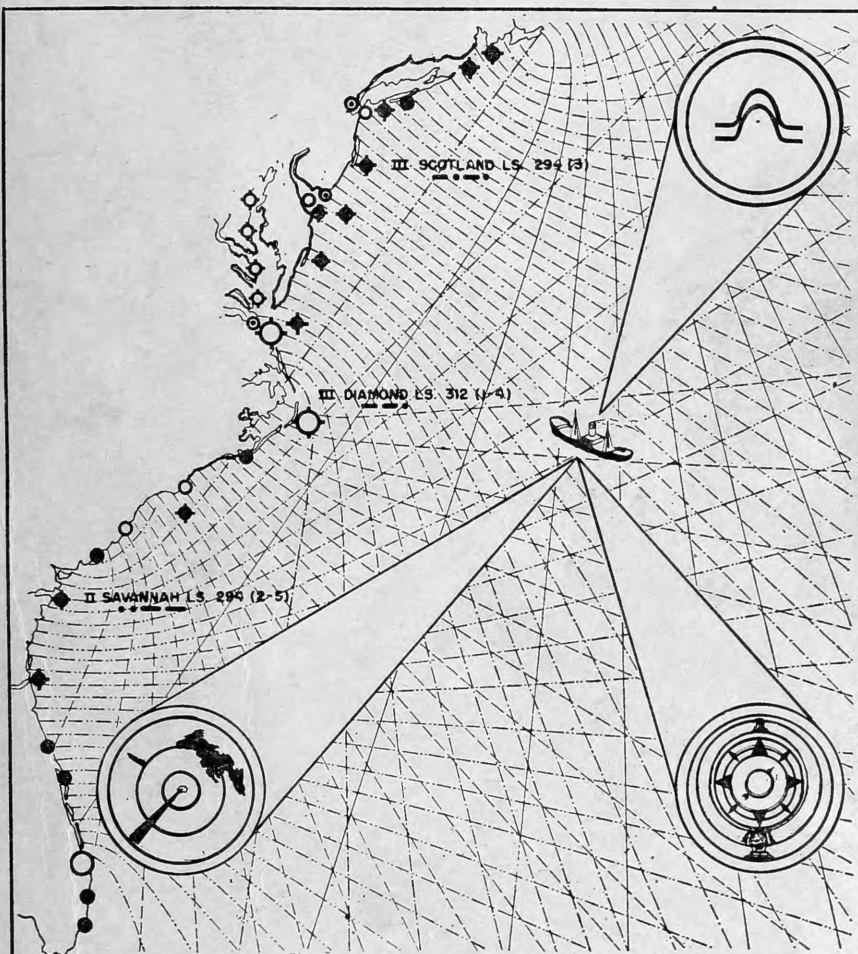
OCEAN ELECTRONIC NAVIGATIONAL AIDS



LORAN, RADIOBEACON AND RADARBEACON SYSTEMS AND LORAN, RADIO DIRECTION FINDER AND RADAR SHIP EQUIPMENT

7-1 **United States Coast Guard • Treasury Department**

Hank — I thought this might be of interest to you. It is old, but you could write to the U.S. Gov't Printing Office and ask for the latest up to date one. To supercede (CG 157-1) (1949)

Bob G

UNITED STATES COAST GUARD
TREASURY DEPARTMENT

ELECTRONIC NAVIGATIONAL AIDS

Loran, Radiobeacon, and Radarbeacon Systems

and

Loran, Radio-Direction-Finder, and Radar Ship Equipment

Revised Edition (1949)
CG 157

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FOREWORD

This pamphlet on Loran, radiobeacons, microwave beacons, Radar reflectors, and Radar is published for the information of the United States maritime industry, commercial airlines and others interested in the application of electronic navigational aids. It is intended to be of benefit to the industries concerned in improving the safety, economy, and efficiency of transportation over the areas of the world.

The information has been prepared largely to answer many inquiries received by the United States Coast Guard on these subjects. The Coast Guard operates an extensive system of Loran and radiobeacon stations for the protection of domestic and overseas transportation. Included in the pamphlet are advisory minimum specifications for marine Radar, Loran receiving equipment, and direction-finder equipment. These advisory specifications are promulgated for the use of those interested in electronic navigational aid equipment, and are intended only as a guide for voluntary use.

Operational tests relating to electronic navigational aids for use by navigators is undertaken by the Coast Guard as a normal function since its duties include the saving of life and property at sea, maintaining and operating aids to navigation, and merchant marine inspection.

It is believed that this nontechnical treatment of the subjects presents sufficient facts for an evaluation to be made in determining the benfits to be derived in applying these equipments to the safeguarding of life and property at sea.

J. F. Farley,
Admiral, United States Coast Guard,
Commandant.

STANDARD LORAN

(A Long Range Aid to Navigational System)

INTRODUCTION

The Loran system is a modern electronic aid to navigation by means of which navigators on or over the ocean can determine their position accurately and quickly, day or night, and under practically any condition of weather and sea. The name "Loran" was derived from the words "**LO**ng **RA**nge **N**avigation," which describe in general terms the system's relative utility when compared to ranges of other electronic navigational aids. The effective range of Loran is as great as 1,400 nautical miles at night and 750 miles during the day (fig. 1–1). The accuracy obtained is comparable to that which may normally be expected from good celestial observations. Even though such precision is attained, the determination of position by Loran requires but 2 to 3 minutes' time.

The navigator can think of Loran merely as a method of determining

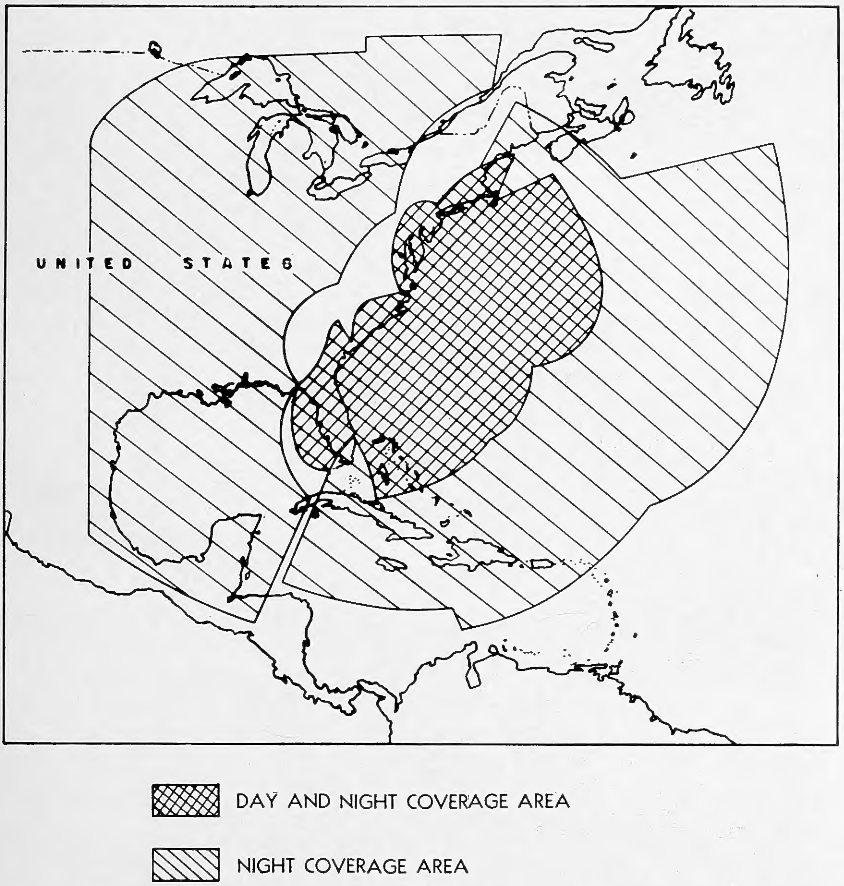


FIGURE 1–1.—Typical day and night Loran coverage area.

lines of position. These Loran lines can be crossed with other Loran lines, sun lines, star lines, soundings, Radar ranges or bearings to provide fixes. Loran lines are fixed with respect to the earth's surface; their detemination is not dependent upon the ship's compass, chronometer, or other mechanical or electronic devices. Loran shipboard equipment requires no special calibration and is not affected by the arrangement or disarrangement of shipboard antennas, cargo booms, ventilators, etc., as in the case of radio direction finders.

Loran signals are on the air and available to navigators for 24 hours per day, and cover the major ocean shipping lanes of the world. Developed as a wartime necessity, the system is now at the disposal of private shipping—any nation, any line, all may make free use of it.

PRINCIPLES OF OPERATION

Loran operates on the following principles:

1. Radio signals consisting of short pulses are transmitted from a pair of shore-based transmitting stations.
2. These signals are received aboard the ship or plane by a Loran radio receiver.
3. The difference in times of arrival of the signals from the two radio stations is measured on a special Loran 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 lines of position, determined from two pairs of transmitting stations, are crossed to obtain a Loran fix.

Since radio signals travel at a constant speed, a direct relationship between time of travel and distance traveled exists. Thus, measurement of intervals of time is, in essence, a measurement of distance itself.

The radio signals which are transmitted by Loran stations are not continuous transmissions such as those of everyday commercial broadcasting stations, but are "pulse" signals, or short bursts of radio energy transmitted at regular intervals. The use of "pulse" signals permits the individual signals to be identified in order that time measurements can be made. This would not be possible if the transmissions were of a continuous character.

Because the basic Loran measurement evaluates the difference in the distances between the navigator and each of two fixed transmitting stations and not the individual distances themselves, there are many points at which the difference would be the same even though the distances varied widely. These points fall along a smooth curve (hyperbola) which is known as a Loran line of position. Therefore, when a navigator has obtained a Loran reading from a pair of transmitting stations he has determined that his true position lies at some point on a particular Loran line of position. By making Loran measurements on a second pair of stations, a second line of position has been identified and the navigator's true position of "fix" has been established at the point of intersection of the two lines.

In order to simplify the navigator's problem of interpreting the Loran data in terms of coordinates of latitude and longitude, Loran charts are available which picture the electronic lines of position with respect to some convenient chart of the region in which the ship is sailing. The same information is available in the form of Loran tables for the convenience of navigators who desire to plot Loran lines of position directly on their regular navigators' chart.

The diagram of figure 1–2 illustrates the basic principles of the determination of position by means of Loran.

EQUIPMENT USED BY THE NAVIGATOR

The Loran equipment used by the navigator on shipboard or aircraft at sea in the determination of his position is known as a receiver-indicator. The receiver performs the functions of an ordinary radio receiver, but delivers its output to a visual indicator rather than to a loudspeaker, and is designed for the reception of pulsed signals rather than ordinary radio signals. The indicator is essentially an "electronic stop-watch" capable of measuring, in microseconds, the difference in times 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 a cathode ray oscilloscope form the equivalent of the dial of a watch.

A vibrating quartz crystal is the balance wheel, and electrical circuits known as "dividers" or "counters" take the place of gear wheels.

Installation of the receiving equipment is quite simple and can be performed in a few hours' time. Actually, installation merely requires simple mechanical mounting of the equipment to the deck or bulkhead, erection of an ordinary radio receiving-type vertical antenna, and plugging in the power cord to the local electrical power source.

OPERATING RANGE AND ACCURACY

Three fundamental characteristics of Loran are of particular importance to navigators using the system. These qualities are the following:

(1) Practicability of Loran operation over longer distances than is possible with older types of radio navigational aids.

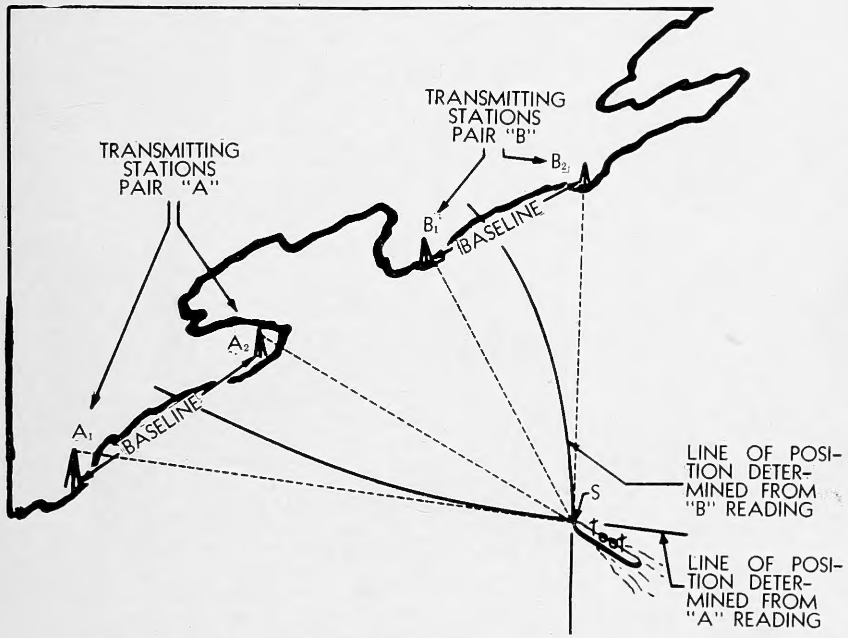


FIGURE 1–2.

Navigator aboard Loran-equipped ship at S establishes "fix" by determining two lines of position, A and B by Loran measurements.
Line of position A is found by measuring the time difference between signals received from transmitting stations A_1 and A_2.
Line of position B is found by measuring the time difference between signals received from transmitting stations B_1 and B_2.
The navigators fix is established at the point of intersection of the two lines of position.
The latitude and longitude of the navigator's position is determined from the Loran data by using either the Loran charts or Loran tables.

(2) High order of positional accuracy attained.

(3) Reliability of Loran under all kinds of weather conditions.

Vessels and aircraft at sea may determine their position by means of Loran both day and night when they are within 750 nautical miles of the transmitting stations. This is based on the reception of "ground waves," which travel on the surface of the earth and are the most stable type of radio waves. At night, however, "sky waves" are received which are radio waves that travel outward from the transmitter until they "bounce" or are reflected from a region of the upper atmosphere known as the "ionosphere" and reach the navigator after reflection (fig. 1–4). The use of "sky waves" extends the range of Loran service at night up to a distance of 1,400 nautical miles from the transmitting stations. However, the positional data obtained by using "sky waves" Loran signals is somewhat less accurate than the information

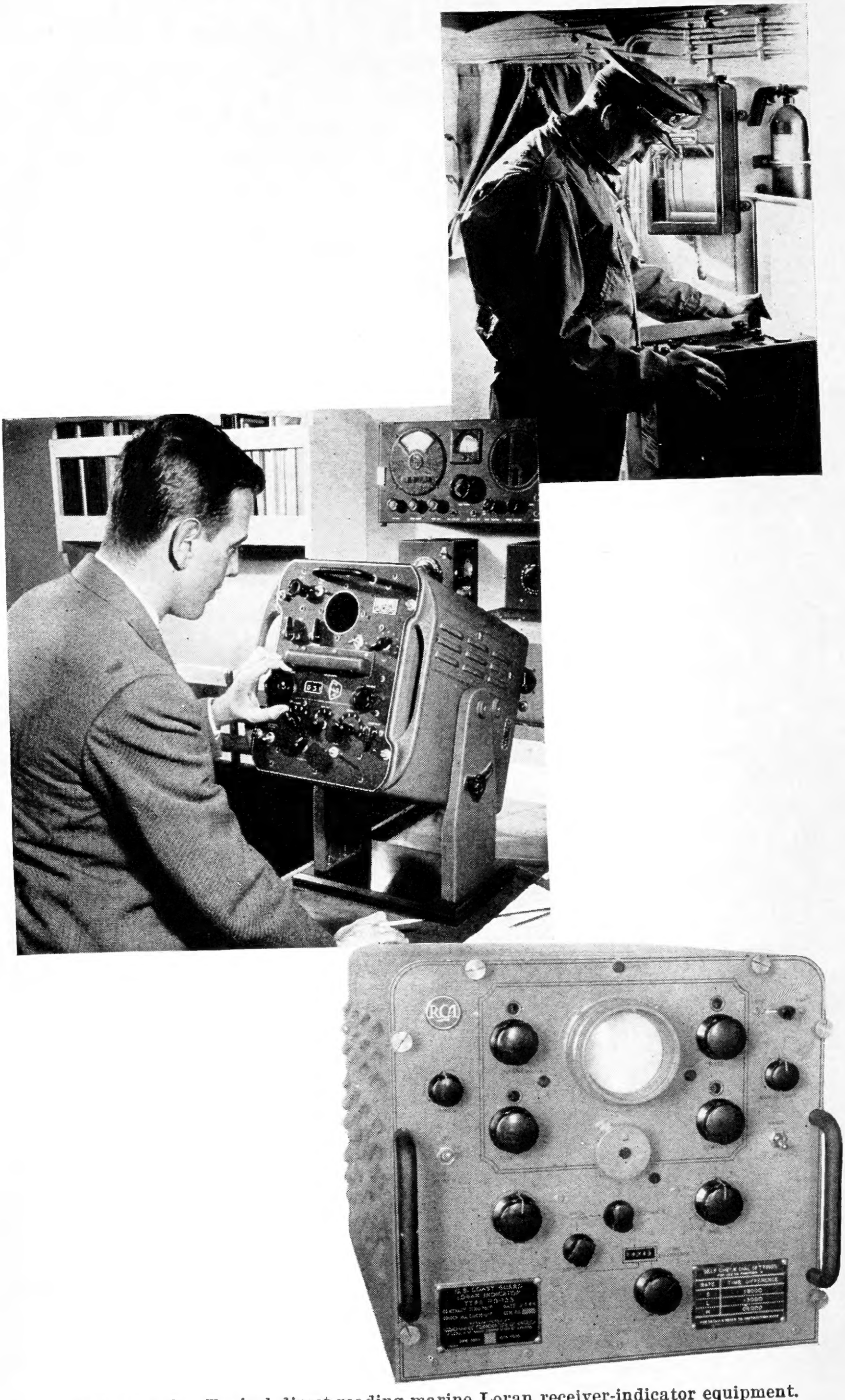


FIGURE 1–3.—Typical direct-reading marine Loran receiver-indicator equipment.

determined through the use of "ground waves," but, nevertheless, is still of a high order of accuracy.

