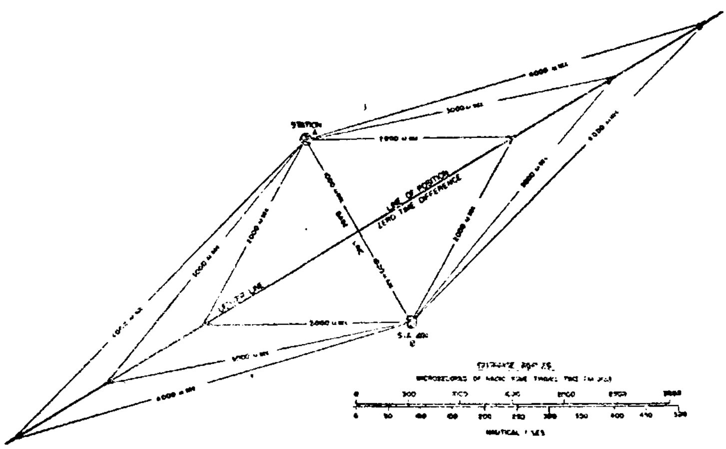


Fig. 3

Simplified Loran station pair with simultaneous pulsing showing center-line of zero time-difference.

Simplified Loran station pair.—Consider two transmitters (stations A and B) separated by a distance of 324 nautical miles, or 2,000 microseconds radio travel time as shown in figure 3. The line between the two stations is called the base line. The line going through the center of the base line and crossing it at right angles is called the centerline. For illustrative purpose only, consider that the two transmitters are sending out their pulses simultaneously ; that is station B transmits a pulse at the same instant as station A. Then at any point along the centerline the two signals will arrive at the same instant since all points on the center line are equidistant from the two stations. Thus if it is determined that the two signals did arrive at the same time, an observer would know that he was somewhere along the centerline.

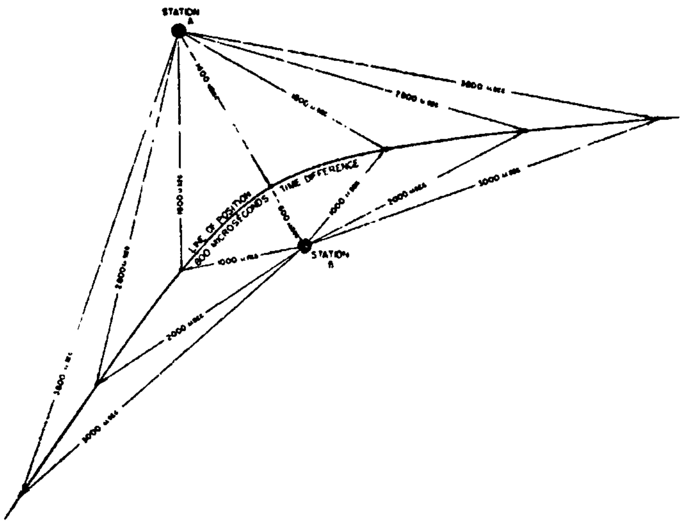


Fig. 4
Simplified Loran station pair with simultaneous pulsing showing line of constant time-difference.

If the observer were nearer station A than station B the pulse from A would arrive first. At any point there would be a definite difference in time of arrival, but a given time difference would be found at a number of points as shown in figure 4. All these points at which the same time difference exists can be connected to secure a line of constant time difference, or a Loran line-of-position. Thus a time difference measurement indicates that the observer is somewhere along a line, but does not indicate his position on that line. Note that the line of position has been determined by merely knowing the difference in distance (difference in radio-wave travel time) from the two stations, without knowing the actual distance to either.

A whole series of lines as shown in figure 5 can be drawn, each for a constant time difference, with zero time difference along the centerline and maximum time difference along the base line extension beyond each station. It will be noted that lines of the same constant time difference exist on either side of the centerline. This is because there is no method of distinguishing between the signals from the two stations and the same time difference is thus obtained on two different lines ; one in the case where the signal from station A arrives first and in the other where the signal from station B arrives first.

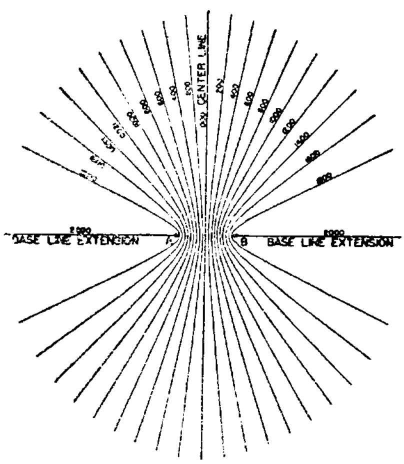


Fig. 5
Lines of constant time-difference from a simplified Loran station pair with simultaneous pulsing. For a given time-difference there are two possible lines-of-position.

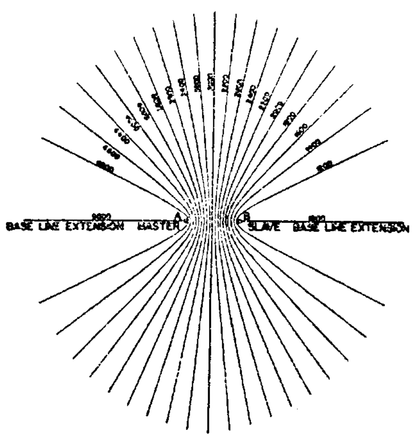


Fig. 7
System of lines-of-position from actual Loran station pair.

Mathematically, the lines of constant time difference are spherical hyperbolas, with the stations located at the focal points.

The interval between Loran lines changes greatly over the coverage area. Along the base line connecting the stations of a Loran pair the lines of position are close together and the value of T changes 12 microseconds per nautical mile. With increasing range the Loran lines spread out ; near the center line at ranges of 1.000 to 1.400 nauticals miles, the reading changes about 1 microsecond per nautical mile. Behind the transmitters, near the base-line extensions, Loran accuracy decreases rapidly—the reading changes only a fraction of a microsecond per nautical mile.

Actual Loran station pair.—The simplified Loran station pair with simultaneous pulsing as described above would have several practical disadvantages :—

(1) When near the centerline the signals from the two stations would arrive at so nearly the same time that overlap of the two pulses would result, with consequent equipmental difficulty in accurate time difference measurement.

(2) There is need for identifying the signal from each station of the pair to remove the ambiguity of two lines of position with the same time difference.

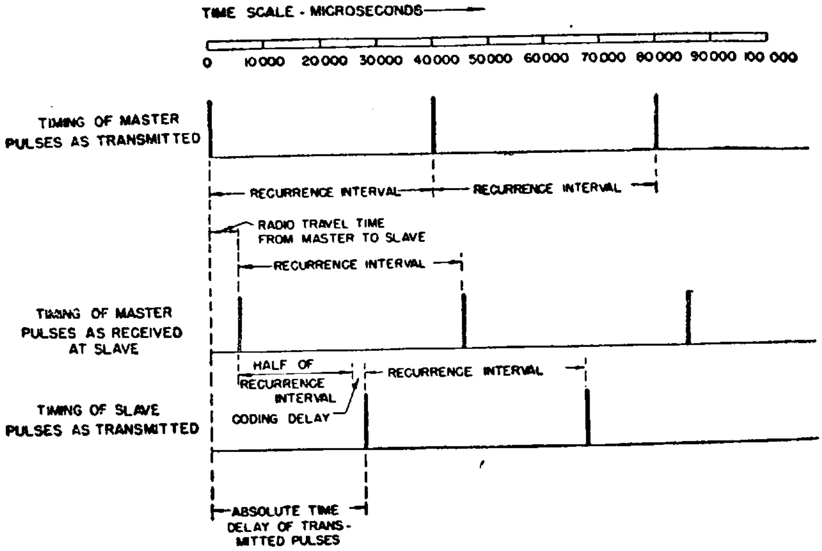


Fig. 6

Time relationship between pulses transmitted by master and slave station in an actual Loran station pair.

To remove these difficulties in the actual Loran system, a method of staggered pulsing has been adopted, as shown in figure 6. First one station known as the master or A type station transmits a pulse. After reception of this pulse, the other station known as the slave or B type station waits a definite fixed time equal to one half the pulse recurrence interval plus an additional small time known as the coding delay, then transmits its pulse.

So that the corresponding master pulse is always received first. This eliminates any ambiguity in identifying the pulses and gives time differences which increase continually from a minimum value at the slave station to a maximum at the master station.

At all points the time interval from a master station pulse to the next slave station pulse is greater than the interval from a slave station pulse to the next master station pulse. This difference in intervals provides a positive method of identifying which signal is from each station, even though the signals look exactly alike. Since the interval between pulses as transmitted is constant, the basic principles of the simultaneously pulsed system have not been altered.

In the measuring process, the time difference is always measured from the master station pulse to the slave station pulse and, as will be described, the time delay of one-half of the pulse recurrence interval is automatically removed. The net result is to provide a family of Loran lines of position for each pair of stations that have a shape identical to those secured with simultaneous pulsing but now the minimum reading occurs along the baseline extension beyond the slave station and the readings increase continuously to a maximum along the baseline extension beyond the master station as illustrated in figure 7. There is now a single line for each time difference.

The lines of constant time difference for each pair of stations are all precomputed taking into account curvature and eccentricity of the earth and other factors, and are made available to the navigator in the form of Loran tables or Loran charts. Therefore the navigator need not concern himself with the detailed theory of the method of establishing the time difference at the stations, or the calculation of the lines. He has merely to follow a methodical measuring procedure aboard his ship, then go directly to the charts or tables and interpolate between plotted or tabulated lines of position to determine the exact line corresponding to the measured time difference.

Arrangement of station pairs in a system.—Loran shore transmitting stations are usually arranged so that the two stations of a pair are separated by 200 to 400 nautical miles, but under unfavorable geographical situations the separation may be as little as 100 miles or as much as 600 miles.

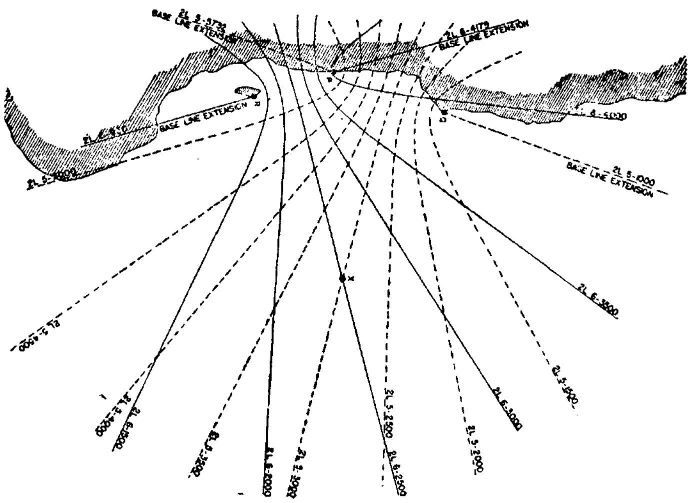


Fig. 8

Two lines-of-position from two pairs of Loran stations provide a Loran fix. P is a double-pulsed master station common to both pairs. Q and R are slaves. Lines with prefix 2L5 are formed by P-Q. Lines with prefix 2L6 are formed by P-R. The meaning of the prefixes is explained later.

Loran stations are arranged so that signals from two or more pairs of stations may be received in certain areas, and thus a Loran fix is obtained by crossing two or more lines-of-position as shown at point X in figure 8. In regions where it is geographically impossible to locate more than one pair of Loran stations, a single pair only may be installed to provide single lines-of-position for homing purposes.

In order to economize on station installations, one station is often made common to two pairs. Usually, the master station is common to both pairs and is double pulsed, the slaves being single pulsed. Double pulsed stations, however, send out two entirely distinct sets of pulses, one set paired with the pulses from each adjacent station. Therefore, from an operating viewpoint, a double pulsed station can be considered as two separate stations at the same location.

A number of Loran stations, constituting a " chain ", operate upon the same radio frequency, but the number of pulses transmitted each second (the recurrence rate) differs for each pair. By setting the equipment for the proper recurrence rate, any desired pair of signals can be observed.

Transmitter and transmitting antenna.—The standard Loran transmitter occupies a space about 5 feet wide, 2½ feet deep, and 6 feet high. It produces its pulse by means of a conventional push-pull oscillator, tuned to a radio frequency of 1750-1950 kc. modulated at the cathodes. This delivers power to a quarter wave transmitting antenna, either a vertical wire about 110 feet high or an inverted L-shaped one about 55 feet along each arm. The oscillator is, in effect, turned on and off by a suitable exciter and modulator, which are actuated by the timer.

The timer.—The main parts of the timer are housed in a cabinet approximately 4 feet wide, 1½ feet deep, and 5½ feet high. It is operated in a room shielded from the radiations of the other apparatus by a sheathing of wire netting. It is connected to a 60-foot vertical receiving antenna, and to the transmitter by a network of circuits and switches. It has a crystal clock, a receiver, three oscilloscopes, and auxiliary circuits.

The crystal clock.—The crystal clock is of very high accuracy. The crystal itself is enclosed in a double walled " oven " inside which the temperature is held close to 140° F. and not permitted to rise or fall more than about 0.5° F. The crystal vibrates 50,000 times a second and through a chain of divider circuits it provides " pips " at intervals of 10, 100 and 1,000 microseconds. A special circuit actuated by one of these " pips " defines each *half* recurrence interval. The pips control an oscilloscope, displaying on its screen a pattern of traces with their markers.

The pips from the crystal also actuate a series of " selector " circuits providing a " timing " pip during each half of the recurrence interval, which may be set by the operator to occur at a given number of microseconds after the beginning of the half interval. One of the timing pips is fed to the exciter of the transmitter, triggering the pulse that is broadcast by the transmitter. If the station is a type A (master) station the pip occurring during the first half of the recurrence interval provides the trigger, if the station is a type B (slave) station the other pip is used.

Synchronization of stations of a pair.—In practice the time difference for one of the pair is specified. This specification determines the absolute delay, from which all other time differences are calculated. The selectors of the local timer are set so that the specified difference separates them, and the crystal clock is adjusted until the local pulse matches the remote pulse. The pulses are thus placed in the correct local time relation, which establishes the correct absolute delay. The stations are then said to be *synchronized* or in *synchronism.*

Master and slave operation.—In practice it is station B that normally adjusts its pulse to the other. The crystal clock at station A is set to the pulse rate assigned to the pair, and thereafter runs without interference. The operator at station B sets his selectors to the correct local time difference, matches his pulse to that of station A by adjusting the rate of his crystal clock, and then maintains this match by monitoring the pulses, retarding his clock if it gains and thus makes the remote pulse appear to lag, or accelerating it if the opposite occurs. The operator at station A sets his selectors to his correct local time difference and also watches the pulses. However, if he notices a variation, he makes no adjustment but by blinking signals to the operator at B, who adjusts as necessary. Station A is therefore called a master station and B a slave station.

Principles of operation (reception).

General.—Loran reception is the measurement of very small time increments, intervals accurate to a millionth of a second. This evaluation is accomplished by measuring the linear separation of reference points on a scale of millionths of a second traced out by a point of light, the tip of a ray of electrons of the cathode ray oscilloscope. This time pattern is visually perceptible because of the persistence of a visual impression on the retina of the eye,

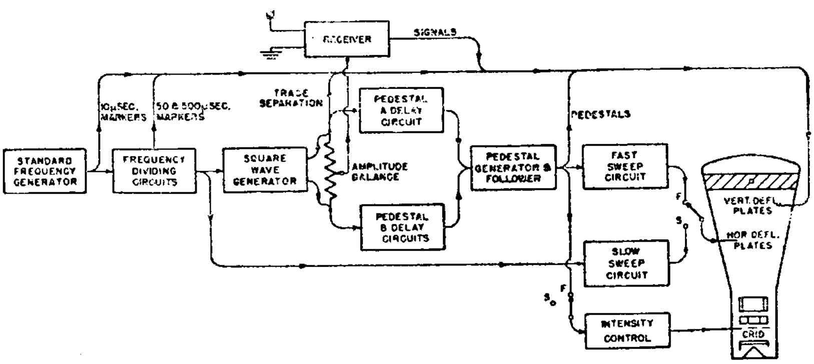


Fig. 9 b
Schematic diagram of receiver circuits.

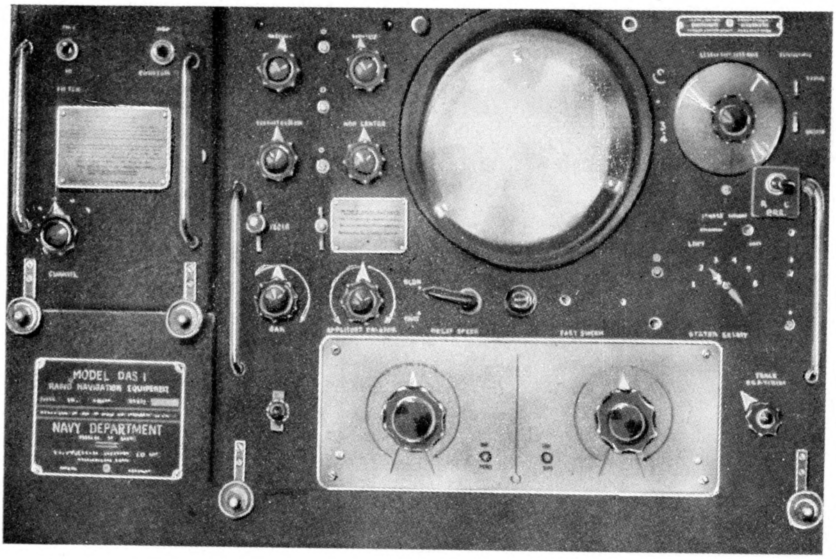


Fig. 9 a
Loran receiver model DAS-1.

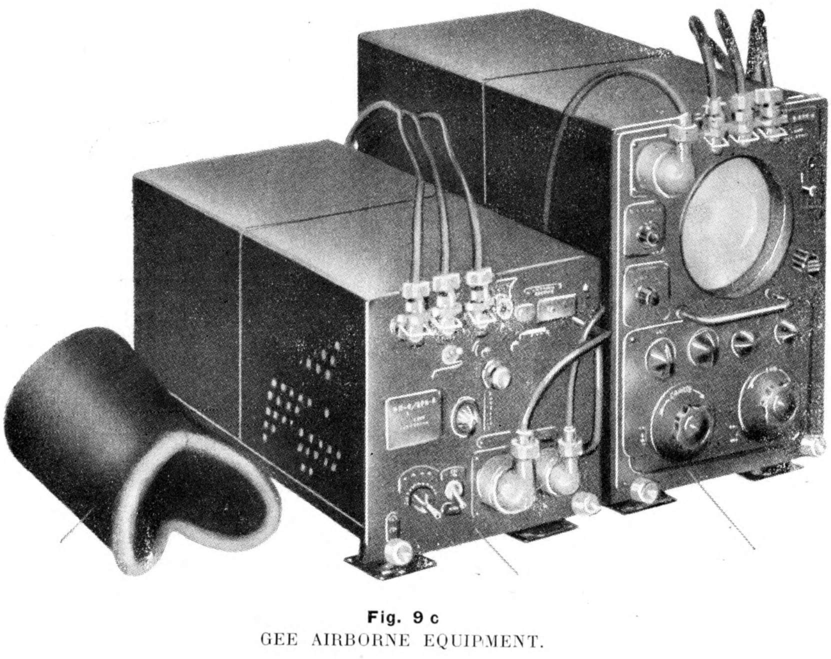


Fig. 9 c
GEE AIRBORNE EQUIPMENT.