One of the surprising facts about Loran is that in a matter of 2 to 3 minutes' time a navigator at sea can determine his position with an accuracy comparable to that obtained from good celestial observations, which require considerably longer to make and which entail somewhat laborious mathematical computations.

The accuracy of Loran fixes varies considerably, depending on the relative position of the navigator and the transmitting stations, the angle at which the Loran lines of position intersect and several other factors.

A very rough rule of thumb has been stated to be that a Loran line of position has an accuracy of better than 1 percent of the distance of the navigator from the stations; thus a navigator 1,000 miles away from the stations would expect the line of position to be well within 10 miles of the proper position. As the stations are approached, the accuracy increases greatly, and along the

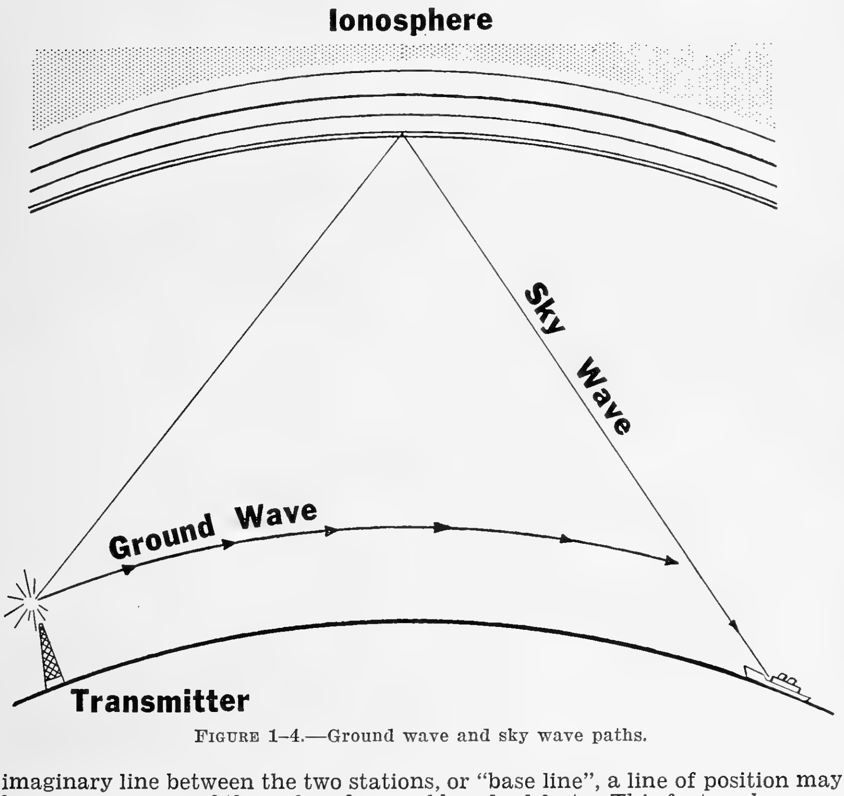


FIGURE 1–4.—Ground wave and sky wave paths.

imaginary line between the two stations, or "base line", a line of position may have an accuracy of the order of several hundred feet. This feature has particular practical value, inasmuch as the physical arrangement of Loran stations is such that a navigator making a landfall usually will approach the shore in this highly accurate area of Loran service. Figure 1–5 shows the pattern that a family of Loran lines of position make with respect to their transmitting stations and points out the regions of accuracy. Figure 1–6 shows a vessel approaching a harbor along a line of position.

Another important feature of Loran to the navigator is the reliability of the signals and the consequent removal of doubt in the navigator's mind as to the dependability of Loran fixes. Loran signals can be received under all ordinary conditions of storms, gales, and other severe weather. This is possible because the ordinary electrical interferences that accompany these conditions obscure the Loran signal for only a few seconds at a time and the

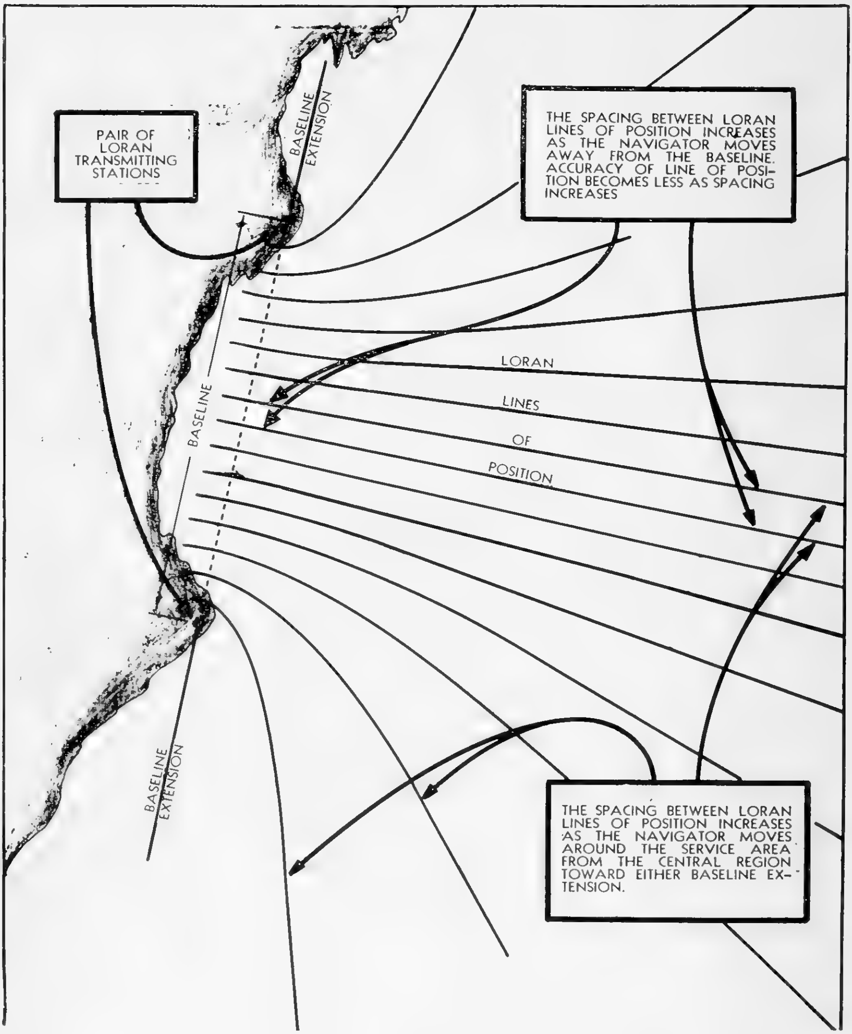


FIGURE 1–5.—Loran hyperbolic pattern.

navigator need only wait for a few moments to obtain usable data. For these reasons Loran is an especially valuable asset to navigation during bad weather.

SUMMARY OF VALUABLE FEATURES OF THE LORAN SYSTEM

The features which make Loran a valuable tool and a highly regarded supplement to the art of navigation are inherent in the technology of the system itself. It is a radio device which makes use of the speed of travel of radio signals as its fundamental principle. This quality is known scientifically to be the most stable and unchanging electrical characteristic of radio waves and consequently the Loran system stems from a firm and proven scientific foundation.

The outstanding features of the Loran system may be summarized as follows:

(1) Loran fixes may be obtained readily at long distances from the trans-

mitting stations. The daytime range is approximately 750 nautical miles. In addition to the range of individual pairs of stations, the integrated Loran system is so arranged that coverage is available over most of the major shipping lanes of the world.

(2) The accuracy of Loran fixes is of high order. Results comparable to those obtained by means of good celestial observations are consistently effected.

(3) Loran operation is nearly independent of the weather. It is not affected by conditions of the sea or air and does not suffer from doubtful effects encountered with older types of radio navigational devices such as direction finders.

(4) The time required to obtain a Loran fix is short. Experienced operators seldom require more than 2 to 3 minutes to establish a fix.

(5) Operation of Loran shipboard and aircraft equipment is relatively simple and navigators may be trained in Loran technique in a very short time.

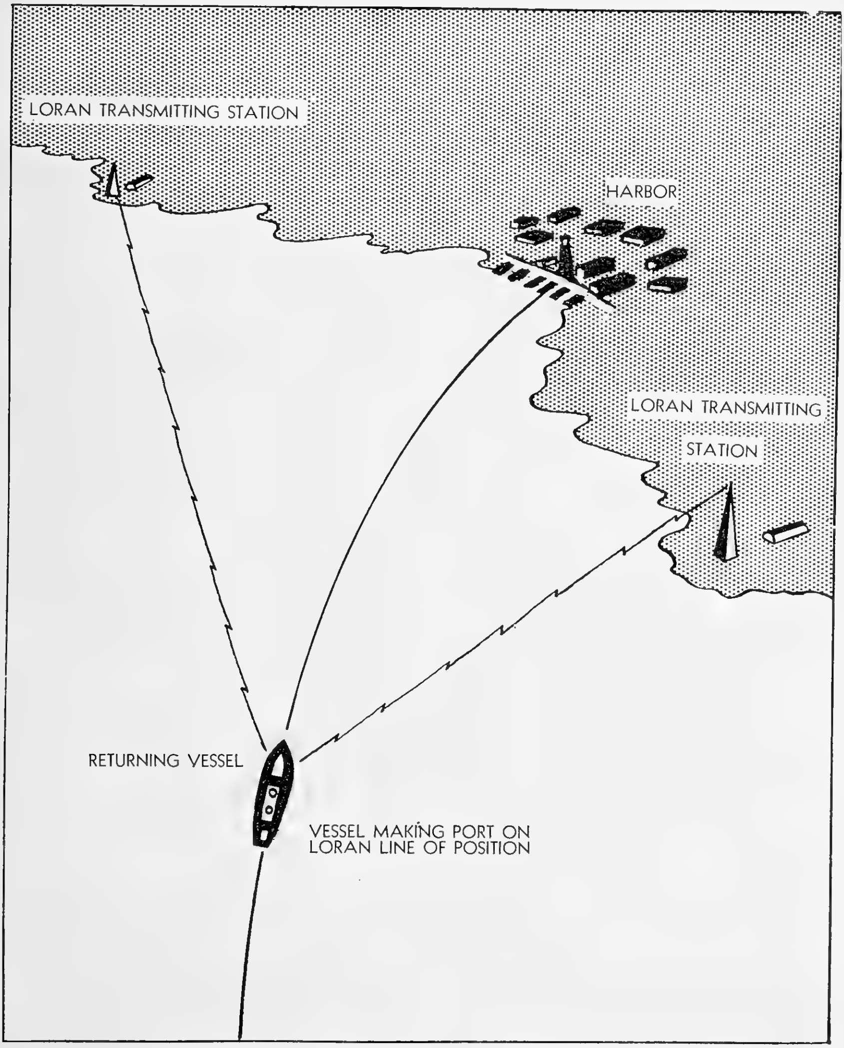


FIGURE 1–6.—Vessel making port on Loran line of position.

(6) Efficiency of long-range navigation is increased. The course sailed may be more direct with a resultant saving in fuel and increase in pay load.

(7) Landfalls may be made at points close to the destination of a vessel.

(8) Loran fixes are independent of other navigational instruments such as compass, chronometer, and other radio equipment. No transmission from

FIGURE 1–7.—Ship's captain obtaining positional data from a compact, lightweight type Loran receiver-indicator.

the vessel or aircraft is required and only a single item of equipment is used which may be installed at any point convenient for the navigator.

(9) Safety at sea is greatly increased through Loran, and in case of disaster, rescue operations are direct. A minimum of time is lost in searching for disabled vessels when the Loran position is included in the distress message. The increase in safety at sea will probably be reflected in reduced insurance premiums as the application of Loran becomes more widespread. This factor alone might easily compensate for the cost of the Loran equipment.

Loran has already played a prominent role in rescue operations. Distress at sea usually occurs during foul weather when determination of position by celestial observations has been impossible for several days. Under such limitations, the distressed vessel's dead reckoning position may be considerably in error.

In the Aleutian area, a distress case occurred which illustrates the value of Loran in the saving of life at sea. Surface vessels and aircraft were engaged in search operations for a barge foundering in heavy seas with eight persons aboard. Positions transmitted by radio from the barge, 24 hours apart, were hundreds of miles different though the craft was not under power. This indicated that she did not have a reasonably correct knowledge of her position, and rescue operations were fruitless. After transmission of the Loran-determined position to surface vessels, the distressed craft was located and all hands rescued in a matter of hours before the water-filled barge sank during 70 miles-per-hour winds.

Thus Loran, through the medium of electronic science, constitutes a fundamental supplement to other methods of navigation, in assisting and protecting lives and property at sea.

CONTROL OF LORAN TRANSMISSIONS

Since the value of the Loran system is equal only to the accuracy of timing of the signals transmitted, every precaution is taken to safeguard the functioning of the system. This is effective to such an extent that the navigator may feel certain that the Loran data which he obtains is correct. This fact has been proved by the acid test of completely successful Loran operation under the most severe conditions.

The nature of Loran transmitting station equipment makes it necessary for the Loran transmitting station operator to observe the signals of both stations continuously during transmission. As a consequence, the man on watch at either station of a pair is in a position to "double check" for the existence of any fault that might occur in the signal of either station.

Loran transmissions can be momentarily at fault due to many possible causes such as electrical failure of a part of the equipment or operating error in manipulating controls. Even though these troubles may be minor and of relatively short duration, it is essential that the navigator be acquainted with the failure instantly and positively. In order to do this, a blinker device is switched in at either of the two stations. "Blinking" produces a characteristic movement of the transmitted signals, which is easily recognizable and serves to warn the navigator that the signals are not to be used for navigational purposes until the "blinking" ceases.

In the event the failure is sufficiently serious to prevent transmission entirely from one of the paired stations, it would not be possible for the navigator to misinterpret the Loran signals, inasmuch as the presence of only one of the expected signals on the air would preclude making any time difference measurements at all from that particular pair. Other pairs would not be affected.

Because of the fundamental checks which are vigilantly maintained on the transmitted Loran signals, the navigator at sea or in the air is assured that any transmissions which he receives, with the exception of "blinking" signals, are accurate, reliable electronic guideposts marking the lines of positions of this modern long-range navigational aid.

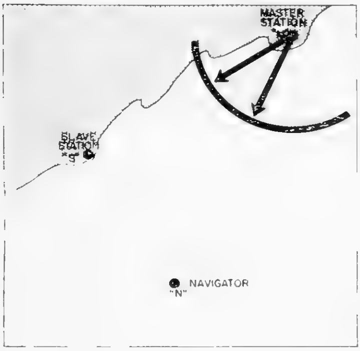
TRANSMITTING STATION FUNCTIONS

Because Loran is concerned with the measurement of radio signals from two different sources, Loran stations operate in pairs. The function of each station of a Loran pair is somewhat different from that of its companion station, and each is given a designation which is descriptive of the role which it performs, namely, "master" station and "slave" station.

The "master" starts the cycle of transmission by sending out a pulse of radio energy which is radiated in all directions including that of both the navigator and the "slave" station. After traveling the distance between the two transmitting stations, known as the "baseline," the pulse transmitted by the "master" arrives at the "slave." This signal is received by means of the Loran equipment of the "slave" station and the time of its arrival is used by the "slave" as a reference for the transmission of its own signal.

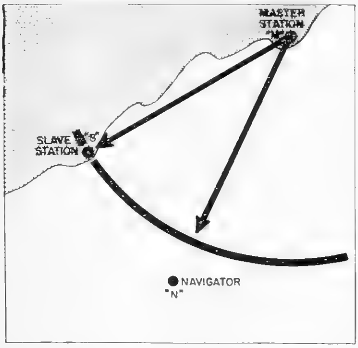
STEP I

NAVIGATOR ABOARD SHIP AT "N" IS WITHIN RANGE OF STATIONS "M" AND "S" AND IS ABOUT TO RECEIVE LORAN SIGNALS



STEP II

LORAN TRANSMISSION CYCLE IS BEGUN BY "MASTER" STATION PULSE IS RADIATED IN ALL DIRECTIONS AND TRAVELS TOWARD BOTH "SLAVE" STATION AND NAVIGATOR

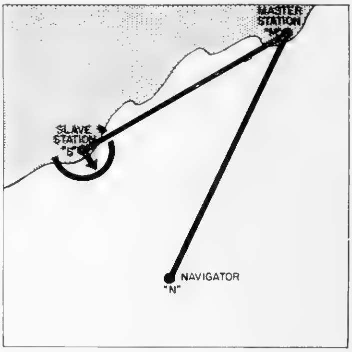


STEP III

PULSE TRANSMITTED BY "MASTER" STATION ARRIVES AT "SLAVE" BUT HAS NOT YET REACHED THE NAVIGATOR

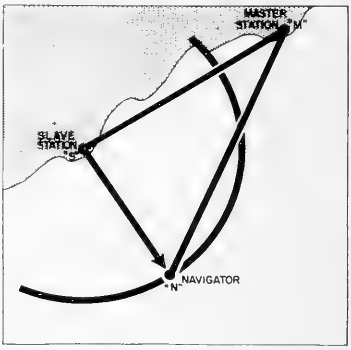
STEP IV

PULSE FROM "MASTER" STATION ARRIVES AT POSITION OF NAVIGATOR. "SLAVE" STATION HAS ALREADY RECEIVED "MASTER" PULSE AND IS WAITING FOR PROPER AMOUNT OF TIME TO ELAPSE BEFORE TRANSMITTING TO ASSURE CORRECT SYNCHRONIZATION WITH "MASTER".



STEP V

AFTER WAITING FOR THE PROPER AMOUNT OF TIME TO ASSURE CORRECT SYNCHRONIZATION, THE "SLAVE" TRANSMITS ITS PULSE. THE NAVIGATOR HAS ALREADY RECEIVED THE PULSE FROM THE "MASTER" STATION.



STEP VI

"SLAVE" PULSE ARRIVES AT NAVIGATORS POSITION SINCE NAVIGATOR HAS ALREADY RECEIVED THE SIGNAL FROM THE "MASTER" STATION, LORAN READING IS TAKEN BY MEASURING THE TIME ELAPSED BETWEEN THE ARRIVAL OF THE MASTER AND SLAVE PULSES. AFTER BOTH SIGNALS HAVE TRAVELLED THROUGHOUT THEIR EFFECTIVE RANGE, THE CYCLE IS REPEATED

FIGURE 1–8.—Sequence of operation of Loran transmitting stations.

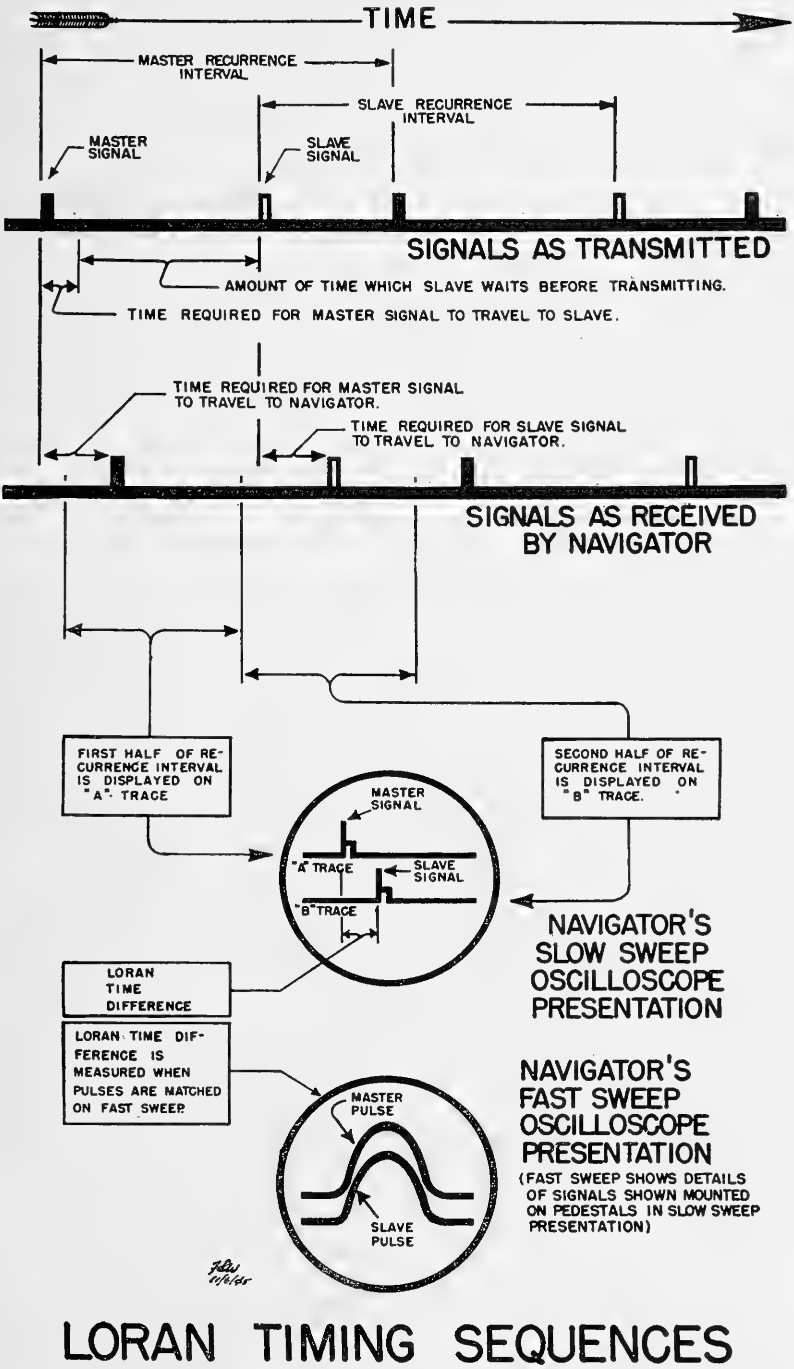


FIGURE 1–9.—Loran timing sequence.

After the "slave" transmits its pulse, the entire cycle is repeated again and again.

Thus the "master" station "sets the pace" and the "slave", by following, completes the Loran transmitting cycle. This is shown diagramatically in Figure 1–9).

By this simple process, a pair of Loran stations send out their guiding signals to the hundreds or thousands of navigators who may be within the area of their service which, in most cases, is well over 1 million square miles!

TRANSMITTING STATION EQUIPMENT

In order to send out a succession of reliable Loran signals to aid navigators at sea in determining their position, the transmitting station has two fundamental responsibilities. The first of these is the generation of radio pulses of the proper frequency, power, and duration. The second is the timing of these radio pulses at the correct intervals and with the required degree of precision. The three major units of transmitting station equipment are the

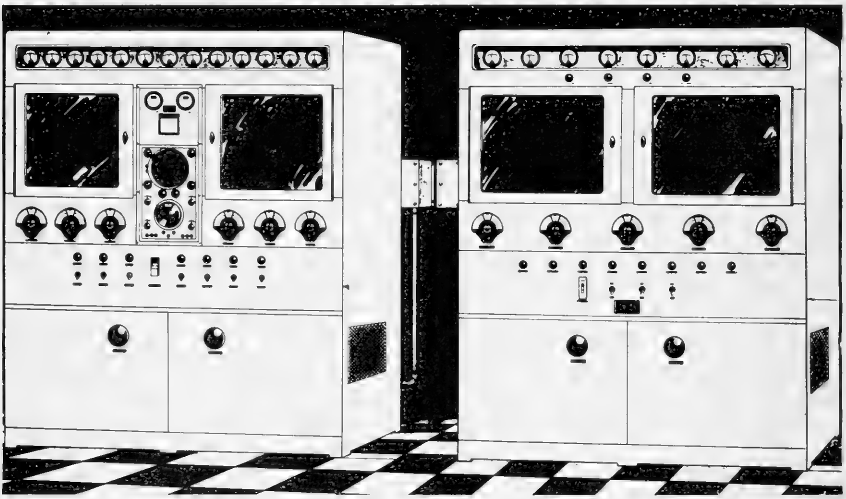


FIGURE 1–10.—View of latest type Loran transmitting equipment.

Loran transmitter, the Loran timer, and the electronic switching equipment.

The Loran transmitter is a "pulse" type of equipment of a special design developed specifically for Loran application. The radio frequency pulses generated by the equipment, while of short duration, contain a great deal of electrical energy and are as powerful as the largest commercial broadcasting stations' transmissions. The Loran transmitter functions in such a manner that a single pulse of radio energy is sent out each time the transmitter receives an electrical timing impulse. The timing impulse is a "trigger" pulse and serves to "turn on" the transmitter for the duration of the pulse. These "trigger" pulses are generated by Loran timing equipment.

The Loran timer is the fundamental unit of equipment on which the accuracy of the Loran system depends. The timer is made up of the following basic components which serve the purposes indicated:

(*a*) *Radio receiver.*—The receiver permits the reception of Loran signals from the distant station and also those transmitted by the local station.

(*b*) *Indicator.*—Based upon the function of the cathode ray tube which permits the operator to "see" electrical impulses, the indicator permits visual inspection of the signals themselves and other basic functions of the equipment.

(*c*) *Oscillator and timing circuits.*—The complex and precise timing functions stem from a crystal-controlled oscillator of the highest laboratory standards. The timing circuits permit the measurement of the time interval between the signals received and furnish the necessary "trigger" pulses for

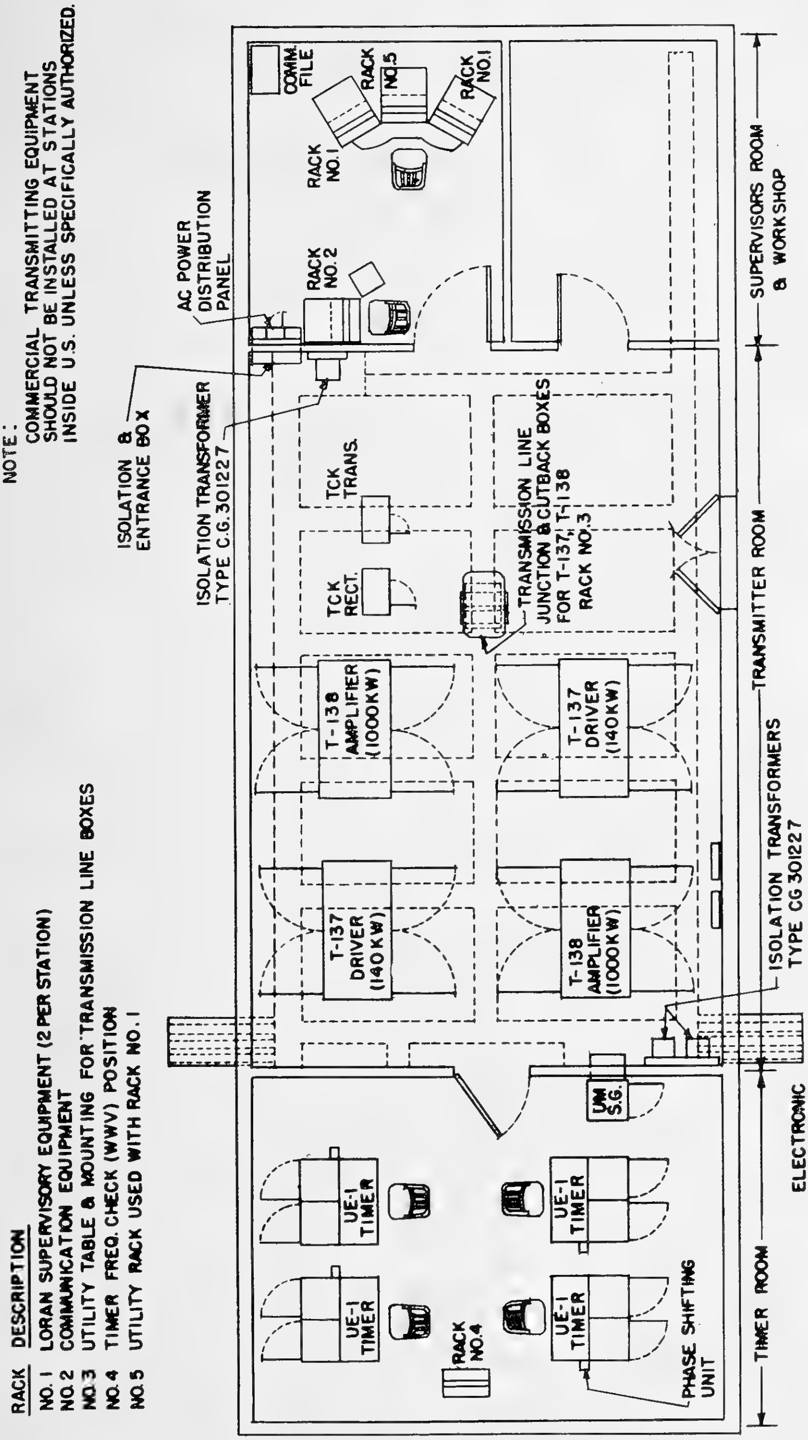


FIGURE 1–11.—Loran equipment building layout.

operating the Loran transmitter and similar timing pulses for other secondary station functions.

Some idea of the high degree of precision of the Loran timer equipments may be illustrated by the fact that a pocket watch of comparable accuracy would run for a period of over 9½ years before it would lose or gain a single second of time.

A third item of equipment which is of fundamental importance in a transmitting station is the Loran switch gear. This is constructed as a separate physical unit and contains the necessary switching equipment to permit the operator to place different units of the station equipment in use by properly connecting them to the other units. The switch gear chassis also houses the "attenuator" unit, an electronic switch which effectively disconnects the

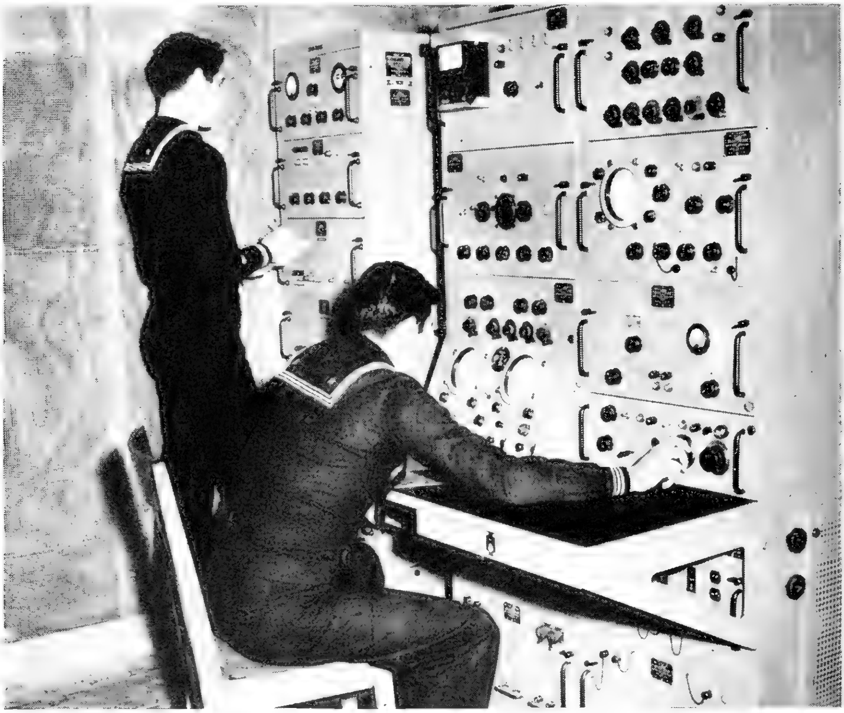


FIGURE 1–12.—Loran station—men on watch at the timing equipment.

receiver unit each time the local transmitter sends out a signal. It is necessary to do this to prevent the receiver from being damaged by the strong signal that is generated in the vicinity of the station's own transmitting antenna. During the interval when the local transmitter is not sending out a signal, the "attenuator" reconnects the receiver to permit the operator to receive the signal from the distant station.

In order to provide reliable Loran service even in the case of minor failures of equipment it is the established practice in equipping Loran stations to provide duplicate units of all of the major items. In this manner an equipment failure causes only a momentary pause in the service, since the stand-by equipment can usually be placed in service in less than a minute's time.

Figures 1–10, 1–11, and 1–12 illustrate transmitting station equipment and installation layout plan.

LORAN SYSTEM DESCRIPTION

(NOTE.—The technical aspects of the Loran system are described in this section for purposes of completeness, to be used for the information of persons who may have occasion to study Loran in some detail. The material pre-

FIGURE 1–13.—Loran signal building.

sented is in tabular form and may be of interest only to those readers who desire electrical system information.)

LORAN.—A long-range aid to navigation for the determination of position, based upon the difference in times of arrival at the navigator's position of radio signals transmitted from two fixed Loran transmitting stations.

TYPE OF TRANSMISSION.—Loran transmissions are "pulse" transmissions. Very short pulses of radio frequency energy are radiated at periodic intervals which are very long compared to the duration of the pulse. During the interval between successive pulses of a station, no radio signal from that station is on the air.