Viseur — Récepteur radio — Indicateur
R-9/APN-4 ID-6/APN-4

the principle utilized in moving picture projection. The time scale is traced in a few millionths of a second and would vanish too quickly to be of use, but the trace is repeated in its identical relationships at the rate of about 25 times per second. One of these visual stimuli persists until the next is received on the retina with the result that the eye sees an uninterrupted picture.

The Loran receiver.—Loran signals are received aboard ship on a Loran receiver which is basically similar to ordinary radio receivers, but specially adapted to Loran (see figs. 9a and 9b). The output of the receiver goes, however, not to a loud speaker or earphones, but to a Loran indicator. The indicator is essentially an electronic watch, whose time record is made visible by the use of a specially designed cathode ray oscilloscope. The indicator measures, in microseconds, the difference in time of arrival of the pulse signals from the two stations of a pair. In the indicator horizontal traces or lines of light on the screen of the cathode ray oscilloscope correspond to the mechanically traced lines of the ordinary chronograph, with the difference that while the ordinary chronograph presents a time record in seconds as units, the Loran indicator presents a time record in millionths of a second.

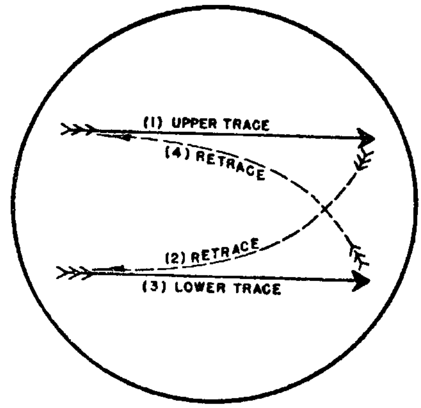


Fig. 9
Schematic representation of the cathode ray tube screen showing formation of traces.

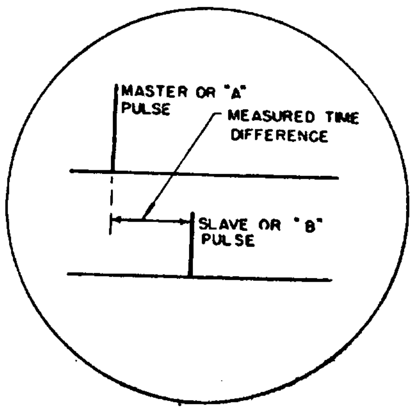


Fig. 10
Simplified drawing of cathode ray tube screen showing received signals.

Time difference measurement.—The Loran indicator has two horizontal traces, shown in simplified form in figure 9. These traces are formed by a moving spot of light, controlled by the electrical circuits within the indicator. During the recurrence interval (for example 40,000 microseconds) between successive pulses from a Loran transmitting station, this spot of light traces out the time pattern as follows :—

(1) The spot sweeps steadily from left to right across the upper part of the screen in a little less than one half the pulse recurrence interval to form the upper or A trace.

(2) The spot snaps downward and to the left in a few microseconds forming a retrace.

(3) The spot sweeps steadily from left to right across the lower part of the screen in the second half of the pulse recurrence interval to form the lower or B trace.

(4) The spot snaps upward and to the left. This retrace like the first takes but a few microseconds.

This sequence of spot movement is repeated rapidly at the recurrence rate of the transmitted pulses. Because of persistence of vision the spot movement appears to form continuous slightly flickering lines of light. Since the spot travels much faster during the retraces they are quite weak, and in some equipments are blanked out completely. The Loran pulse signals from the Loran receiver are applied to the indicator in such a way that the spot of light is jerked upward whenever a pulse is received. Thus the traces are displaced upward to form vertical lines at times corresponding to the time of arrival of the Loran signals as shown in figure 10. If the rate at which the trace pattern is repeated (the sweep recurrence rate) is exactly the same as the recurrence rate of the Loran pulses, the spot has just time to run over its entire path between successive pulses from a given station. The upward displacement of the trace will then take place at the same point on succeeding sweeps, and a stationary pulse will appear on the screen. If, however, the sweep recurrence rate is slightly faster than the recurrence rate of the Loran signals, each pulse will appear a little to the right on successive sweeps and so appear to drift in that direction. If the sweep recurrence rate is slower than the Loran pulse recurrence rate, the pulses will appear to drift to the left. This is analogous to the ordinary movie where persistence of vision makes objects appear to stand still when they are in the same position in successive pictures and appear to move when they are in slightly different positions in successive pictures.

If the pulse from the A or master station is on the top trace, the B or slave pulse will be on the bottom trace and to the right of the pulse on the top trace. This is true because the interval between master and slave pulses is always more than one-half the recurrence interval, and during this time the spot of light will travel over more than half its total path. The pulses must be in these positions for the time difference measurement but will not necessarily so appear when the equipment is turned on, since the time at which the traces start has no direct connection with the time at which the Loran signals arrive. However, the indicator is provided with a Framing (left-right) switch which can temporarily change the sweep recurrence rate slightly and make the signal pattern as a whole drift along the traces until the pulses are in the desired positions. If by chance the slave pulse is put on the top trace,

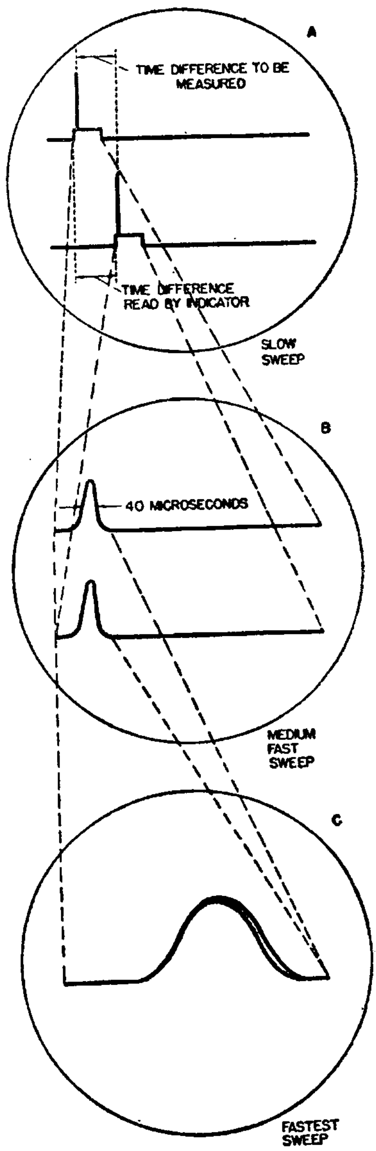
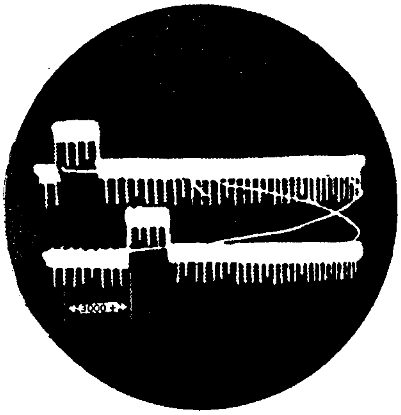


Fig. 11

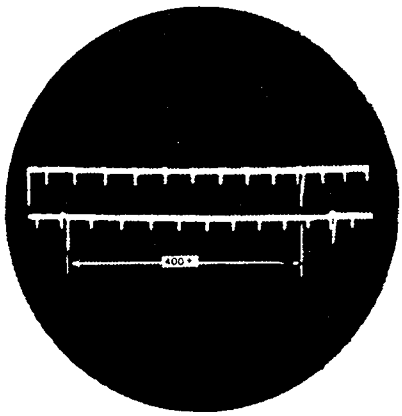
Simplified pulse positioning process. Parts A, B, C, showing varying stages of the process.

the master pulse either will be on the top also or on the bottom trace to the left of the slave pulse on top, and further manipulation of the Framing (left-right) switch is needed.

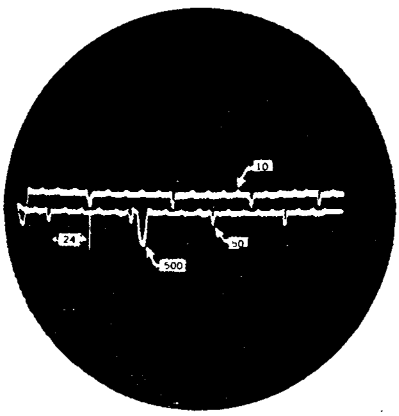
The time difference measurement is taken as the horizontal distance from the master pulse to the slave pulse as shown in figure 10. This convention automatically cancels out the fixed delay of one half the pulse recurrence interval, which was added at the slave station, and gives smaller and more convenient numbers to deal with. As a rough measure of the time difference this distance could be scaled off and compared with the total trace length which is known to be equal to nearly one-half the recurrence interval, however greater accuracy is needed and a more precise method must be used. Portions of the traces are electrically magnified, the signals are accurately positioned at corresponding places on the magnified portions, and then the relative displacement of these portions is accurately measured. When the entire recurrence interval is displayed on the traces the portion to be isolated and magnified is distinguished by being raised a little above the rest of the trace forming a pedestal. The A pedestal on the top trace is fixed in location near the beginning of the sweep. The B pedestal on the bottom trace is movable by means of delay controls. The display of the entire recurrence interval is called the *slow sweep,* the display of the magnified portions is called the



(a) Slow sweep. Each marker representing 500 microseconds. Reading is 3.000+



(b) Medium fast sweep. Short markers represent 50, long markers 500 microseconds. Reading is 400+.