RADIO FREQUENCY.—Loran signals are transmitted at the present time on two frequency channels in the United States:

1950 kilocycles.
1850 kilocycles.

PULSE DEFINITION.—The Loran pulse signal is of approximately 80 microseconds duration and the rectified envelope has a shape similar to that of a sine wave when viewed on a Loran receiver. It is customary to measure pulse width at one-half amplitude; standard width is thus considered to be 40 microseconds.

PULSE REPETITION RATES.—Loran pulses are transmitted at a number of different repetition rates. Differences in repetition rate are the means of identification of particular pairs of stations. Specific pulse repetition rates are assigned in several general categories with the particular rates of each category being only slightly at variance with a convenient rate known as the "base rate." Present "base rates" and "specific repetition or recurrence rates" are tabulated on the following page.

LORAN TIMING SEQUENCES.—(Loran timing sequences are shown in fig. 1–8.) Master and slave stations are pulsed at exactly the same pulse recurrence rate. The master pulse is transmitted first and, after traveling the distance of the base line, arrives at the slave where it is received and used as a timing reference. After waiting for a predetermined length of time which is necessary to establish correct Loran synchronization, the slave station transmits its pulse. The amount of time that the slave waits, or delays, is always fixed at an amount greater than one-half of the recurrence interval plus a coding delay (usually 1000 u/s). As a consequence, the master signal is always transmitted during the first half of the recurrence interval and the slave transmission always occurs during the second half of the interval, regardless of the navigator's position with respect to the stations. The signals are received and viewed by means of a cathode ray oscilloscope using a time base equal to the recurrence interval, but divided into two equal half-interval traces so placed on the scope by the sweep circuits that two half-

BASE RATE 25 CYCLES (PULSES) PER SECOND

Specific rate designation	Frequency (c. p. s.)	Interval (microseconds)
0	25	40,000
1	25 1/16	39,900
2	25 1/8	39,800
3	25 3/16	39,700
4	25 1/4	39,600
5	25 5/16	39,500
6	25 3/8	39,400
7	25 7/16	39,300

BASE RATE 33 1/3 CYCLES (PULSES) PER SECOND

Specific rate designation	Frequency (c. p. s.)	Interval (microseconds)
0	33 1/3	30,000
1	33 4/9	29,900
2	33 5/9	29,800
3	33 2/3	29,700
4	33 7/9	29,600
5	33 8/9	29,500
6	34	29,400
7	34 1/9	29,300

New Loran transmitting station equipment is capable of operation on a base rate of 20 c. p. s. to provide for future expansion of the system without requiring additional radio frequency allocations.

traces appear with the first half directly above the second half. Both traces are horizontal in time sweep.

The controls of the receiving instrument are adjusted until the master signal is viewed near the beginning of the upper, or A, trace. The slave signal will appear in its proper place on the lower trace. Measurement of the Loran time difference is made by evaluating the horizontal displacement of the slave station with respect to the master in terms of time, microseconds. By this physical arrangement of the traces the half recurrence interval delay which was introduced by the slave is effectually canceled from the measurement. Loran readings thus obtained may be interpreted in conventional coordinates by the use of Loran charts or tables. A fast speed time base having a duration of roughly from 100 to 300 microseconds is provided to permit visual examination of the pulse envelope itself which is necessary to establish the precise adjustment required in making a Loran reading.

BLINKER SIGNAL.—The timers at Loran transmitting stations are equipped to perform a function known as blinking. The signal is used to indicate that the transmissions should not be considered reliable during the period of blinking. In general, blinking causes the received pulse to rhythmically swing back and forth as viewed on the slow sweep, and to rhythmically appear and disappear on the fast sweep. In the few exceptions to this method, there is a rhythmic appearance and disappearance on both slow and fast sweeps.

LORAN RECEIVER-INDICATOR FUNCTIONAL SPECIFICATION

RADIO RECEIVER

OPERATING RADIO FREQUENCIES.—The radio receiver of a Loran receiver-indicator is provided with four radio-frequency channels and may be set for operation on any of the frequencies tabulated in the system specification. In operation, receiver tuning is fixed and a four-position switch provides simple means of changing channels. Inasmuch as only two transmitting frequencies are allocated for standard Loran, the four-position frequency selector switch, if provided, permits future system flexibility.

RECEIVER SENSITIVITY.—The receiver has a sensitivity sufficiently high that a signal of approximately 10 microvolts delivered by the antenna to the receiver input will result in full scope deflection of the cathode ray indicator. Receiver and indicator form an integrated unit and are not intended to function separately.

BANDWIDTH.—Early designs incorporated a total bandwidth of the order of 80 kilocycles at 6 db. down. Current trends are toward considerable reduction and total bandwidths of 45 kilocycles or less at the same decibel limitation are contemplated.

DIFFERENTIAL GAIN AMPLIFIER.—The receiver incorporates a differential amplifier which operates in synchronism with the incoming signal recurrence frequency to permit amplification of each of the two signals received at different ratios. This feature permits presentation to the cathode ray indicator of signals of equal amplitude. Sufficient range of operation is provided to permit accommodation of incoming signals having a ratio of strengths as high as 1,000 to 1. Earlier equipments had an operating limit of roughly 100 to 1.

INDICATOR

FUNCTIONAL PURPOSE.—The indicator unit contains the necessary circuits to perform all of the timing functions of the equipment with the required precision. It contains the sweep generators and the cathode ray tube for presentation of the signals received.

MASTER OSCILLATOR.—The basic timing medium of the equipment is a precision, crystal-controlled, master oscillator. The oscillator possesses a high order of short time stability, in the order of a few parts in 10 million. Manual means of adjustment is provided to vary the frequency over a range of more than 200 parts in a million. This adjustment permits cycling the oscillator until the timing of the receiver-indicator is in exact step with the recurring pulses received from the transmitting stations.

TIMING MARKERS.—Through the medium of its timing circuits, the indicator provides a sequence of precise timing markers spaced at convenient intervals to facilitate measurement of time sequences with a basic accuracy in the order of plus or minus 1 microsecond.

TIME BASE.—The sweep generators provide a slow sweep as outlined in the system specification which covers the entire recurrence interval by means of a divided trace. A fast sweep lasting in the order of 200 microseconds or less is provided and by means of delay controls may be positioned to examine the particular section of the time base at which a signal appears. For convenience in identification and for purposes of triggering and delay measurement a pedestal or raised rectangular pulse appears on the slow sweep presentation in the portion covered by the fast sweep. Timing arrangements are made to permit the fast sweep generator to fire at a predetermined point on both the upper and lower traces.

MATCHING PULSES.—To measure Loran time differences, the time base is cycled with respect to the transmissions until the master and slave signals appear at convenient points on the upper and lower traces, respectively, with adjustment being made such that the fast sweep generator fires precisely in the region of both signals. The signals are examined on the scope operating on fast sweep and a fine adjustment is made until the pulses are superimposed or matched with respect to time. Time-difference measurements are made by means of timing markers, or, in the newer equipments, are read directly from a mechanical counter.

EQUIPMENT POWER REQUIREMENTS.—Loran receiver-indicators for shipboard installation are designed to operate on 115-volt (nominal), 60-cycle, single phase, alternating current, and require from 200 to 300 watts.

Aircraft equipments are made to operate on voltages of from 80 to 115, single phase, alternating current, and on frequencies from 360 to 2,460 cycles. Equipments require less than 300 watts.

RECEIVING ANTENNA.—Receiving antenna installation is simple since only a vertical wire is required. A length of 50 to 60 feet is considered desirable, although satisfactory operation is experienced when physical conditions require considerable decrease in the effective antenna length.

METHOD OF OBTAINING LORAN READINGS.—The majority of Loran receiver-indicator equipment now in use was developed and manufactured during the war. This equipment requires that time difference determination's be made by matching master and slave pulses and then, by switching to additional scope selection positions and by reference to a set of markers, counting the divisions and thereby arriving at the reading. Receiver-indicators are now being manufactured and installed which incorporate direct-reading counters; thus once the pulses are matched, all that is necessary to determine the time difference reading is to refer to a counter device which shows directly the proper numerical reading.

FIGURE 1–14.—Loran-equipped trawler *Deep Sea* uses Loran as a primary aid to navigation in the Bering Sea.

NEW DEVELOPMENTS IN STANDARD LORAN EQUIPMENT

The postwar period up to the present time has produced Loran equipment, both for shipboard and transmitting stations, which is designed with emphasis on commercial Loran requirements. Manufacturers of electronic equipment have brought forth a number of excellent Loran receiver-indicators designed for installation and use on vessels ranging all the way from passenger liners to fishing craft. The equipment incorporates all modern circuit achievement, and is particularly useful to seagoing people who have little technical knowledge of electronic gear. All commercial shipboard Loran equipment is readily available in the electronic equipment trade channels.

In keeping with the pace set by the manufacturers of Loran receiving equipment, great progress has been made in Loran transmitter design. The United States Coast Guard has procured and installed new transmitters which, by decreased bandwidth, have reduced possible interference to other services and are capable of transmitting signals of greater power. This will result in improved service to the commercial user of the Loran system.

USER TRENDS OF THE LORAN SYSTEM

The installation of Loran equipment on private shipping vessels is going ahead rapidly. This is especially true with regard to Loran installations aboard fishing craft. The adoption of Loran by fishermen to locate exact fishing ground positions on the various banks has resulted in shorter and more profitable trips.

Loran is used by the majority of aircraft flying the various oceans. Most transoceanic airlines have found Loran to be an excellent and proven aid to navigation system. The ease and rapidity of obtaining Loran lines of position or fixes is particularly useful in air navigation.

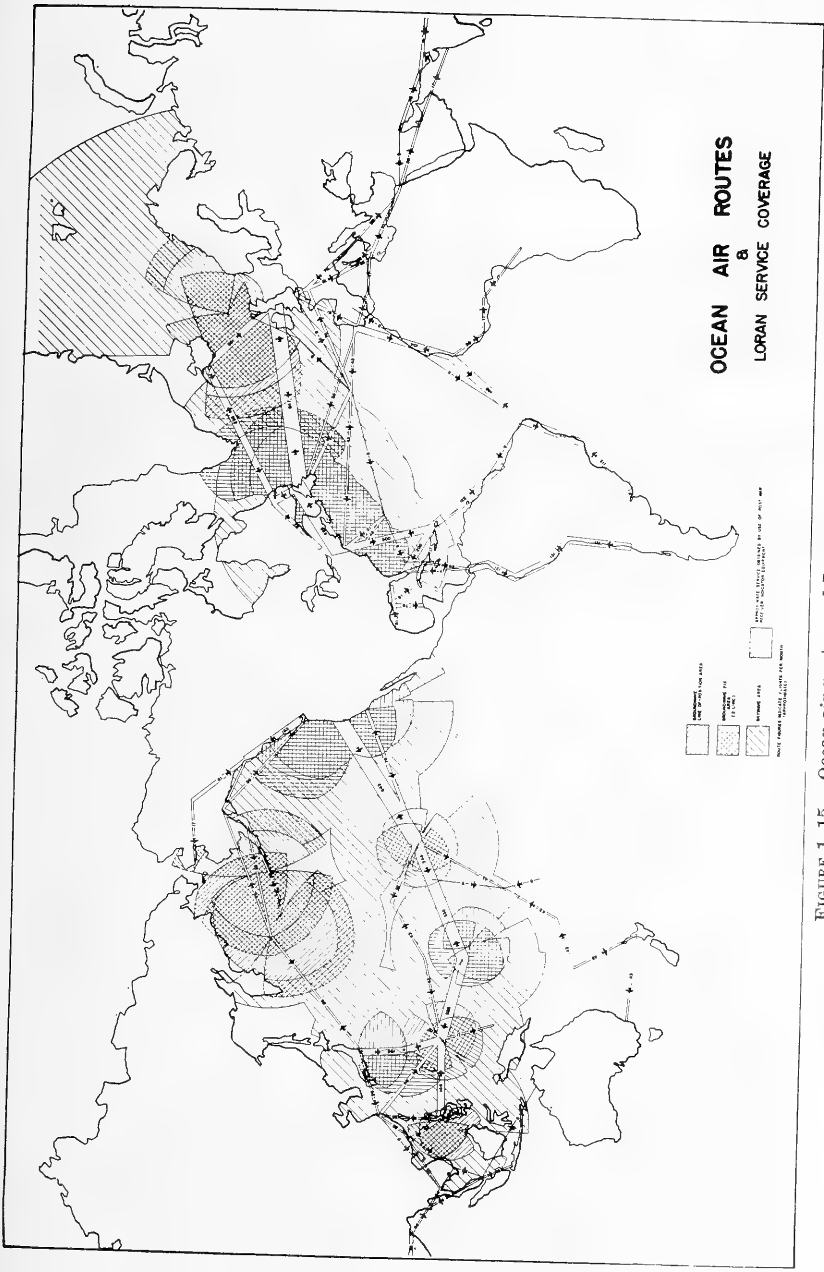


FIGURE 1–15.—Ocean air routes and Loran service coverage.

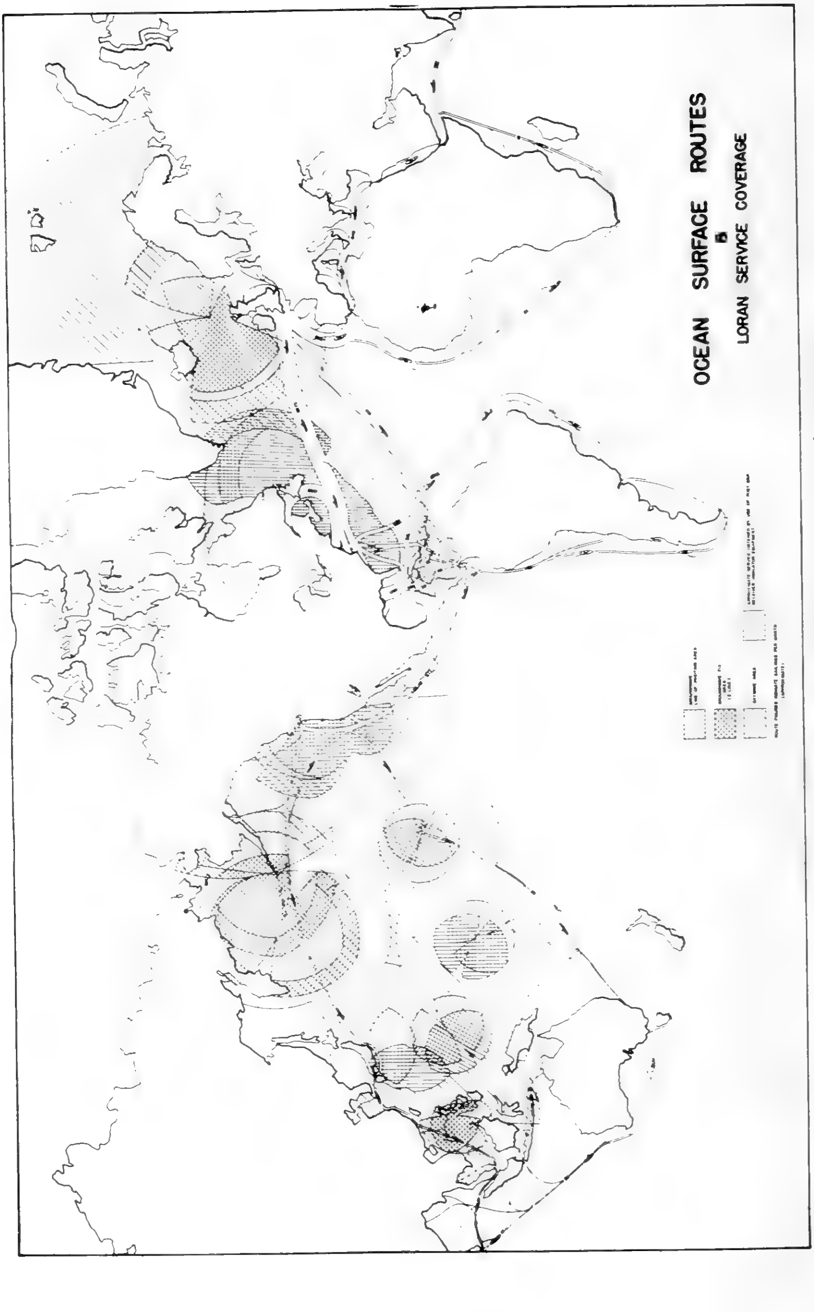


FIGURE 1-16.—Ocean surface routes and Loran service coverage.

MARINE RADIOBEACON SYSTEM

A Medium Range Aid to Navigation System

INTRODUCTION

Every mariner and every person who travels upon the sea recognizes radio for its many contributions to increased safety. The earliest application of radio to safety at sea was communication between ship and shore. This has been the means of saving the crews and passengers of many foundering vessels which otherwise would have been listed simply as "missing." Incidental to this came the broadcasting over the whole sea area of accurate time and weather warnings, giving the mariner a frequent check on his chronometer and on weather conditions. In 1921 the first successful radiobeacons were established in the approaches to New York. The system of navigation from radiobeacons, by means of bearings taken from direction finding equipment on shipboard, has become well established as a most important method of enabling vessels to check their positions.