(c) Fastest sweep. Markers represent 500, 50, and 10 microseconds as shown. Reading is 24.

Fig. 12

Photographs of traces of model DAS-1/DAS-3 equipment illustrating markers and a typical time-difference reading.

(a) Slow sweep. Each marker representing 500 microseconds. Reading is 3.000 +.

(b) Medium fast sweep. Short markers represent 50, long markers 500 microseconds. Reading is 400 +.

(c) Fastest sweep. Markers represent 500, 50 and 10 microseconds as shown. Reading is 24.

fast sweep. Several fast sweeps provide different degrees of magnification. A much condensed version of the positioning process is shown in figure 11. In figure 11 A the master pulse has been placed on the top pedestal and the delay controls have been manipulated to place the bottom pedestal under the slave pulse. In figure 11 B the portions of the traces on top the pedestals have been magnified to the entire screen width (medium fast sweep) and the shape of the pulses can be more clearly seen. The slave pulse has been placed approximately below the master pulse by further manipulation of the delay controls, and both pulses have been drifted to the left portion of the traces with the Framing (left-right) control. In figure 11 C the left portion of the medium fast sweep has been further magnified to the entire screen width, and the separation of the top and bottom traces has been eliminated. Then the pulses have been adjusted to the same height by means of the balance control, that height made convenient with the gain control, and the left edges of the pulses superimposed or matched. When this has been done, the relative displacement in microseconds of the upper and lower pedestals is exactly the same as the relative displacement of the leading edge of the two pulses, and the next step is to measure this relative displacement of the pedestals in microseconds.

An illustration of the traces and markers and a typical time difference reading is shown in figure 12. The displacement of the pedestals to the nearest 500 microseconds is obtained by counting 500 markers on the slow sweep as shown in figure 12 A. The fractional portion of a 500 microseconds interval is determined to the nearest 50 microseconds by measuring the displacement between a 500 microseconds marker on the lower trace and the next 500 microseconds marker to the right on the upper trace, using the medium fast sweep as shown in figure 12 B. The fractional part of 50 microseconds is determined to the nearest microsecond by measuring the displacement between a 50 microseconds marker on the lower trace and the next 50 microseconds marker to the right on the upper trace, using the fastest sweep as shown in figure 12 C. The 10 microseconds markers aid the interpolation. The total time difference reading is the sum of the separate readings. In the example of figure 12 this is 3,000 plus 400 plus 24, or 3,424 microseconds. In actual practice the readings are made in the reverse order from the above as an operating convenience.

An autodial receiver-indicator has been constructed in which the readings are obtained from the settings of a calibrated dial.

Detailed characteristics of Loran signals.

Identification, radio-frequency channel.—Loran stations do not transmit call letters as most radio stations do and identification of station pairs is entirely by two distinguishing characteristics : radio-frequency channel and pulse-recurrence rate. Different groups of Loran stations operate on different radio frequencies or wave lengths, just as ordinary individual radio stations. The Loran receiver has provision for switching between several pretuned radio-frequency channels on the same principle as a push-button receiver.

Pulse-recurrence rate.—In order to economize on radio-frequency channels a number of pairs of Loran stations are operated on the same radio-frequency channel, but each pair operates at a different pulse-recurrence rate. Signals from all Loran stations on the same channel appear on the scope screen, provided the ship is within range of the stations, but these signals drift across the screen at varying speeds. The operator can select a pair of stations by means of switches which make the sweep-recurrence rate of the indicator the same as the pulse-recurrence rate of the desired pair. These signals will then be stationary, while signals from other pairs drift across the screen and can be ignored.

Station identification symbols.—Each pair of Loran stations is given a three character identification symbol, where the first character is the channel, the second the basic pulse-recurrence rate, and the third the specific pulse-recurrence rate. These symbols are used in Loran tables and on Loran charts.

Loran terminology.—In the Loran system the abbreviations and symbols used are :—

T —tabulated reading in microseconds.

Tg—ground wave reading in microseconds.

Ts—sky wave reading in microseconds.

Frequency channels (preceding **L** or **H**) :—

1	1950 kc.
2	1850 kc.
3	1900 kc.
4	1750 kc.

Basic pulse recurrence rates

L (low)	25 per second.
H (high)	33 1/3 per second.

(Additional basic rates may be added.)

Specific recurrence rates assigned for station identification (following **L** or **H**) :—

0, 1, 2, 3, 4, 5, 6, 7.

The following examples indicate the application of Loran terminology to each line. In the legend 1L3-2120, 1 denotes the frequency—1950 kc. ; L, the basic pulse recurrence rate—25 per second : 3, the station recurrence rate—3 ; and 2120 the T (reading) for that line.

The first three characters of the legend give all information necessary for setting equipment to obtain readings from any one station pair.

Blinking, on-off or shifting.—The accuracy of Loran depends on the transmitting stations keeping their signals correctly timed or synchronized. When, because of transmitter trouble or other technical difficulties, correct synchronization cannot be maintained, a distinctive signal known as *blinking* is sent out. There are two different types of blinking signal, the first type of which consists of the signal appearing and disappearing at intervals of about two seconds. The second consists of a shift of the signal to the right about 1,000 microseconds and back at intervals of about 2 seconds. A time difference reading should not be made when the signals are blinking because the timing of the transmitted signals may not be correct.

Ground waves and sky waves, General.—The range of Loran stations, the type of signal received, and the accuracy of the resulting time difference measurement are affected by the path over which the radio waves travel. A portion of the radio energy travels out from the transmitter paralleling the surface of the earth. This is known as the ground wave. Another portion of the radio energy travels upward and outward, encounters electrified layers of the atmosphere (known as the ionosphere) and if conditions are favorable is reflected back to the receiver. Reflections from the ionosphere are known as sky waves (see fig. 1).

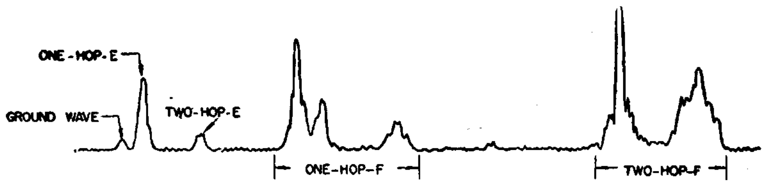


Fig. 13

Appearance of ground wave and sky wave pulses.
Detailed view of signals from one station (as received near limit of ground wave range).

Since the ground wave path and the various sky wave paths are of different lengths, a single transmitted pulse may be received as a series or train of pulses as shown in figure 13. As the ground wave path is shortest, the ground wave if received, will always be the first pulse in a train, the one-hop E-layer reflected pulse is next and secondary pulses (multiple-hop E-layer and all F-layer reflections) follow.

Selection of pulses to be matched.—The Loran indicator will give a reading no matter what ground wave or sky wave pulses are matched, but in order to get the correct reading the proper pulses must be selected. This is the critical part of Loran operation and must be carefully performed. The rules of selection are as follows :—

(1) If ground waves can be received from both stations of a pair they should be used and a " G " put after the time difference to indicate its nature. Even weak ground waves are to be preferred to strong sky waves because sky waves are subject to variations in timing and changes of shape known as *splitting* and *fading* caused by variations in the ionosphere.

(2) If no ground wave is received from either station of a pair, the two one-hop-E sky waves should be matched, an " S " put after the time difference reading to indicate its nature, and a sky wave correction applied.

(3) If a ground wave is received from only one station of a pair, the usual procedure is to ignore it, match the two one-hop-E sky waves and apply the sky wave corrections as above. In some instances however a special correction is provided for matching the ground wave from one station to the one-hop-E sky wave from the other. Such time-difference readings should be marked " SG " if the master sky wave is used or " GS " if the slave sky wave is used.

Only the first sky wave, reflected once from the ionosphere, is considered sufficiently stable and reliable for navigational use and then only at ranges exceeding 250 miles from the transmitter. When the first sky waves are matched, in the absence of ground waves from one or both stations of a pair, a " sky Wave correction " must be applied to the reading to compensate for the differences between the sky wave and ground wave paths. In certain instances special supplementary tables of corrections may be provided to permit the matching of the first sky wave from one station with the ground wave from the other.

The sky wave correction.—The sky wave correction compensates for the fact that the one-hop-E sky wave path is longer than the ground wave path. Loran lines of position in tables and charts are computed on the assumption that the signals travel via the ground path. The sky wave correction reduces a sky wave time difference reading (" S " reading) to an equivalent ground wave time-difference reading so that the lines-of-position in tables and charts can be used.

Range of sky waves and ground waves.—General.—It is important than an appreciation be had of the factors which affect the range of Loran signals. These factors include :—

(1) Time of day.

(2) Geographical region and ionospheric conditions.

(3) Static.

(4) Type of signal path, over sea or over land.

(5) Possible directional affects of the shipboard receiving antenna.

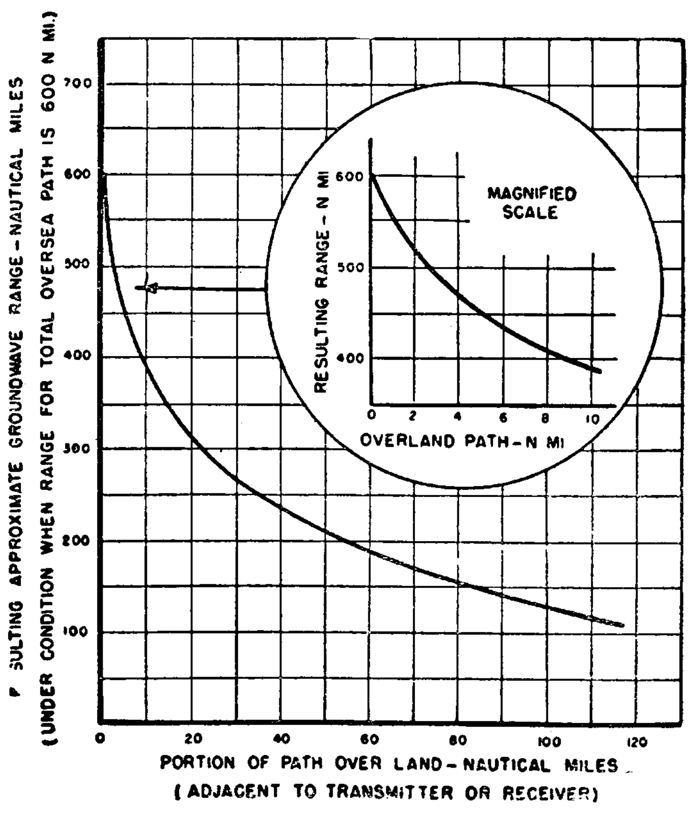
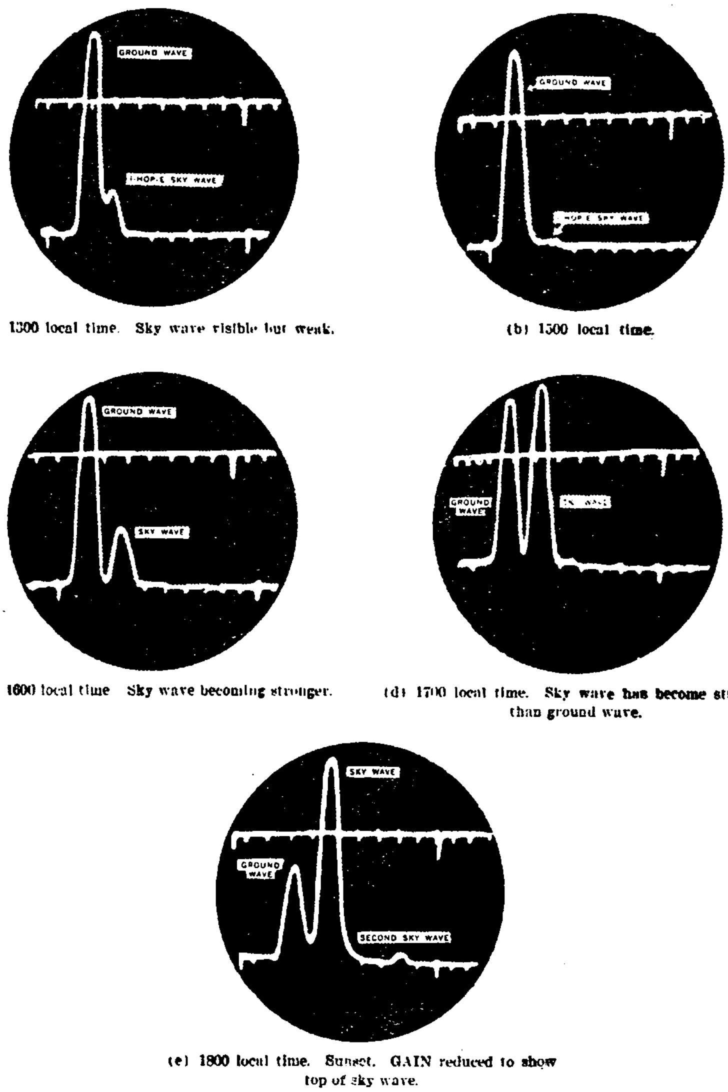


Fig. 13 a

Typical effect of land on ground wave range. Where land is not adjacent to transmitter or receiver reduction in range is much less than shown.

Effect of intervening land on range.—The range of the Loran ground wave is greatly reduced by intervening land. The general effect is shown in figure 13 A. This curve shows the resulting range for various amounts of average type land adjacent to the transmitter or to the receiver under conditions when the range oversea is 600 nautical miles. The effect is somewhat less when the land is not adjacent to the transmitter or receiver, but is intermediate in the path, and it varies greatly with the type of land. In aircraft increased altitude reduces the effect of land. It is difficult to predict the range of a Loran station when land intervenes. Loran stations are always located so that signal paths are as much as possible over water in the direction of greatest importance.

The sky wave paths are so far above the earth that signal strengths are not affected by intervening land unless this land is within 20 or 30 miles of the transmitter or receiver.



(a) 1300 local time. Sky wave visible but weak.

(b) 1500 local time.

(c) 1600 local time. Sky wave becoming stronger.

(d) 1700 local time. Sky wave as become stronger than ground wave.

(e) 1800 local time. Sunset. GAIN reduced to show top of sky wave.

Fig. 14

Typical variation in appearance of signals with time of day. Distance to station 550 nautical miles. Date March 1944. Location 40° to 45° north latitude. (Balance control turned so that no signals show on top trace.)

Where such intervening land does exist, sky waves will be considerably weaker and less reliable, and the average range of the one-hop-E sky wave may be reduced to about 1,100 miles or less.

Identification of ground waves and sky waves.—The identification of ground waves and sky waves is the principal operational problem in Loran, and it must be solved correctly if satisfactory results are to be obtained. In making the identification the following should be considered :—

(1) The ships location relative to the stations, and the type of signals that might be expected.

(2) The appearance of the signals under observation.

(3) The spacing of the pulse under observation relative to other pulses in the train.

The problem of identification will be solved almost automatically 90 percent of the time if observations are made at hourly intervals. It will then be possible to see how conditions are changing, and it will be possible to have a good idea as to what type of signals to expect before even looking at the scope. In addition, any temporary mistakes in identification will be made more obvious by the sudden discrepancy with respect to previous Loran fixes.

Appearance of ground waves and sky waves.—Sky waves have two inherent characteristics that can be used to distinguish them from ground waves. First, sky waves are subject to fading. At times this fading may be quite rapid, completing an up and down cycle in less than a minute, at other times the cycle of fading may be extremely slow and a sky wave may appear very steady like a ground wave, for several minutes. Second, sky waves are subject to splitting, which consists of breaking into two or more humps, which fade more or less independently. Splitting may be a source of error in making sky wave readings, since the leading edge of the pulse (the left edge) may be momentarily split down into the noise, and the pulse apparently shifted over several microseconds. In general the greater the distance to the transmitter, the steadier are the sky waves. The one-hop-E sky wave generally is much steadier than multiple-hop-E sky waves or F-layer sky waves.

In contrast to sky waves the ground wave is generally steady in amplitude and is always free from splitting, although if it is weak it may flicker from noise. Also, there are occasions when violent rolling of the ship may cause the ground wave amplitude to vary somewhat. However in this case, all signals should vary more or less together.

The variation in appearance of ground and sky waves with local time is shown in figure 14.

The signals from the several stations can be readily identified. On the slow sweep the master signal is on the upper trace and the slave signal to the right on the lower trace on all receiver models except the AN/APN-9. On this model both signals are initially set on the lower trace, slave signal to the left. When the **function** switch is turned to position « 2», the slave signal appears on the upper trace and the master signal on the lower trace.

In any station pair the master station is always mentioned first ; thus for QJ the master station is Q and the slave station is J. In several instances a single station sends out signals on two recurrence rates; for example, station Q is common to pairs QJ and QG. If a ground wave is observed from Q on rate 0 (QJ) a similar ground wave will be received on rate 1 (QG). Recognition of these several common stations and their two identical signals will reduce errors in the identification of ground and sky waves.

Loran charts and tables.

General.—Precomputed lines of constant time-difference for each pair of stations, taking into account curvature and eccentricity of the earth and other factors are made available to the navigator by the U.S. Hydrographic Office in the form of Loran charts and tables. The navigator, therefore, has merely to follow a methodical measuring procedure aboard ship, then go directly to the charts or tables and interpolate between plotted or tabulated lines of position to determine the exact line corresponding to the measured time-difference.

Method of compiling Loran charts.—The constant time-difference lines of which a Loran chart is composed, are very nearly spherical hyperbolas. The equation of a spherical hyperbola can be written either in spherical polar coordinates or in spherical rectangular coordinates. Practically it is inconvenient to compute Loran hyperbolas from either of these formulas, because of the rather laborious transformation to the terrestrial coordinates, latitude and longitude. Loran charts and table have, therefore, been prepared by choosing points of even latitude and longitude, computing distances from both stations and taking the differences, tabulating the resulting time-differences and then interpolating to obtain latitude and longitude for each desired even time-difference—a laborious process likewise, but one which is adapted to routine machine computation. The distances are converted to radio wave travel times (in microseconds) by using an accurate determination of the velocity of radio waves over the earth's surface. From these travel times, the time difference is found by subtracting the travel times from the reference point to the stations and adding the fixed delay between stations and the coding delay at the slave station. The time-differences throughout the area are then interpolated and tabulated in book form. The Loran charts are drawn by connecting with a smooth line all references points which have the same time-difference.

Service areas.—The catalog of Loran charts and service areas are given in H.O. Publication No. 1-L of 1st April 1946.

LORAN TABLES

Loran Tables. Loran Tables, supply the coordinates necessary for the construction of Loran lines. These coordinates, based always on ground wave reception, are applied primarily for use by surface ship navigators. They may be plotted upon the same type of chart used for celestial navigation. Loran charts are thus obtained, and any special chart may be so constructed if tables of that area are available.

The tables in general comprise several sections, each pertaining to an established pair of Loran stations. The component parts of each section are : chartlet, sky wave corrections, and tabulated coordinates.

The chartlet shows station positions, area covered, and general direction and distribution of Loran lines emanating from a station pair.

Sky wave corrections are the same as those found on the charts and are arranged for entering with D.R. latitude and longitude.