Direction-finder navigation is not restricted to bearings on regularly established radiobeacon stations, as the same navigation principles apply to bearings on any fixed radio station whose position is known, or on any mobile radio station, as another ship whose position has a significance in the navigation of the observing vessel.

FIGURE 2–1.—Cape Cod Light Station, Massachusetts. Established 1798. Rebuilt 1857. Top of lantern 66 feet above ground. Light 183 feet above water. Foundation: rubble stone masonry. Signals: First order electric apparatus. Flashing white every 5 seconds. Flash 0.2 second, eclipse 4.8 seconds. 13,000 candlepower. High-power class A radiobeacon. Special antenna in background. Fog signal: horn, diaphragm, electric; blast 3 seconds, silent 12 seconds.

MARINE RADIOBEACON SYSTEM OF THE UNITED STATES

There were 186 radiobeacons (fig. 2–2) in operation on the coasts of this country on April 1, 1949, constituting a large system of aids to navigation. This system, operated by the United States Coast Guard, is important among the system of lights, buoys, and other navigational aids, the maintenance of which is a principal function of the Coast Guard. Radio-beacons add greatly to the completeness of aids to navigation systems and fill an important gap in previously available facilities. The United States maintains far more radiobeacons than any other one country.

Because of the many factors affecting navigation it is somewhat difficult, from an analysis of statistics, to show the effect of radiobeacon navigation in the way of increasing safety, but the following figures are of interest. On the Great Lakes the benefits from radiobeacons were remarkably effective during 1927–30. In this 4-year period there were 31 strandings in a group of 470 vessels, or 1 for each 15 vessels. For the years 1923–26, before the advent of radiobeacons, there were 76 strandings in a comparable group of 572 vessels, or 1 stranding for each 7.5 vessels. Shipping interests state that the influence of radiobeacon navigation was an important factor in the reduction thus shown.

Further developments in equipment and in methods of use for radiobeacons are always under consideration for the improvement and development of the radiobeacon system.

RADIOBEACON NAVIGATION

Radiobeacons are radio stations installed at lighthouses, on lightships, or at other points shown on the charts, for the sending out in all directions of radio signals, for the purpose of guiding marine navigation. Radio direction finders are special radio receivers with rotating coil antennas capable of receiving radio signals.

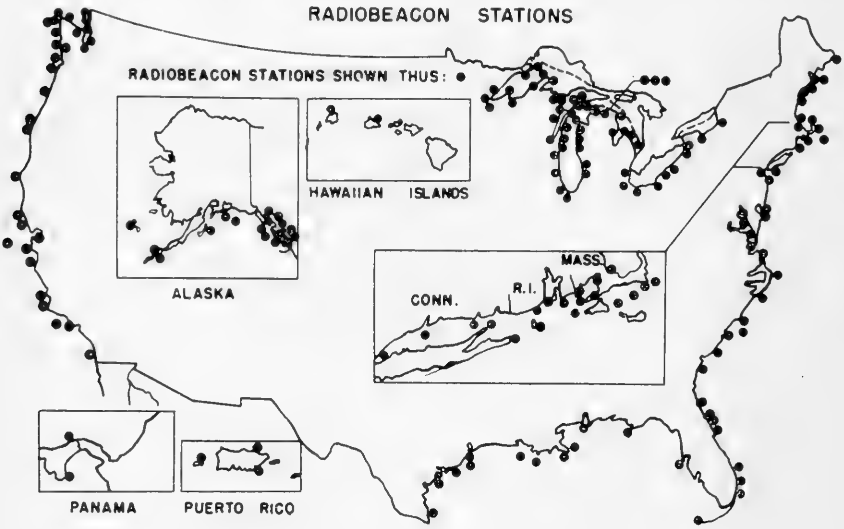


FIGURE 2–2.—The Marine Radiobeacon System of the United States, 1949.

When first introduced, these installations were called radio fog signals or wireless fog signals because they were originally planned for use in fog; but they have developed, as will be described, into valuable aids in either fog or clear weather. Therefore, the restrictive name, "radio fog signal," was considered inappropriate.

In this country, the direction finding equipment on shipboard nearly always is installed in such a way and the transmitted characteristic signal is such that the navigator himself can conveniently take distinct and easy-to-recognize radio bearings. The general problems and practice of navigation are then the same when using radio bearings as they are with visual bearings on lighthouses or other known objects. The practical differences between radio and sight bearings are not differences in principle, but in the availability of the former at much greater distances and under all conditions of visibilty or fog. The radiobeacon is located at a definite point shown on the chart.

It sends out signals by radio in all directions around the horizon, as does a lighthouse by means of light beams, and it is distinguished from the neighboring signals by a definite characteristic, as is the light.

The radiobeacon may be used as a leading mark for which to steer directly, the navigator correcting the course from time to time by successive radio bearings. Thus, such a signal off an entrance or other objectives may be approached with certainty from a considerable distance. This is a valuable use of radiobeacons, especially when these signals are located on lightships, as illustrated by the signals on Nantucket Lightship and Ambrose Lightship, which guide trans-Atlantic vessels to the approaches of New York Harbor.

The signal emitted by a radiobeacon follows a great circle course. Radio bearings may be plotted without applying a correction on a Mercator chart if the difference in longitude involved is not in excess of 1° or 2°. When the difference is larger, a correction usually must be applied which will be found in H. O. Publication No. 205. "Radio Navigational Aids," under Radio Bearing Conversion Tables.

A bearing from a radiobeacon station may be combined with information from other sources, as from an intersecting line of position from an astronomical or Loran observation, from soundings, from dead reckoning, etc., to locate the position of the vessel.

A ship may also be located by radio bearings on a single radiobeacon by taking two bearings on a station with an intervening period of time, and plotting these with respect to the distance and course run between bearings. With radio bearings, because the signals are not operating continuously

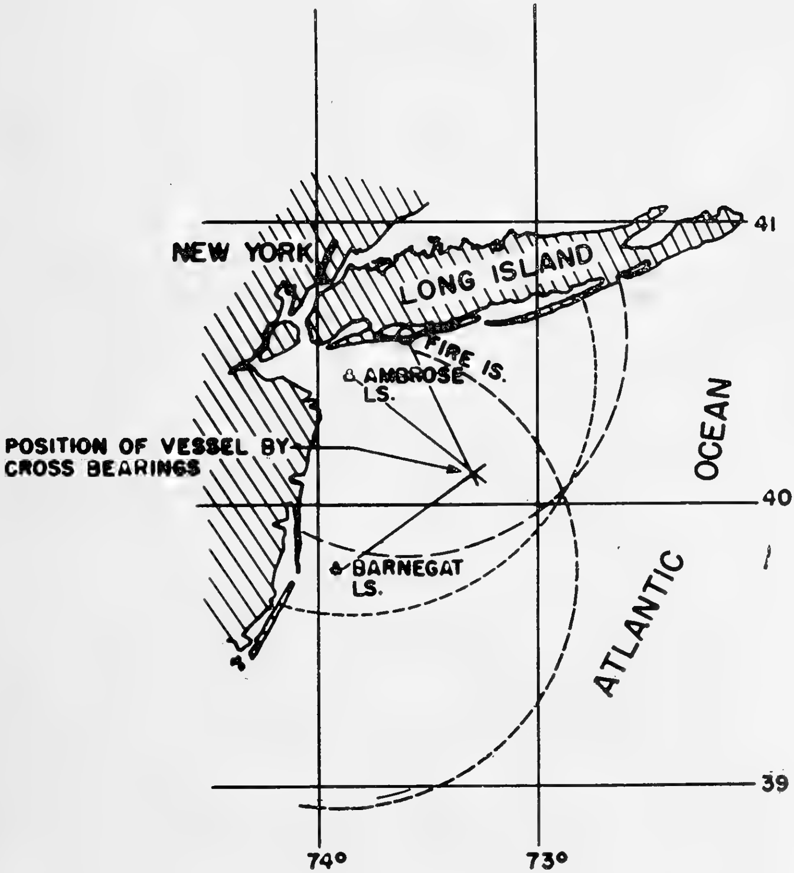


FIGURE 2-3.—Radiobeacons in the approaches to New York and how they may be used by vessels.

excepting during fog, advantage should be taken of bearings at suitable angles as opportunity offers.

The common method of locating a ship by cross bearings may be employed in radio navigation using two or more radiobeacons, or visual and radio bearings in combination. Of course, the usual principles apply as to employing stations which will give good intersections, and as to allowing for the distance run between the times of taking bearings if the interval is appreciable.

United States radiobeacons are operated at intervals on a fixed time schedule in clear weather and continuously during fog; adjacent stations send for successive minutes. This facilitates the taking of radio cross bearings, as does also the location in important localities of two or three stations sufficiently close for cross bearings.

Radiobeacons in the approaches to New York, illustrating their use in navigation, are shown in figure 2–3. Figure 2–4 illustrates how in actual practice a navigator may fix his position by cross bearings on three Pacific coast radiobeacons. The angles between the stations in figure 2–4 are not such that a small triangle of most probable position will be formed as in figure 2–3. Such cases are common along some steamship routes, but the fixes are extremely valuable, nevertheless, and may be good despite the small angle at which two of the lines cross. It will be noted that in figure 2–4 the correctness of the bearing of the station to the north is confirmed or independently checked by that of the station to the south to give the distance off-shore, while bearing of the station to the east gives a cut at a good angle to determine the progress of the vessel along the coast.

For additional information on accuracy of bearings, plotting, and other matters, the navigator should consult the current issue of H. O. Publication No. 205, "Radio Navigational Aids."

Radio bearings from a ship may, of course, be taken on any sending station shown on the chart, transmitting on a frequency within the range of the direction finder receiver. A considerable number of such radio stations throughout the world have been listed on which bearings may be taken from ships equipped with radio direction finder equipment. Many of these stations

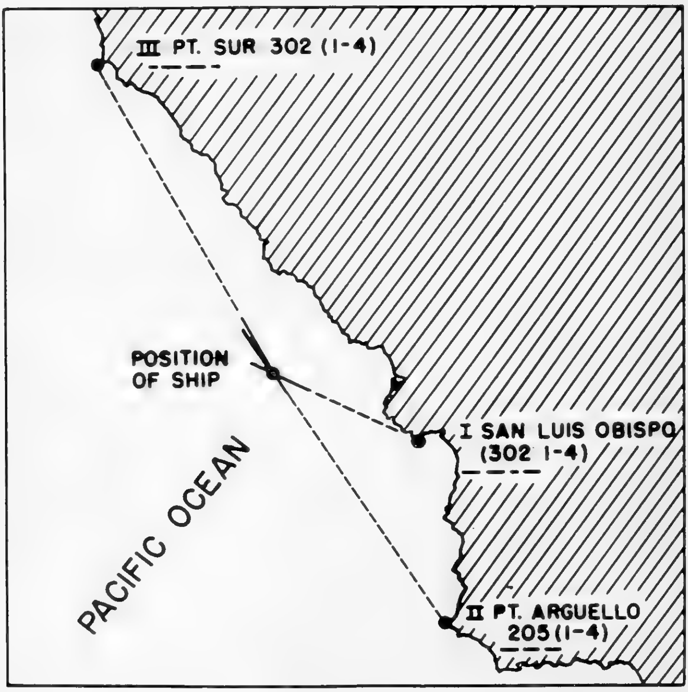


FIGURE 2–4.—Determination of ship's position from three good radiobeacon bearings plotted on the chart.

on request will transmit signals to permit radio bearings being taken. However, because of their dependable and convenient operating system, it is more satisfactory in navigation to use bearings on the radiobeacons specially established for this purpose.

A number of cases have been reported of the indirect use of radio bearings in navigation. A vessel equipped with a radio direction finder and knowing its own position has been able to assist other vessels by means of radio bearings. Thus, where a vessel seeking another in distress is unable to locate it because of inaccurate reported position, neither having a radio direction finder, a third vessel so equipped has been able to guide the rescuing vessel by the use of radio bearings.

There has, in the past, been discussion of the relative merits of using radio bearings obtained from the ship and from fixed radio direction finder stations on shore, but the question was of importance only in the development stage. As soon as the improvement of the marine radio direction finder made practicable the obtaining of reliable radio bearings from the ship, the advantages became apparent of having such a valuable navigational instrument located so as to be directly available to the navigator for the various and general uses to which it may be applied on shipboard. This system conforms to the standard practice of the sea in retaining the location of the navigating instruments on the ship and placing the responsibility for their use and for the navigation of the ship in the hands of the master. The navigator can use such checks as he deems best, and knows what reliance to place on radio bearings in comparison with his other means of guiding the vessel. Any number of vessels properly equipped may take bearings simultaneously on a radiobeacon, just as they can on a lighthouse, without interference with each other. The United States Coast Guard no longer operates fixed direction finder stations.

The direction finding equipment on shipboard (see fig. 2–5) has come to be recognized as a navigational instrument essential to all larger vessels, and has been extensively installed on smaller vessels. Its use tends directly to economy of operation, and to increased safety.

The International Conference on Safety of Life at Sea, held at London, England, in 1948, prescribed that every ship of 1,600 tons gross tonnage and upwards when engaged on international voyages must be provided with an approved radio direction finding apparatus.

The Communications Act of 1934 as amended and revised to September 1, 1948, requires that any passenger vessel of 5,000 tons gross tonnage and upward navigating in the open sea be provided with an efficient radio direction finding apparatus.

The use of radiobeacons greatly aids a navigator either to follow a desired or prescribed course, or to avoid a congested route. It has been reported, for example, that since this system came into service, steamers on Lake Superior have been better able to adhere to the west- and east-bound traffic lanes agreed upon on that lake.

The use of radio bearings taken on board ship may result in considerable saving of time. Besides the particular value of this in rescue and relief work, it also increases the efficiency of operation of the vessel. It is frequently possible by means of radiobeacon bearings to make port in fogs which formerly have prevented the ship from proceeding.

The use of radiobeacons on inland waters has received a thorough test on the Great Lakes, Long Island and Vineyard Sounds, and Chesapeake Bay, where it has proved most valuable.

LOCATION AND DISTRIBUTION OF RADIOBEACON STATIONS

Radiobeacons are located at various sites (shore and marine) so that they may be of utmost usefulness to the mariner in locating his position. (See fig. 2–2.) On account of their much greater range it is evident that the general needs of navigation in this respect for any given length of coast have been supplied by a much smaller number of stations than are required in respect to lighthouses, or to sound fog signals.

In the United States the radiobeacons are divided into four general classes, as follows:

Class A.—Reliable average range of 200 miles.
Class B.—Reliable average range of 100 miles.
Class C.—Reliable average range of 20 miles.
Class D.—Reliable average range of 10 miles.

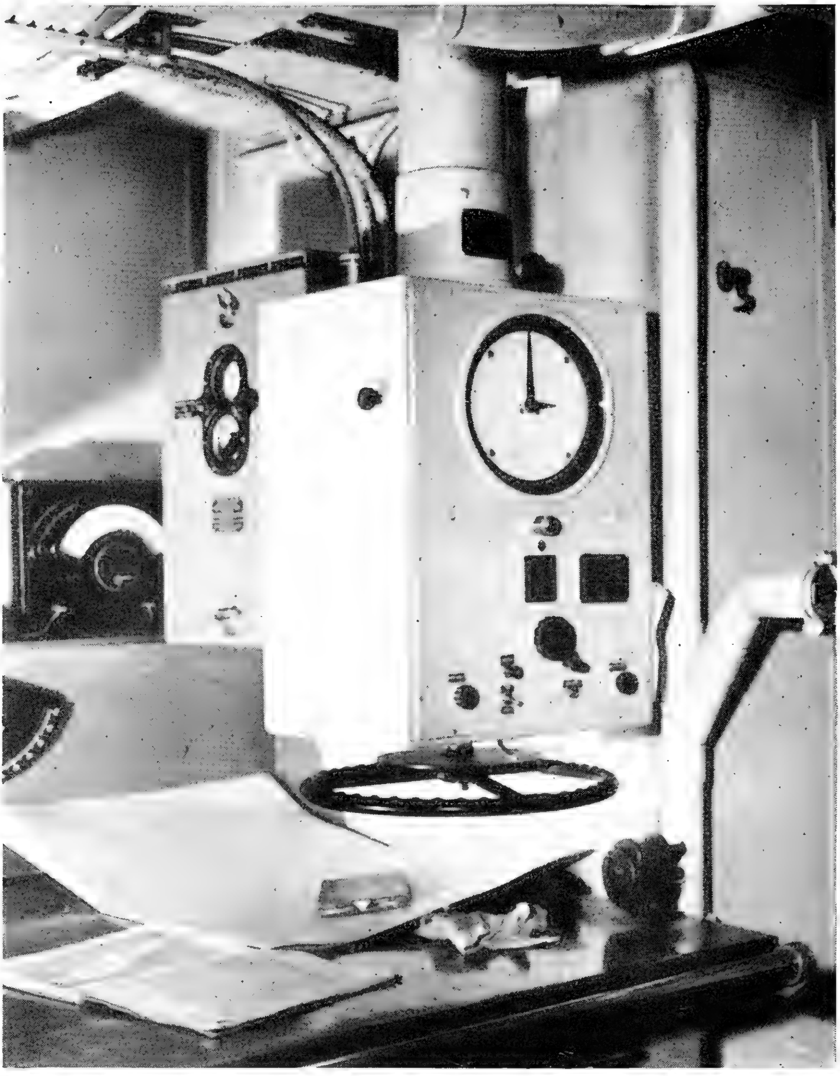


FIGURE 2-5.—A modern radio direction finder installed aboard ship.

Cape Cod Radiobeacon, Massachusetts, and Point Arguello Radiobeacon, California, are high-power class A radiobeacons which have effective ranges of about 400 miles.

The most powerful sound-in-air fog signals under favorable conditions may be heard at distances of 10 to 15 miles, but their ordinarily dependable range is not over 5 miles, and, under unfavorable conditions, they are lost at distances shorter than this. The coast lights are visible for 15 to 20 miles and large lighted buoys for about 9 to 12 miles. It is therefore readily seen that the radiobeacons have a much greater range of usefulness, in fog as well as in clear weather. This is illustrated by the fact that on the outside Atlantic coast of the United States, north of Cape Hatteras, there are but 19 radiobeacons. This length of coast requires five times this number of sound fog signals, and they are effective over only 2 percent of the area served by the radiobeacons. The same length of coast has 150 outside lights.

In order to lessen interference, the power of radiobeacons is limited to that

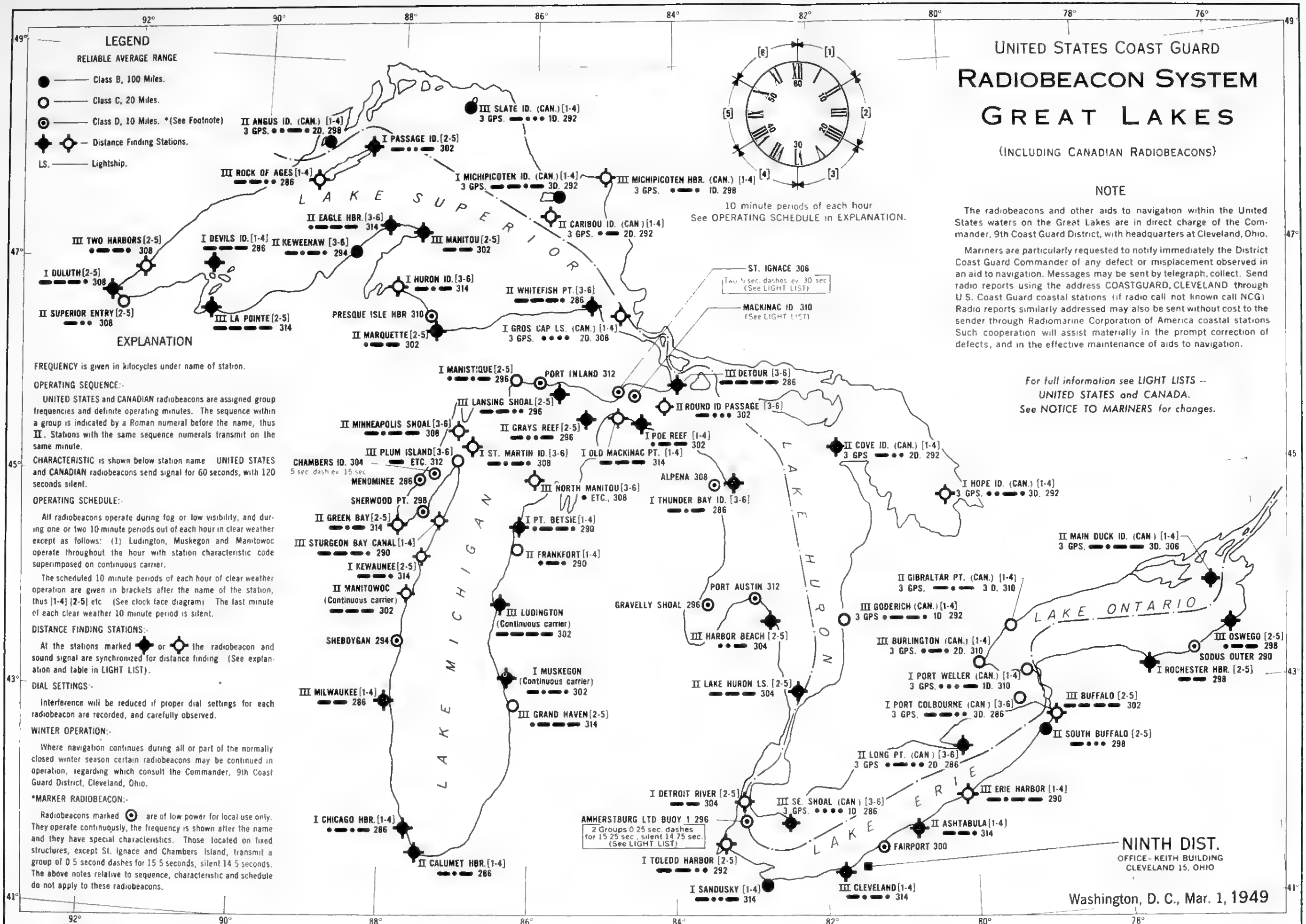


FIGURE 2-6.—Radiobeacon system, Great Lakes.

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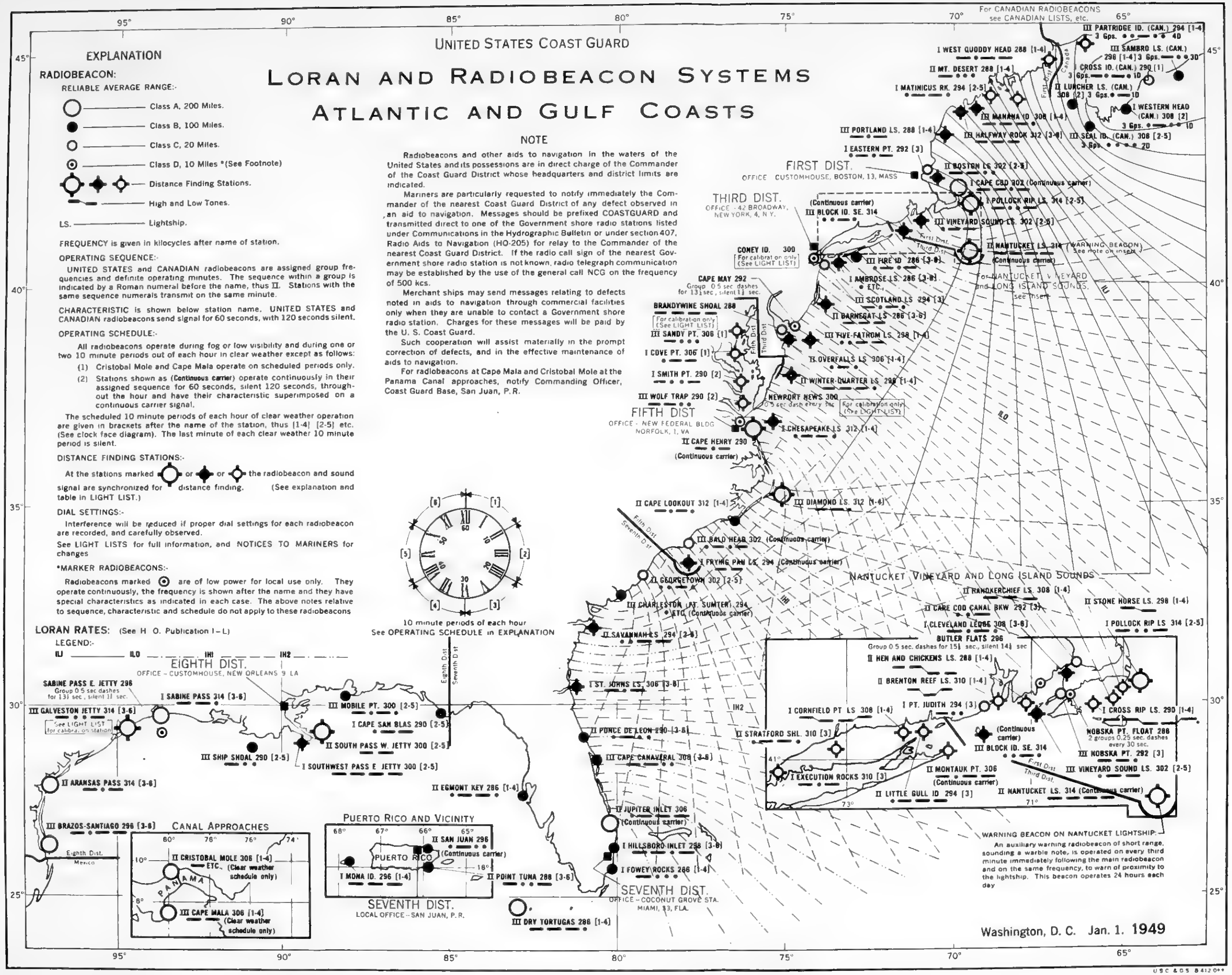

. FIGURE 2-7.—Loran and radiobeacon system, Atlantic and Gulf coasts.

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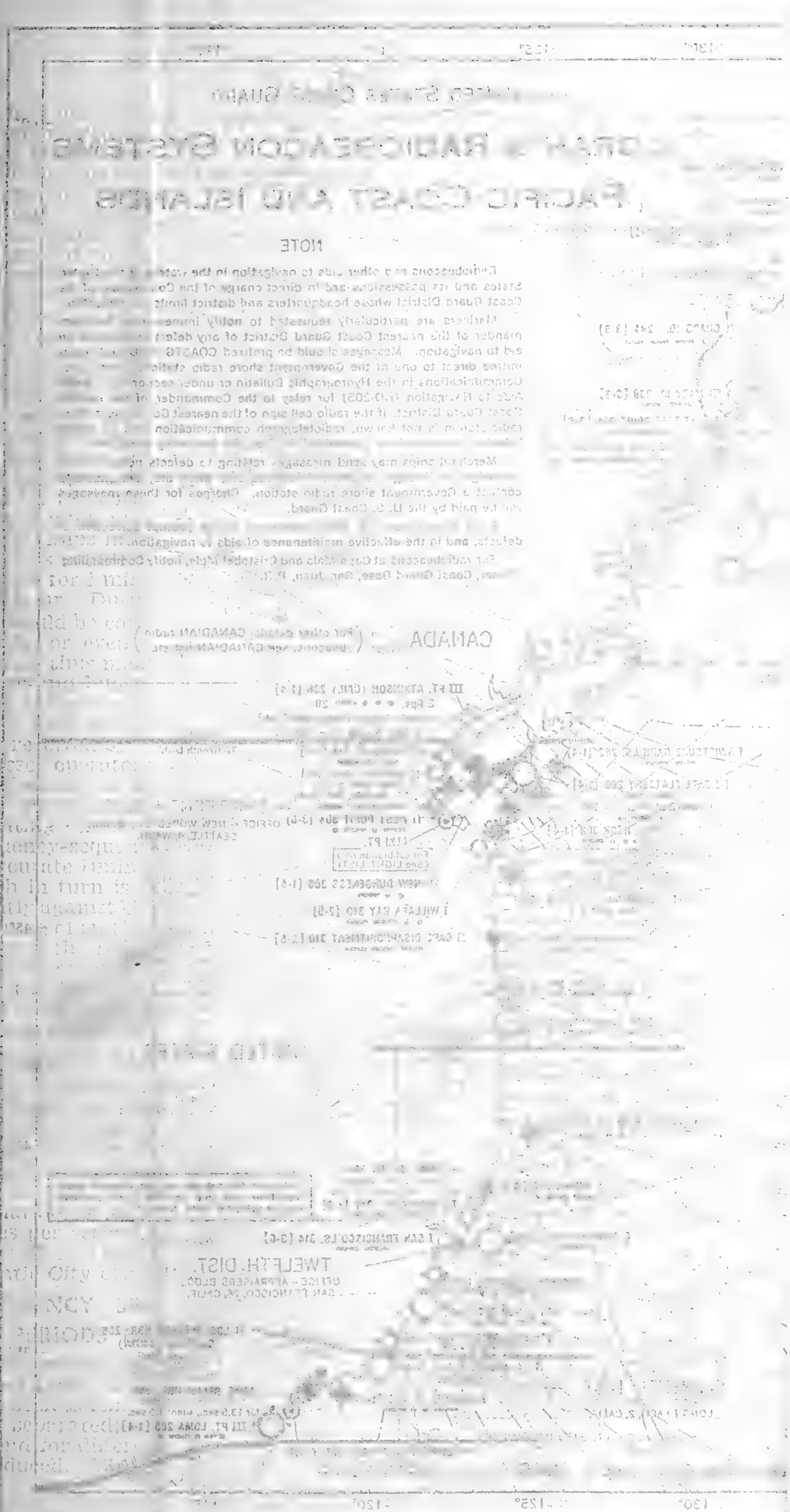
RADIOBEACON SYSTEMS
PACIFIC COAST AND ISLANDS
NOTE
Radiobeacons and other aids to navigation in the waters of the United States and its possessions are in direct charge of the Commander of the Coast Guard District whose headquarters and district limits
Mariners are particularly requested to notify immediately the Commander of the nearest Coast Guard District of any defect in aid to navigation. Messages should be prefixed COASTG
mitted direct to one of the Government shore radio stations
Communications in the Hydrographic Bulletin or under section Aids to Navigation (H.O-205) for relay to the Commander of the Coast Guard District. If the radio call sign of the nearest Government radio station is not known, radiotelegraph communication
Merchant ships may send messages relating to defects
contact a Government shore radio station. Charges for these messages will be paid by the U. S. Coast Guard.
defects, and in the effective maintenance of aids to navigation.
For radiobeacons at Caja Mala and Cristobal Mole, notify Commanding
, Coast Guard Base, San Juan, P.R.
CANADA
For other details: CANADIAN radio beacons, see CANADIAN list etc.
TWELFTH DIST.
OFFICE - APPRAISERS BLDG.
SAN FRANCISCO, 26, CALIF.
125°
120°
130°

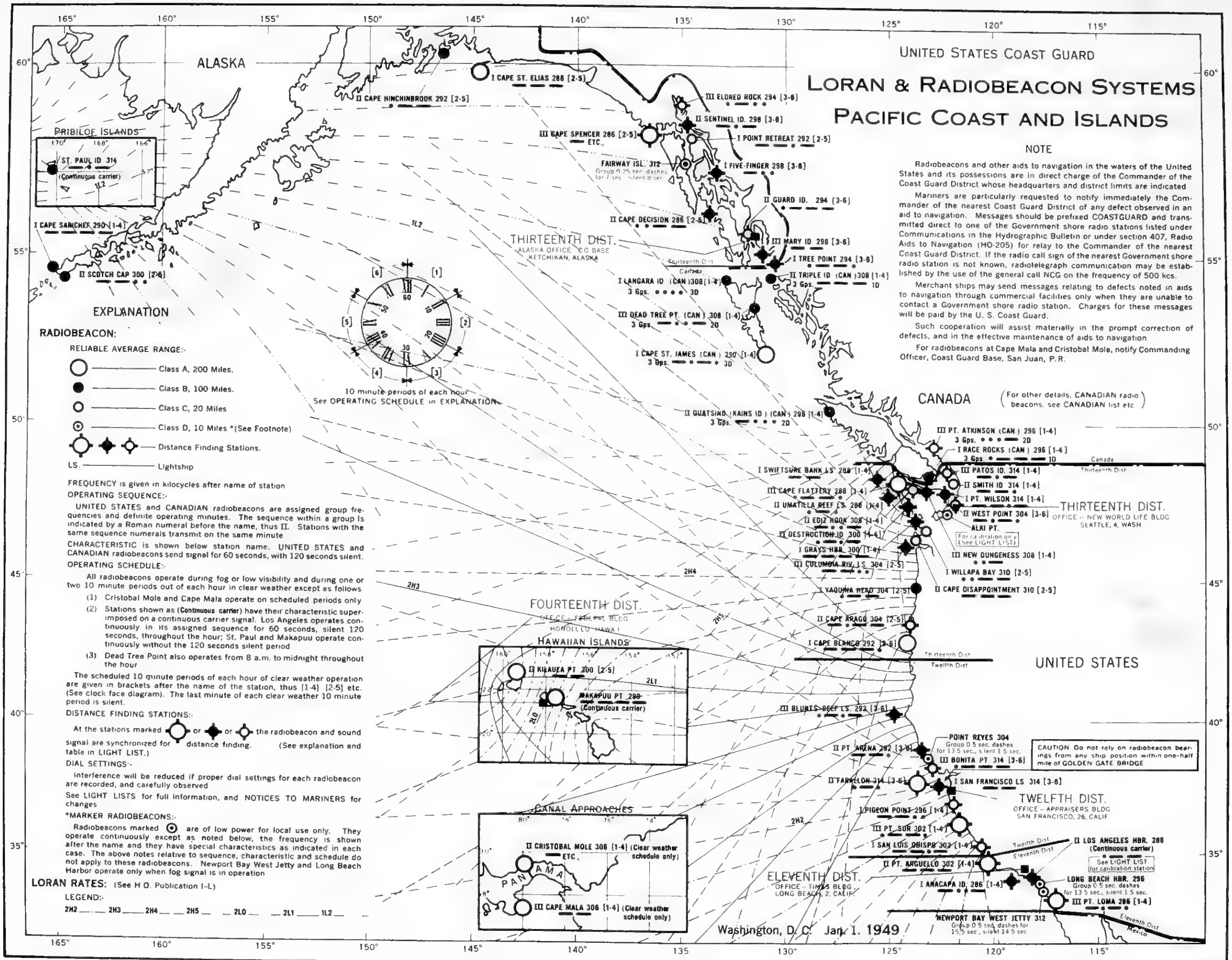

FIGURE 2-8.—Loran and radiobeacon system, Pacific coast and islands.