The basic table is arranged in vertical columns headed with the complete legend defining the curve upon which lie all the computed coordinates for that specific value of T. Besides the column heading, tables are entered additionally with latitude or longitude and the other coordinate (longitude or latitude) is found tabulated to the nearest tenth of a minute. In general, points are computed sufficiently close to permit drawing a straight line through two consecutive points to determine the Loran line.

Columns are headed by values of T corresponding to ground wave readings, i.e., $T = Tg$. In general, T is tabulated at intervals of 20 microseconds, but near the base line extensions a few lines are inserted at intervals of 10 microseconds. Values of T corresponding to the base line expensions are so marked.

All the points required to definite a Loran line are given in a column. Since Loran lines of position from each pair of stations spread out in all directions, it is sometimes necessary to tabulate the latitudes at which the line intersect meridians, and sometimes necessary to tabulate the longitudes at which the lines intersect parallels. The tables are so arranged that the latitude always appears to the left of the accompanying longitude.

Over the entire coverage area, points are listed at intervals of one degree of latitude or longitude. Near the transmitting stations, where the lines curve sharply, additional points are inserted at intervals of 30' or 15' ; the spacing of the points has been chosen so that the navigator may safely use the straight line joining any two adjacent tabulated points. The maximum error between these straight line segments and the true Loran line will not exceed half a mile except within 20 miles of the transmitting stations. In that region, the curvature of the lines is excessive and straight line segments may be in error by as much as 2 miles. A plot of three consecutive points will always show the degree of curvature present and indicate the true line.

A chartlet preceding each table shows Loran lines for each hundred microseconds. Navigation should not be attempted on these chartlets.

Interpolation to the exact T desired is easily performed by reference to the column designated by Δ. This column gives the rate of change of latitude or longitude in hundredths of minutes per microsecond change in T.

Sky wave correction. When a reading is made by matching the first sky wave from each station of a pair, the reading, Ts, must be corrected to the equivalent ground wave reading Tg. The corrections in microseconds are tabulated for each pair of stations at points separated by whole degrees of latitude and longitude. Whether the correction to Ts should be added or subtracted is marked in the Sky Wave Correction Tables.

The table of corrections is readily entered with the D.R. position. If, however, the D.R. position is quite uncertain and the sky wave corrections in that area are large, a preliminary solution can be made and used for a second entry into the table. Interpolation in the table should be made whenever the sky wave corrections are changing rapidly. Failure to interpolate may cause appreciable errors in navigation.

Sky wave corrections are tabulated over the region between 250 n. m. and 1.400 nautical miles from the transmitting stations. Where the correction is uncertain, no value has been tabulated. Never attempt to extend sky wave corrections into areas not covered by the table.

UNITED STATES HYDROGRAPHIC OFFICE LORAN PUBLICATIONS ARE DISTRIBUTED AS FOLLOWS (Les Publications de l'Hydrographic Office des Etats-Unis relatives au Loran sont réparties de la manière suivante) :—

H.O. No. 221, Vol. 1 : North Atlantic.
Rates (combinaisons) : 1 H 1, 1 H 2, 1 L 0, 1 L 1, 1 L 2, 1 L 7.
Vol 2 : North Atlantic.
Rates (combinaisons) : 1 L 3, 1 L 4, 1 L 5, 1 L 6, 1 L 6 (b), 3 H 4.

H.O. No. 221-A : North Pacific.
Rates : 1 L 0, 1 L 1, 1 L 2.

H.O. No. 221-B : Central Pacific.
Rates : 2 L 0, 2 L 1, 2 L 2, 2 L 3, 2 L 4, 2 L 5.

H.O. No. 221-C . South Pacific.
Rates : 2 H 4, 2 H 5, 4 H 2, 4 H 3, 4 H 6, 4 H 7.

H.O. No. 221-D : Asiatic Area.
Rates : 4 L 6, 4 L 7, 4 H 4, 4 H 5, 1 L 6, 1 L 7 (4 L 0, 1, 2, 3, 4, 5 China-Burma coverage discontinued November 1945) (zone de couverture Chine-Birmanie interrompue en novembre 1945).

H.O. No. 221-E : West Coast U.S.A.
Rates : 2 H 1, 2 H 2, 2 H 3, 2 H 4, 2 H 5.

PAIRS (RATES) OF LORAN STATIONS ARE DISTRIBUTED AS FOLLOWS (June 1946)

Les couples (ou combinaisons) de stations Loran sont répartis de la manière suivante (Juin 1946)

NORTH ATLANTIC.

Rates	Stations
1 H 1 = C H	
1 H 2 = C G	
3 H 4 = (Aberdeen-Bizerte)	N = Narsak, Groenland.
1 L 0 = S H	L = Battle Harbor, Labrador.
1 L 1 = S B	V = Bonavista, Newfoundland.
1 L 2 = D B	P = Port-aux-Basques, Newfoundland.
1 L 3 = V L	K = Vik, Iceland.
1 L 4 = N L	A = Mangersta, Hébrides.
1 L 5 = U K	U = Skovanes, Faeroe.
1 L 6 = U A	W = Norwick, Shetland.
= U W	D = Deming.
1 L 7 = D P	B = Baccaro.
	S = Siasconset (Sandy Hook).
	H = Bodie Island (Cape Hatteras).
	C = Folly Island (Charleston).
	G = Hobe Sound (Galveston).

WEST COAST OF NORTH AMERICA.

2 H 1 = A L	L = Guadalupe.
2 H 2 = A G	G = Point Arguello, Cal.
2 H 3 = A B	A = Point Arena, Cal.
2 H 4 = W B	B = Cape Blanco, Oregon.
2 H 5 = W S	W = Point Grenville, Washington.
	S = Spring Island, Vancouver.

NORTH PACIFIC : ALASKA, ALEUTIAN.

1 L 0 = C T	M = St. Matthew Island.
1 L 1 = P M	P = St. Paul Island, Pribilof Island.
1 L 2 = P U	U = Umnak Island.
	C = Amchitka Island, Andreanof Island.
	T = Attu Island, Near Island.

CENTRAL PACIFIC.

Hawaian Area.........	2 L 0 = Q J	Q = Leahi Point, Niihau.
	2 L 1 = Q G	G = Frigate East Island.
		J = Upolu Point, Hawaii.
Marshall Isl. Area ...	2 L 2 = D K	K = Kwajalein.
	2 L 3 = D L	D = Majuro Island.
		L = Makin Island.
Phœnix Isl. Area......	2 L 4 = R E	E = Baker Island.
	2 L 5 = R F	R = Gardner Island.
		F = Atafu Island.

MARIANAS ISLANDS, ETC...

4 H 2 = H V	V = Guam.
4 H 3 = S V	S = Saipan.
4 H 4 = K J	U = Peleliu (Palau).
4 H 5 = K O	T = Pulo Anna.
4 H 6 = T U	M = Morotai.
4 H 7 = T M	K = Iwo Shima (Ogasawara).
	J = Okinawa.
	O = Oshima (Tokyo).

ASIATIC AREA.

Philippine Isl.........	1 L 6 = L B	L = Naulo Pt. Luzon.
—	1 L 7 = R B	B = Talampulan Island.
		R = Tarumpitao Point (Palawan Isl.).
China—Burma Coverage :	4 L 0, 1, 2, 3, 4, 5	= discontinued November 1945.
Bengal.................	4 L 6 = X Y	X = Charchapi.
—	4 L 7 = Z Y	Y = Puriorissa.
		Z = Cocanada.
South Pacific-	2 H 4 = W N	A = Champagny Island.
Australia	2 H 5 = W A	W = Sir Graham Moore Island.
		N = Bathurst Island.

Total 54 stations forming 38 pairs or rates.
Number of charts overprinted for Loran system approximates 180 sheets. (June 1946.)

Au total 54 stations constituant 38 couples ou combinaisons.
Le nombre total de cartes imprimées en surcharge pour l'emploi du système Loran se monte à environ 180 feuilles (juin 1946).

LORAN CHARTS

Loran navigation charts are published by the Hydrographic Office and the Aeronautical Chart Service U.S.A.A.F. for use aboard ships and aircraft. Ground wave lines of position from the various stations pairs are printed in distinguishing colors and are further identified by the legends described above. The colors for printing Loran lines are green, brown, blue, and magenta. Each color is used for two rates. Lines of position are shown at the closest interval of T satisfactory for the scale of the chart. This varies between 100 and 10 microseconds on H.O. charts.

In some areas where 5 or 6 rates overlap, only the 3 or 4 more useful ones are plotted on the charts. Lines of other rates can be obtained from the tables.

Any particular line desired but not printed on the chart can be put in by the navigator using the Loran tables.

The tables give complete coverage over water for each pair of stations.

As basic information the Loran charts carry isogonic lines, the VL-30's and VL-70's carry the location of some radio stations, and aircraft facilities. Soundings are not shown.

Charts are available on several scales. The various series designation of H.O. charts are:—

SERIES	SCALE
VL-70	70 n. m. per inch at mid-latitude.
VRL-200	About 68 n. m. per inch.
VL-30	30 n. m. per inch at mid-latitude.
VL-15	15 n. m. per inch at mid-latitude.
N (No. Pacific)...............	15 n. m. per inch at mid-latitude.
NW (No. Atlantic)............	1° long. is 4 inches.
L-14	14 n. m. per inch.

H.O. Publication 1-L, Loran Charts and Service Areas Catalog shows ground wave coverage, sky wave coverage, and a chart index of Loran service in the Atlantic, Asiatic and Pacific areas.

The sky wave corrections, in microseconds, are entered on the charts in the same color as the corresponding Loran line at the intersection of degree lines of latitude and longitude. The sign before the correction denotes whether it should be added or subtracted to the observed reading. To distinguish between corrections for two or more lines of the same color, the folowing system has been devised :—

Sky wave corrections for all low basic recurrence rates (L) are indicated by **vertical** numerals ;

Sky wave corrections for all high basic recurrence rates (H) are indicated by **italic** numerals ;

Each sky wave correction will carry a numerical exponent indicating the recurrence rate to which it applies.

Accuracy of Loran fixes.

General.—The accuracy of a Loran fix is determined by the accuracy of the individual lines-of-position used to get the fix and by their angles of intersection. The accuracy of an individual line-of-position in turn depends upon the following factors :—

(1) Synchronization of the transmitting stations.

(2) Skill in matching and identifying signals.

(3) Skill in reading the indicator.

(4) Uncertainty of sky wave correction (when sky waves are used).

(5) Position of the ship relative to the transmitting stations.

(6) Accuracy of tables and charts.

1. **Synchronisation of the transmitting stations.** If the error in synchronization exceeds the tolerable limit, usually set at plus or minus 2 microseconds, one or both stations will **blink** their signals. Since two types of "blinkers" are in use, the signals will either go off and on or jump back and forth by 1.000 microseconds with a period of a few seconds. **No readings should be made upon a signal that is blinking.**

2-3. **Accuracy of matching and reading the signals on the indicator.** The accuracy with which readings are obtained from the receiver-indicator depends largely upon the care and judgment exercised by the operator. With a reasonable signal-to-noise ratio, an experienced operator should be able to match the received signals and read the indicator within one microsecond of the correct value. With experience even extremely weak signals can be matched within a few microseconds.

Errors in the operation of the receiver-indicator may be minimized by consideration of the following items :—

(a) *Signal Matching.* The received signals should be superimposed and their leading edges matched in strict accordance with the instructions in the operational manual.

(b) *Indicator calibration.* If dial readings are to be used, the calibration of both coarse and fine delay dials should be carefully checked immediately before each set of readings. The last two figures of the reading, to be added to the coarse and fine delay dial readings, must always be obtained from the oscilloscope screen. Under no circumstances should an attempt be made to take the complete reading from the coarse and fine delay dials.

The reading on the oscilloscope screen is correct regardless of the calibration on the coarse and fine delay dials. Therefore readings made entirely from the oscilloscope screen are free of calibration errors. Maladjustment of the equipment may produce errors of 500 microseconds. Special care should be taken to eliminate errors of 50 or 500 microseconds when reading the indicator.

(c) *Indicator Reading.* Special care should be taken to eliminate errors of 50 or 500 microseconds when reading the indicator. With the AN/APN-9 receiver model, always add 100 microseconds to the total reading.

Loran Indicator ID-6A/APN-4—ID-6B/APN-4.

4. **Accuracy of the sky wave corrections.** Because the ionosphere, which reflects the sky waves, does not remain at a constant height above the earth, the sky wave corrections will vary slightly about the average values tabulated. Sky waves are most reliable far from the transmitters. At distances of 800 miles or more, carefully made sky wave readings, with the proper corrections, will generally be correct within 8 microseconds. At lesser distances the uncertainty increases, but even at 250 miles from the nearer transmitter of a pair, the error in a sky wave reading will generally be less than 30 microseconds. On extremely rare occasions errors of twice those amounts may occur. The convergence of Loran lines near the transmitters offsets much of the large uncertainty in sky wave observations at short ranges. Consequently the positional uncertainty resulting from the use of sky waves remains approximately constant with distance from the transmitting stations except near the base line extensions.

5. **Accuracy due to position of the observer.** The separation of the Loran lines, which governs the accuracy of the system, is a function of distance and direction from the transmitting stations. The relative accuracy of Loran over the coverage area is apparent from the spacing of the lines on the charts and chartlets.

The most favorable position, from the standpoint of minimum separation between Loran lines of position, is on the base line between the transmitters.

The most unfavorable positions are adjacent to the base line extensions, where the separation between the Loran lines can be several nautical miles per microsecond, even within ground wave range of the stations. The regions within 25 microseconds of the base line extensions for ground waves and within 200 microseconds for sky waves must be treated as areas of low reliability, and Loran lines near the base line extensions should be treated with **caution.**

6. **Accuracy of the Loran tables.** All Loran tables (H.O. 221, 221-A, etc.) used in the construction of charts have been computed for ground wave observations, Tg, and are correct to a small fraction of a microsecond.

In remote parts of the earth where many of the assigned geographical coordinates are uncertain, small discrepancies may appear between predicted Loran readings and those observed at points fixed by reference to landmarks. Inaccuracies in the geographical location of landmarks result from inadequate or incomplete survey data for certain areas now having Loran coverage. In a few cases, the urgent need for rapid installation of Loran stations to meet wartime operational requirements combined with adverse weather conditions prevented extensive astronomical observations to establish precisely the coordinates of the stations. In cases where station errors have been determined, chartlets with the corrections overprinted, are shown on pages 29 through 37, in H.O. Publication 1-L. All discrepancies between predicted and observed readings should be noted in detail in the reports on Loran operation. Such information will permit the navigational charts and Loran to be reconciled.

Crossing angles of position lines.—Loran stations are arranged so that the crossing angles of the lines-of-position from various pairs of stations are as good as possible consistent with geographical considerations. Over large parts of the service areas of Loran stations crossing angles of 30° or better are obtained. But near the extreme limits of sky wave coverage, if all the stations are situated along one coast or in a similar arrangement, crossing angles may be quite small. In this situation positions are obtained with relatively good accuracy in the direction perpendicular to the lines-of-position but with relatively poor accuracy along the lines-of-position. Where crossing angles are small, the practice of averaging a number of readings will result in considerably improved fixes.

Of course, uncertainty can be greatly reduced by using three or more Loran lines-of-position or by combining Loran lines with other lines-of-position. When determining the most probable position from such a fix careful consideration should be given to the relative accuracy of the various Loran lines, which may vary greatly, depending on whether ground waves or sky waves were used, whether signals were strong or weak and upon the spacing of the lines-of-position in that region.

If the ship moves appreciably between readings for different lines of position, the lines must be advanced or retarded in accordance with standard navigational practice to compensate for the distance made good between readings.

Timing and positional uncertainty.—The timing uncertainty, which is a number of microseconds, results in a corresponding uncertainty in the location of the hyperbola, which may be regarded not as a sharp line but a band or zone. If the time difference reading is between 3,570 and 3,578 microseconds the "line-of-position" is the zone between the hyperbolas having these two time differences. In general if the timing uncertainty is x microseconds and the half width of the zone y miles at the place where the measurement is made, and if

$$w = \frac{y}{x}$$

then the quotient w will be the distance apart at that place, in miles, of two hyperbolas that differ by one microsecond of time difference. It is called the positional uncertainty. The actual uncertainty in the location of the navigators line of position is the product of the timing and positional uncertainties.

If ⅜ of a mile per microsecond is considered a typical positional uncertainty and 2½ microseconds a typical-timing uncertainty for a hyperbola obtained from ground waves emitted by two standard stations, and if ¾ and 8 are the corresponding quantities for a hyperbola obtained from sky waves from the same stations, the actual uncertainties are 1 mile and 6 miles, respectively. It is to be remembered that these are single observations, not averages of a series, and also that the margin of uncertainty is generous ; the chances are a little better than even that the actual error is less than half the uncertainty.

Uncertainty of the ship's position.—The navigator usually obtains his fix from observations upon two pairs. Where his two hyperbolas cross, the positional uncertainty of one hyperbola is in general different from that of the other. The timing uncertainties may be different also. The intersecting "lines-of-position" are therefore strips of different widths, and their sides enclose a quadrilateral figure that is nearly a parallelogram (see fig. 18). This figure represents the navigator's fix. Its shape and size depend not only upon the uncertainties of both lines-of-position, but also upon the angle at which they cross. The size and shape of the parallelogram can be calculated, but it is better to judge the amount and direction of the uncertainty by inspection of the chart, experience, and common sense.

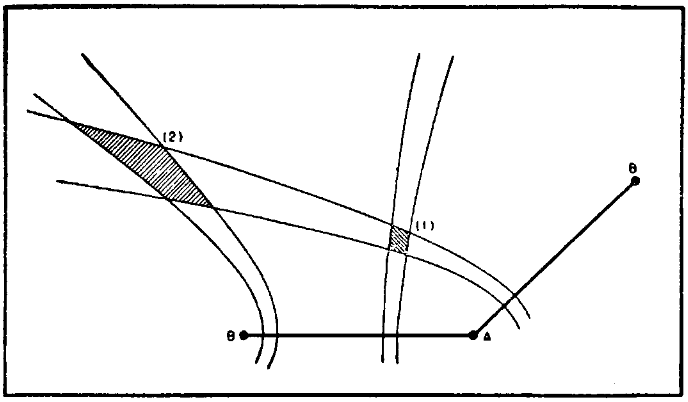


Fig. 18
Uncertainty of the ship's position.

Plotting the ship's position.

Lines of position.—A single observation or indicator reading denotes a line of position on the earth and on the navigator's chart. Lines of position corresponding to readings that are multiples of twenty (or some other convenient number) appear on Loran charts. In general, the navigator's reading will not coincide with one of these ; he must draw in his line properly interpolated between the adjacent chart lines and parallel to them. An observation of pulses from another pair of stations gives the navigator a second line of position intersecting the first line, it is similarly drawn and labeled with the reading and watch time. If the navigator is on a slow ship, the ship's change of position is negligible during the interval between observations, and the point where the lines intersect is the ship's position at both the recorded times. But a fast ship moves a considerable part of a mile in a minute. In this case the lines of position must be considered to move and should be advanced or retarded in conformity with accepted navigational practice.