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which is necessary, according to the various purposes of the stations. For the same reason the primary stations are restricted to a few widely separated points of strategic importance to navigation, which are valuable as landfall stations or for long distance approach.

Local, low-power radiobeacons have been placed on inside waterways, such as Strait of Juan de Fuca, Long Island Sound, and Chesapeake Bay, but the greater number of radiobeacons are of intermediate power, and are located and spaced to meet the usual requirements, both for coastwise and lake navigation, and for approaching entrances. These signals are now sufficient in number so that a vessel near the coasts of continental United States or on the Great Lakes will always be within range of one of these signals and usually two or more of them.

In general, radiobeacons are located at all important entrances and at outstanding intermediate points along the coast. There are only a few that have not been placed at established lighthouses. This is advantageous because such positions are shown on the charts and are well known to mariners and because this is the most economical arrangement, both as to installation and operation of radiobeacons. (See figs. 2–6, 2–7, and 2–8.)

Lightships have been found to be the most valuable and convenient stations for radiobeacons. They are in the positions of greatest importance to the navigator, and they may be steered for directly and passed on either side. All lightships have radiobeacons.

In this country, during periods of good visibility, radiobeacon signals are sent out for 1 minute out of each 3 minutes, for one or two 10-minute periods each hour. During fog and low visibility they are operated continuously.

It would be convenient to the navigator to have long, continuous operating periods, or even to have the radiobeacons send continuously without any silences, thus making these aids to navigation always available, as are lighthouses and buoys. The system that is in use is a compromise, adopted to lessen interference. Masters of vessels who understand the necessity of the simple plan of operation are satisfied with the system and many letters have been received by the Coast Guard confirming this statement.

Vessel operators may request and obtain the continuous operation of a radiobeacon for purposes of calibration of ship radio direction finder equipment, providing calibration is undertaken during the station's clear weather operating schedule and providing no other radiobeacon station in the same frequency-sequence group is observed in operation at the time.

Accurate timing of radiobeacon signals is accomplished by a signal timer which in turn is controlled by a primary clock. The latter is checked frequently against U. S. Naval Observatory time signals, thus making possible the grouping of stations with a minimum of interference. In addition, the signal timer at the light station controls all timed aids-to-navigation signals and the starting and stopping of the equipment necessary to make these signals. The signals and equipment controlled include distance finding sound signals, main light, radiobeacon, engine generator starting, and warming transmitters, all controlled in their proper sequence.

FREQUENCY BAND RESERVED FOR RADIOBEACONS

The International Radiotelegraph Conference at Washington in 1927, and the regulations attached to the convention, provided that radiobeacons "shall use waves of 285 to 315 kilocycles per second (1050 to 950 meters)", and that continuous or modulated continuous waves would be used. This frequency allocation has remained the same until 1947, when the conference of the International Telecommunication Union, Atlantic City, made a change. The regulations of that conference allocated the frequency band 285 to 325 kilocycles per second for marine radiobeacon operation in ITO region 2. The entire United States radiobeacon system is within the area defined by the Atlantic City conference as region 2.

FREQUENCY SEPARATION AND SYNCHRONIZATION OF SENDING PERIODS OF MARINE RADIOBEACONS

Interference is a problem affecting the navigational use of radiobeacons as it does other uses of radio. To minimize interference, the following steps have been taken. Frequencies of adjacent stations or groups of stations have been separated; adjacent stations in a group have been synchronized so as to send for different minutes; and the power of the signals has been limited or reduced. With the operating schedule of 1 minute on and 2 minutes silent,

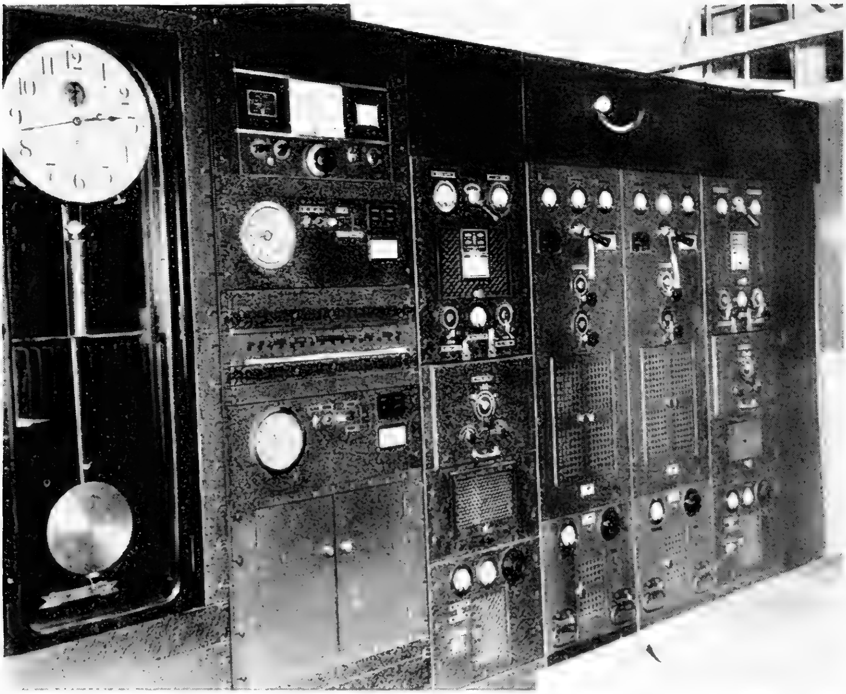

FIGURE 2–9.—The lineup of equipment at a class A radiobeacon station. One of the primary clocks shown at the left.

it is convenient to synchronize stations in groups of three, and this grouping and synchronization has been extended to the whole system. Radiobeacons transmit on even frequencies in the band 285 to 325 kilocycles (i. e., 286, 288, 290, etc.).

SIGNAL CHARACTERISTICS

The radiobeacon is an aid to navigation and is therefore made as conveniently available to the navigator as practicable. Consistent with this idea, the characteristics assigned to radiobeacon stations in this country have been limited to brief and simple combinations of dashes and dots, corresponding in no case to more than a single International Morse code symbol. They are thus differentiated on the same principle as are lights along the coast, a system to which navigators are accustomed. The entire transmission for any station is a repetition of the assigned signal, without variation. There is a minor exception to this in the case of distance-finding stations. The advantage in this arrangement is that whenever a radiobeacon is heard its identity is immediately apparent, even to a navigator who is not a radio operator. There appears to be no difficulty in differentiating radiobeacon signals from other transmissions, and therefore the use of a common distinguishing letter for all radiobeacons has been considered unessential.

TYPE OF MARINE RADIOBEACON EMISSION

All marine radiobeacon stations in the United States emit type A2 signals. This type of emission is obtained by either keying the modulating audio frequency or by the keying of the modulated carrier.

Radio direction finders have generally been designed so as to be capable of taking bearings on either unmodulated continuous wave or modulated continuous wave signals.

MARINE RADIOBEACON TONE CHARACTERISTICS

The audio modulation frequency of 1000 cycles has been adopted in the United States as the standard tone for marine radiobeacons. However, tonal characteristics of radiobeacon marker stations (low power) are varied in order to facilitate identification where installations become congested.

DISTANCE FINDING STATIONS

A large number of radiobeacon stations are now equipped so that a vessel in the vicinity provided with radio may, by a single observation, determine its distance from the station. If the vessel has a radio direction finder and takes a radio bearing at the same time, its position at once is determined by the distance and the bearing. Without the radio bearing, the distance observation locates the vessel somewhere on a circle of that radius from the radiobeacon. As the method is dependent on the hearing of a sound-in-air signal, it is subject to the same uncertainties as affect such fog signals, and the distance to which it may be used is limited by the range of audibility of the sound signal.

The signals consist of blasts from a sound-producing device (fog signal) synchronized with radio-tone signals. Since the radio signals arrive practically instantaneously (speed 186,000 mi./sec.), the later arrival of the sound signal (speed approximately 1,100 ft./sec.) gives an indication of the distance traversed by the latter, therefore of the vessel's distance from the station. At distance finding stations, transmission of the characteristic radiobeacon signal is curtailed 8 seconds before the end of the operating minute, and a 1-second dot followed by a 5-second dash are transmitted simultaneously with blasts of corresponding lengths from the sound signal device. An observation consists of noting the time difference with reference to any distinctive part of the signals—for example, the end of the long radio dash and the end of the long sound blast. Dividing the time in seconds by 5.5 gives the distance in nautical miles with an error which should not exceed ± 10 percent. The distance finding signals are transmitted only in thick or foggy weather when the fog signal is operating.

The method is applicable to stations equipped with sound-in-air fog signals capable of being brought to full power of sound in a very brief time.

All distance finding stations and their method of operation are shown in Coast Guard Light Lists covering areas where radiobeacons are located.

EQUIPMENT OF A RADIOBEACON STATION

The equipment of a radiobeacon station consists of a transmitter, primary clock, signal timer, warning device and accessories. All apparatus, so far as practicable, is installed in duplicate with convenient means for switching from one transmitter, generator, or signal timer to another in case of trouble, so as to insure continuity of service.

TRANSMITTER.—The transmitter is selected on the basis of output power which, in turn, is dependent on the desired range. Transmitters and power amplifiers are available for 5, 25, 150, 750, and 1,500 watts output. The radiobeacon transmitter is in most respects similar to a communications transmitter.

MASTER CLOCK.—Two types of primary clocks are employed to exercise control over timed functions at the radiobeacon stations. One is a jewelled, weight-driven, pendulum clock capable of maintaining an accuracy within 2 seconds in 24 hours. These clocks are installed at shore radiobeacons where vibration is not excessive. The second type is a jewelled, temperature-compensated, marine-escapement clock which has an accuracy within 5 seconds in 24 hours. This latter type is used at all lightship radiobeacons, and at shore stations where vibration is excessive. The function of either type clock is to make an electrical contact once each minute to furnish correcting impulses to the time, which, in turn, regulates the functions of the radiobeacon station.

SIGNAL TIMER.—The heart of the control system of the radiobeacon station is the timer mechanism. The timer is a mechanical device having a series of cams accurately rotated with respect to standard time. The cams actuate contacts to which are connected the various circuits of the radiobeacon and auxiliary equipment, controlling them in desired sequence and at predetermined intervals accurately based on standard time. As stated above, the timer cams are kept in synchronism with standard time by means of the impulses supplied through the clock contacts. The timer controls any or all of the following functions at the radiobeacon station characteristics; code tone, transmitter on and off, clear weather or fog schedule of transmission (1 min-

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ute on—2 minutes off is the usual program of transmission), engine generator starting, timing of lights, sound fog signals, warning signals, and radiotelephone schedules.

WARNING DEVICE.—In order to insure reliable service from the radiobeacon, an automatic warning device is used in the station which rings a bell whenever the transmitted signal is interrupted, out of time, or seriously impaired in strength or modulation. Aural reception of the radiobeacon signal is also provided for monitoring purposes. The unit, known as the Radiobeacon Supervisor and Alarm, consists of a radio receiver fed from a short antenna of sufficient length to pick up the radiobeacon signal, a clock which drives cam-operated contacts, and various copper-oxide rectifiers, relays, resistors, etc., which serve to operate a spring-wound warning bell under contingencies noted above. A loud speaker and an output meter provide the operator with data on the radiobeacon signal.

ANTENNA.—The transmitting antenna is selected to suit the physical factors of the site, the transmitter power and the desired range. For high power radiobeacons, insulated steel towers are used. Antenna coupling houses fed through concentric cable are used with tower-type antennas. For low power or limited range, an insulated vertical mast or whip-type antenna, or a vertical wire with T flat-top, is satisfactory. A good ground is essential for an efficient antenna system, and in some locations where the soil is rocky or sandy a counterpoise system of radials is employed.

ACCESSORIES.—In addition to the major items described, various accessory and power supply items are required at a radiobeacon station. Accessories include racks and special panels carrying switches, terminals, cable adaptors, storage lockers, and shelves. These items are necessary for the proper installation, inter-connection and switching of the radiobeacon equipment. For 115-volt d-c radiobeacon installation, a 54-cell storage battery, two d-c engine generators, and two rotary converters, are required. If 115-volt a-c power is available, the only power equipment needed is an auxiliary 115-volt a-c engine generator, and special rectifiers to provide d-c power for the radiobeacon timers. Spare parts, including vacuum tubes, are provided for maintenance purposes.

CLASS D MARKER RADIOBEACONS ON LIGHTED BUOYS

The United States Coast Guard has developed a low power, class D radio marker beacon for installation on lighted buoys. Such installations are required where harbor entrances and channels must be marked by a radiobeacon but where it is not practicable to affect a shore installation. Figure 2–10 shows the type of buoy used for the installation and the method of mounting the antenna.

RADIO DIRECTION FINDERS FOR SHIP USE, AS DEVELOPED IN THE UNITED STATES

The radio direction finder is an instrument for observing, by means of radio, the direction of a station sending radio signals. Briefly, in navigation, it is an instrument for taking radio bearings. As generally used in marine navigation in the United States, it consists of a loop antenna mounted above the ship's pilot house, with its axis extending downward into the pilot house, and carrying a handwheel and reference indicator over a magnetic compass, dumb compass, or gyro repeater in the pilot house. (See figs. 2–5 and 2–11.) This loop can be rotated by the navigator or observer. The loop is connected to a radio receiver in the pilot house. Using this receiver, the navigator picks up the desired station, then revolves the loop and notes the varying strength of the signal until a point is reached where the signal is lost entirely or nearly lost. This is called observing the minimum. At this point the plane of the loop is perpendicular to a line connecting the ship and the station heard, and the reference indicator is so placed with respect to the loop that it then points directly to the station. Such radio bearings may then be used in navigation on the same general principles as sight bearings are used.

In a well-designed and adjusted radio direction finder, the point of minimum, or no signal heard, is sharp, and bearings may be taken with an accuracy of 1° or 2°. Even when the minimum is not well defined, a fairly accurate bearing may be obtained by swinging the loop to each side, until the signal becomes just audible, and taking the mean of the readings in these two positions.

FIGURE 2–10.—A typical marker radiobeacon on a lighted buoy.

The method of radio direction finding is based on the directive properties of the so-called coil antenna when used for the reception of radio signals. The radio direction finder includes a coil antenna, and operates on the principle that the amount of electromotive force induced in the vertical loop of wire by an arriving electromagnetic wave depends on the angle between the plane of the loop and the wave front. When the plane of the coil is parallel to the direction of the sending station, the intensity of the signal will be a maximum. As the coil is rotated, the intensity of the signal diminishes until a minimum is reached when the plane of the coil comes to a position at right angles to the line of direction of the signal. The directional characteristic of a coil antenna is illustrated by the diagram in figure 2–12 where the distance from the center of the coil to any point in the circumference of the circles is proportional to the strength of the signal from a direction passing through that point.

FIGURE 2–11—Weatherproof housing of a modern radio direction finder loop antenna mounted above deck.

As the diagram indicates, the minimum is well-defined, and the maximum is not; that is, the strength of the signal varies rapidly with movement of the coil near the minimum, but varies slowly with movement near the maximum. For this reason, the minimum is used in observing bearings. Otherwise there would be important advantages in taking bearings on the maximum, in the way of greater audibility and of thus diminishing the effect of interference.

In a rotatable coil of practicable size the voltage induced by a radio signal is very small. For the employment of such small coils for radio direction finding purposes it is essential that there be great amplification.