When greater accuracy than can be obtained from small-scale charts is necessary, Loran tables are used. From them are extracted the latitude and longitude of two (or three for greater accuracy) points at which the reading would be obtained. A line is drawn on the chart through these points. This is a line-of-position and corresponds to one of the lines of a Loran chart.

Examples.

Example 1.—At 0924 on 24 July 1945, the D. R. position of a ship was latitude 56°15' N.; longitude 163°35' W. Loran readings were obtained in quick succession as follows :—

T_G = 1L1-3160 and T_G = 1L2-2820.

Required the Loran fix.

The Loran tables give the following data :

TABLE PM.—1L1-3160

Lat.	Δ	Long.
56°11'.6 N.	—40	164° W.
55°50'.2 N.	—46	163° W.

TABLE PU.—1L2-2820

Lat.	Δ	Long.
56°06'.1 N.	+ 16	164° W.
56°13'.7 N.	+ 17	163° W.

When the Loran lines are plotted, the fix is obtained as 56°07'.5 N., 163°49'.0 W

Example 2.—At 2207 on 7 September 1945, a ship was in DR position, latitude 50°56' N., longitude 177°53' W., proceeding at 12 knots on course 164° true. Loran sky wave readings were obtained as follows :—

at 2202 T_S = 1L2-1961 and at 2207 T_S = 1L1-3047.

Required the 2207 Loran fix.

RATE 1.

T_S = 1-3047, sky wave correction — 11, equivalent ground wave reading T_G = 1-3058. $T_G - T$ = 1.3058 + 1-3060 = — 2.

	TABLE PM 1L1-3060		T_G = 1L1-3058	
Lat.	Long.	Δ	Correction	Long.
50° N.	178°24'.7 W.	— 102	+ 2.0	178°26'.7 W.
51° N.	177°44'.6 W.	— 93	+ 1.9	177°46'.5 W.

RATE 2.

T_S = 1L2-1961, sky wave correction — 18, equivalent ground wave reading T_G = 2-1943. $T_G - T$ = 2-1943 — 2-1940 = + 3.

	TABLE PU 1L2-1940		T_G = 1L2-1943	
Lat.	Δ	Long.	Correction	Lat.
50°48'.5 N.	+ 37	178° W.	+ 1.1	50°49'.6 N.
51°20'.9 N.	+ 32	177° W.	+ 1.0	51°21'.9 N.

When the Loran lines are plotted and that for T_S = IL2-1961 (T_G = 2-1943) is advanced 1.0 miles on course 164° true, the 2207 Loran fix is obtained as 50°53'.5 N., 177°51'.0 W.

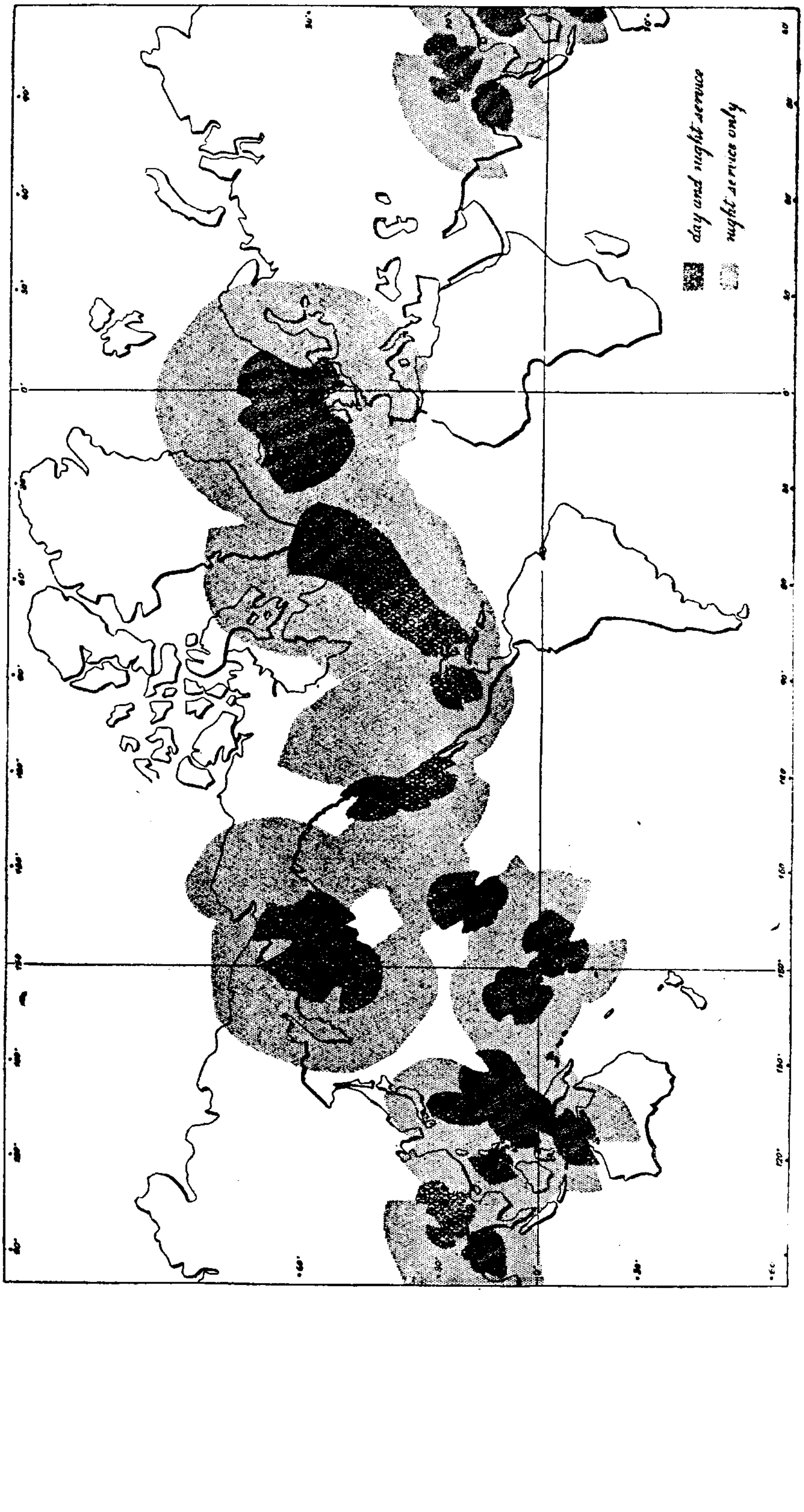


Fig. 15 a
Loran coverage at the end of hostilities.

Operational reports.

Analysis of ship reports from the Southwest Pacific.—An analysis of reports from 20 ships in the Southwest Pacific area for the 5 months from February to June 1945 indicates that during the daytime ground waves are received when the ship is over 800 n. m. from the transmitting stations, and at night sky wave signals are usable with caution out to 1,400 n. m. The apparent error of a line-of-position when compared to a celestial fix is 1.2 n. m. for ground wave and 3 n. m. for sky wave reception. When crossing angles of two Loran LOP's are greater than 40°, the error of fix is less than 3 n. m.

Navigators' comments.—A report from a Loran-equipped ship, a Coast Guard cutter is as follows :—

" The Loran equipment has been used regularly for the past 3 weeks and the results were most successful. On a trip from Adak to Dutch Harbor (14 Nov.-16 Nov.) the Loran fixes agreed almost exactly with DR positions and soundings. On the return trip to Adak (20-23 Nov.) the Loran fixes and DR were again extremely close with the exception of while this unit was in the area just west of Bogoslof Island and in the immediate vicinity of the base line extension. During each trip a sun or star sight was impossible.

" On Saturday, 27 November, this unit departed Dutch Harbor for Attu. Loran positions were extremely accurate leaving Unalaska Island but poor visibility made it impossible to get accurate bearings from the islands. Throughout the morning the Loran observations were within 2 miles of our DR. During the night, as the result of a force 9 wind and condition 9 seas this unit became separated from the convoy. Because of the location of the equipment and the rolling and pitching of the ship it was impossible to get accurate readings throughout the night.

" Having ridden out the storm for 12 hours in mountainous seas the DR was not considered accurate. Loran positions were therefore used. At 1530 a three-bearing fix by RDF gave a position 2 miles south and 3 miles behind the DR as laid off from the last Loran position taken at 1230.

" At 0839 the next day the first thousand fathom curve of Bowers Bank was crossed giving a reliable advance. DR 53°42' N., 179°16' W. Loran position 53°39' N., 179°14' W. also on the thousand-fathom curve. Inasmuch as the sea was running from the north the 3-mile set to the south indicated by Loran was considered very possible.

" At 1340 a sun line was obtained, the first and only one of the entire trip. At 1703 a Loran cross indicated a position of 1½ miles south of the estimated position.

" At 1141 the Loran position was 5 miles south of DR 8 miles south at 1202 and 10 miles south at 1238. A slight hunting had been noticed in the ship's gyro but comparison with the magnetic had not shown any serious error. An azimuth was not possible because of the typical Aleutian weather. At 1510 contact was made with the convoy and comparison with their position showed the Loran to be correct. It was the first indication of what later proved to be a serious gyro error, and the Loran equipment showed it immediately.

" Loran positions showed that we were not making as much good as expected, a fact later confirmed. Upon crossing Bowers Bank the Loran fixes were within 1 mile and at 1827 the Loran fix of 53°52' N., 170°44' E. checked exactly with the estimated position obtained from a run of soundings while crossing Bowers Bank.

" This unit is very satisfied because it has been most reliable. It was quick to show the error in the gyro ; even quicker than by comparison with the magnetic compass.

" Bad weather has made it impossible, except on rare occasions, to obtain sun sights so that an accurate comparison cannot be made. From experience, however, Loran is considered by this unit to be the outstanding single piece of equipment yet installed. "