The radio direction finder should preferably be installed in a position easily accessible to the ship's navigator. The navigator desiring to take a radio bearing simply closes a switch, manipulates a single adjustment until the characteristic signal of the desired rediobeacon is heard, rotates the radio direction-finder loop until the sound becomes a minimum or is inaudible, and then reads the radio bearing. No knowledge of radiotelegraphy is necessary on the part of the navigator. In addition to the desirability of locating the direction-finding equipment at a convenient location, easily

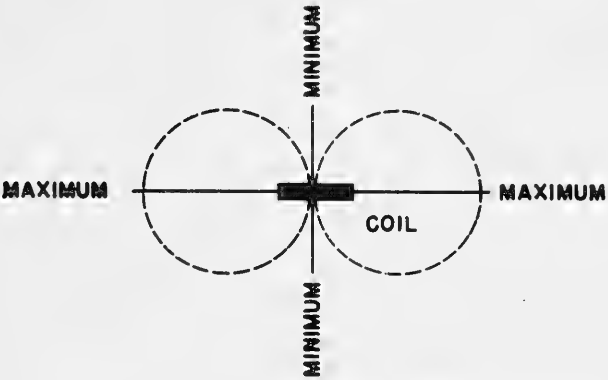


FIGURE 2–12.—Illustrating the directional characteristic of a coil antenna.

available to the ship's navigator, consideration must be given to the location of the direction finder loop antenna. This antenna should not be located behind or near large metal objects such as vessel stacks, superstructure, trunks, etc. In most vessels the choice of loop antenna location will be a compromise due to necessity. The ideal location aboard any vessel would be one where the loop antenna is well clear of all objects, permitting maximum use and accuracy of the direction finder equipment.

It is especially important that a radio direction finder have good selectivity so as to be able to eliminate interference from other radio signals on other frequencies when taking a bearing. For the usual needs of navigation it is not essential that it be capable of taking radio bearings from great distances.

There are several other types of radio direction finders in other countries, the most widely used of which is the fixed-loop (Bellini-Tosi) direction finder, which employs a small rotatable search coil. All radio direction finders, however, operate on the same basic principles.

CONTINUOUS CARRIER MARINE RADIOBEACONS FOR AUTOMATIC RADIO DIRECTION FINDER USE

In recent years automatic radio direction finders have made their appearance, especially in aircraft. These devices, when manually tuned to the desired station, will rapidly and automatically indicate the bearing of that station. In order to provide the best possible navigational service, where required, the United States Coast Guard has modified 16 marine radiobeacon stations for continuous-carrier, tone-keyed (1,020-cycle) operation for ADF use. Two of the stations modified provide continuous service. These two installations are outside the continental limits of the United States. The remaining 14 stations provide service in the same manner as the conventional marine radiobeacon, i. e., continuous carrier, in-sequence operation. This type of service requires that the particular station share an assigned radiobeacon frequency with two other stations. This is necessary in order to make available to the user of the system a maximum number of radiobeacon stations operating in the limited radio-frequency spectrum available. The non-automatic type of direction finder is not affected by the continuous-carrier, tone-keyed type of transmission; bearings may be obtained from such stations without difficulty.

OCEAN STATION VESSEL RADIOBEACON SERVICE

The United States Coast Guard maintains ocean station vessels on a number of ocean stations in the Atlantic and Pacific for the primary purpose of furnishing aeronautical weather information. One of the many auxiliary duties of these vessels is to provide radiobeacon service to transoceanic aircraft. The service provided is scheduled continuous-carrier, tone-keyed signals, transmitted in the aeronautical radiobeacon band. Essentially the equipment installed in the vessels is the same as that provided for coastal marine radiobeacon stations.

MICROWAVE BEACONS AND OTHER RADAR AIDS

INTRODUCTION

Radar, to the layman, may appear to be the "cure-all" for short range navigational problems. It is commonly known that Radar is an electronic means by which a vessel or aircraft may see through fog, darkness, or in generally reduced visibility. To see or detect objects in advance permits safe rendezvous or altering of course, whichever is desired. If these were the only considerations of the problem, the solution would be simple indeed; however, in areas of considerable traffic a more important consideration is the problem of target identification. The problem is well presented by several quotations from letters from Merchant Marine Masters in the Hydrographic Bulletin, April 24, 1948:

"The most difficult problem when using Radar for navigation is the identification of the target.

"With a good navigational plot, most objects can be identified by their relative position. But, if the ship's position is not accurately fixed it is usually very difficult to positively identify the Radar target. Lightships are an important aid in entering port or in coasting in fair weather or foul, but, without a visual bearing, identification of a lightship by Radar is often very difficult because of the focusing of ship traffic near them. Also, in fog many ships will anchor in the vicinity of the lightship, causing additional confusion. There should be an identification system to positively identify every Radar navigational aid.

"It is earnestly recommended that a type of signal generator be devised for installation on major navigational aids that will give a positive identifying characteristic on the conventional PPI scope.

"Radar reflector beacons are a great step forward and should be increased in number. But due to the small reflecting surface on the masts of lightships, it is recommended that Radar reflectors be installed to increase the range at which lightships can be detected."

The problem of positive Radar target identification is not a new one but is one which came into being with the first use of Radar. The problem has been met to date by two means: (1) By increasing the strength of the reflected signals returned to the navigators Radar, and (2) the transmission of additional Radar signals to the navigator. In the first category is the passive beacon, or Radar reflector, which is simply a mirror method of reflecting a strong portion of the Radar wave back to its source. The second category is further subdivided into (*a*) responding beacons (those which are triggered by the navigators Radar) and (*b*) those which operate continuously without being triggered by the user.

RADAR REFLECTOR

The simplest form of these Radar aids, the one which offers a great deal in return for very little power consumption, is the "passive radar beacon," or Radar reflector. This device is one which requires no electronic equipment or electrical power, and little maintenance. It is merely a physical arrangement of such material and design as to reflect back to an ordinary Radar most of the energy which strikes its surface. To the user then, this has the effect of presenting a much clearer and larger target than any random geometric configuration of similar size, and one which can be picked up at relatively longer ranges. The Radar reflector is not an amplifying device, an therefore cannot improve the reflecting efficiency of any object which is itself a good Radar target. It will, however, make a good Radar target out of an object that normally reflects little or no Radar energy. Its primary application is for mounting on buoys, important landmarks, etc., so as to facilitate their identification.

Groups of these corner reflectors are shown in figure 3–1. Several of the individual reflectors in the circular arrangement shown insure that they will reflect adequately in any direction from whence a Radar wave may arrive. These reflectors are constructed of lightweight aluminum alloy, and do not materially affect the buoyancy characteristics of the buoys on which they are mounted. The United States Coast Guard is now in the process of determining the best possible reflector types and mountings for lighted, can, and

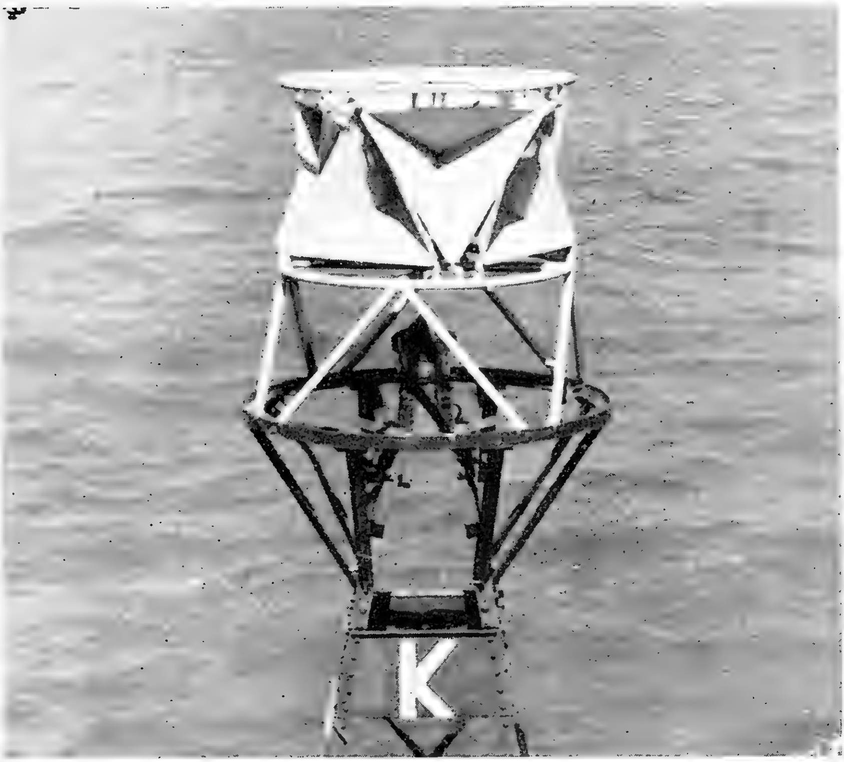


FIGURE 3–1.—Cluster of Radar corner reflectors mounted on standard lighted buoy.

nun buoys. It is quite possible that the reflector mounting arrangement shown in figure 3–1 will be replaced. Future design will incorporate the corner reflectors in the buoy light tower proper, just below the light as illustrated in figure 3–2a. Corner reflectors of the future will be constructed of steel instead of aluminum to assure maximum ruggedness.

Figure 3–3 shows a Radar photo taken during reflector test runs in Baltimore Harbor. Each circular range line on the scope indicates one mile. The vessel was approaching the end of the marked channel. Reflector buoy No. 1C is located at 176°, 4.1 miles (almost split by the bearing cursor), at the southern end of the marked channel. Here the Radar return from the reflector buoy can be seen to be nearly as strong as that from the tug and tow which is about one-half mile SSE of the reflector. The very large "pip" located at 181°, 3.4 miles is Baltimore Light, a large structure. Note that the line of buoys extending 335° from the center of the scope steadily decreases in intensity until they cannot be seen past 2.2 miles even though these are the same size buoys as those equipped with reflectors. There are two buoys showing up at 178°, 2.8 miles; but during actual observation of the Radar scope these "pips" were unstable and not continuously bright at this distance, whereas the reflector showed bright at all times. Another reflector buoy, No. 3B, is located at 060°, 3.7 miles, with no other buoys in the vicinity for comparison. In actual use the stationary buoys are readily distinguished from moving ships on the Radar scope. In addition coordination of Radar information with that of the charts would help to identify the buoys.

MICROWAVE BEACONS

Progressing from the Radar reflector, the simplest of all forms which the Radar beacon may take, the next step for marine use was the development of a powered beacon known as the "Ramark." This Radar beacon is essen-

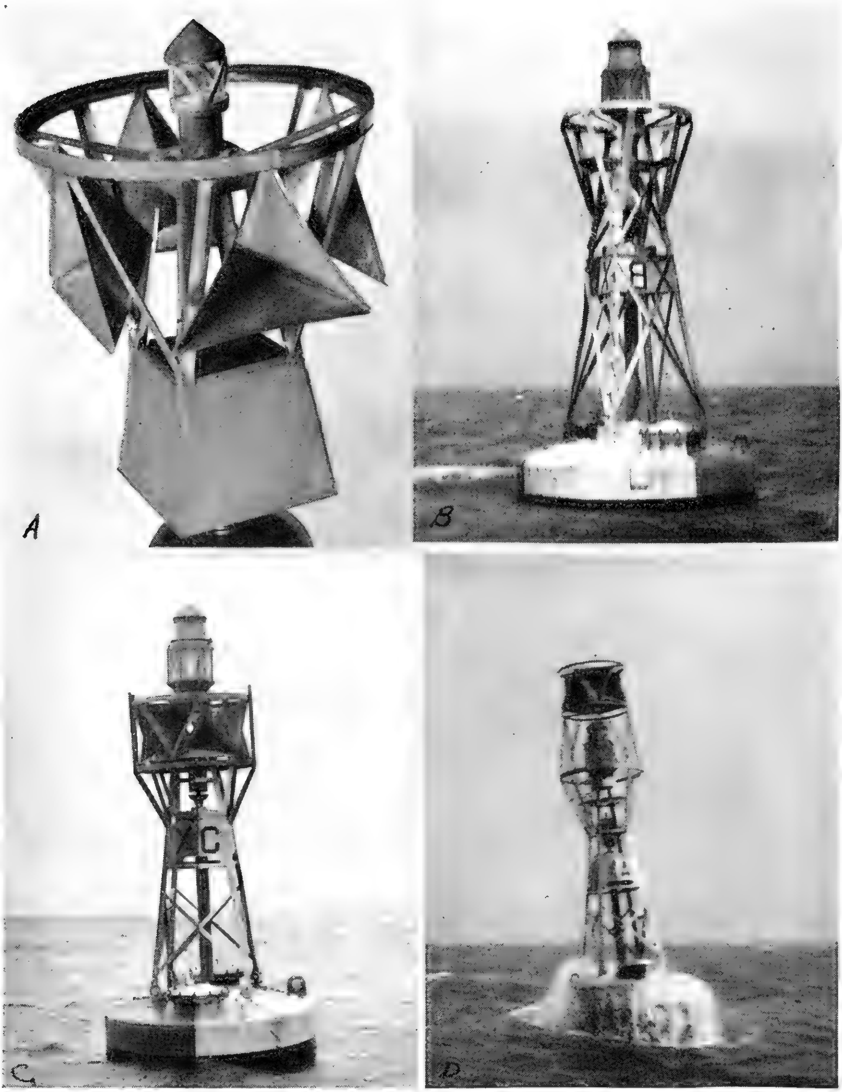


FIGURE 3-2.—Views of Radar reflector-equipped buoys.

tially a continuously pulsing microwave transmitter at some known location. It may be picked up by any navigational Radar whose receiver is capable of being retuned slightly to the established beacon frequency, as the Ramark frequency differs slightly from that of the normal search frequency. When the navigator's Radar receiver is so tuned, the Ramark appears as a continuous azimuth line on the Radar scope, while reflections from objects are obliterated from it. (See fig. 3-4.) Also, this beacon may be utilized by vessels having only a microwave receiver and directional antenna.

At the recent ITU conference in Atlantic City, Radar beacon frequencies of 3256 megacycles (S-band) and 9310 megacycles (X-band) were allocated. These frequencies differ from the normal search frequencies in these

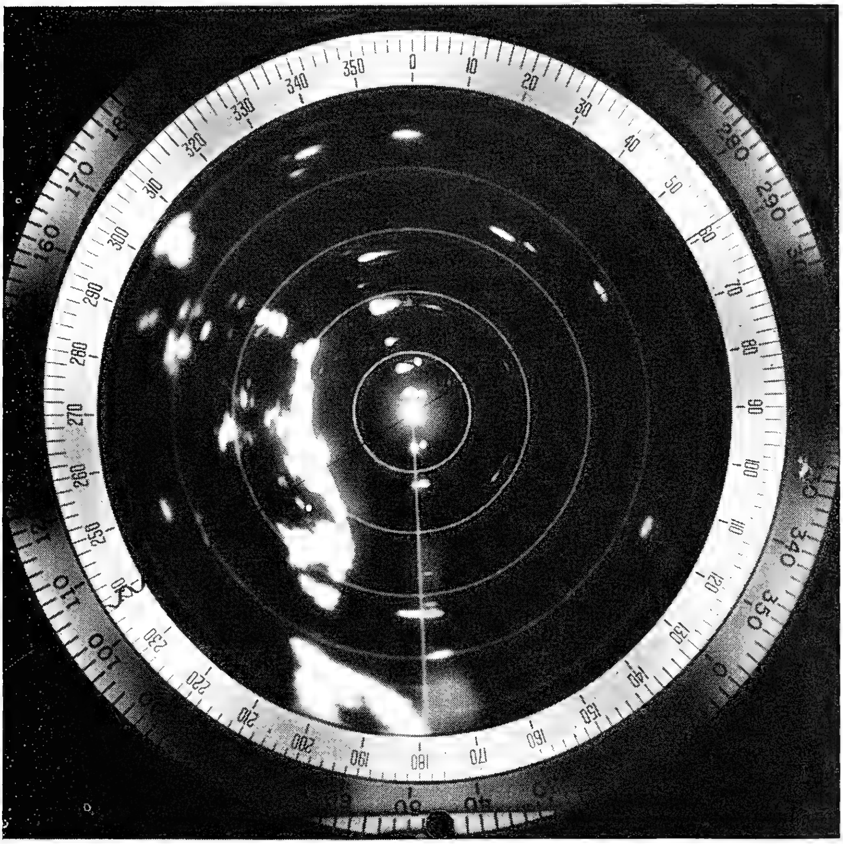


FIGURE 3–3.—PPI scope, showing echoes obtained from reflector-equipped buoys.

bands by approximately 10 to 175 megacycles. Most of the merchants ship Radars in use may receive the Ramark frequency by the addition of a modification to the Radar. To facilitate this tuning, the later-type commercial Radar models are equipped with a single switch which automatically sets the Radar receiver to the Ramark frequency. This is usually accomplished by allowing the switch to cut in a separate local oscillator in the Radar receiver, tuned to the proper Ramark frequency. The latest Coast Guard type TRSC–1 Radar is equipped for Ramark reception.

RAMARK

It appears that the Ramark is the Radar beacon form which offers the most promise for peacetime use. Therefore, in the Coast Guard, active developmental work has been pursued for some time on Ramarks for both the X- and S-bands. The ultimate goal of the Ramark program is to provide stable, reliable, and relatively inexpensive equipment suitable for long periods of unattended operation at important landmarks where they will serve for positive identification of established navigation reference points.

In its present form, the equipment required for a Ramark installation is quite simple, consisting of a low-power source of radiofrequency energy and a keying device, simple antenna, and power supply. A complete beacon transmitter is contained in one cabinet. It is desirable that the Ramark equipment be compact, highly rugged and reliable, of low-power drain, capable of

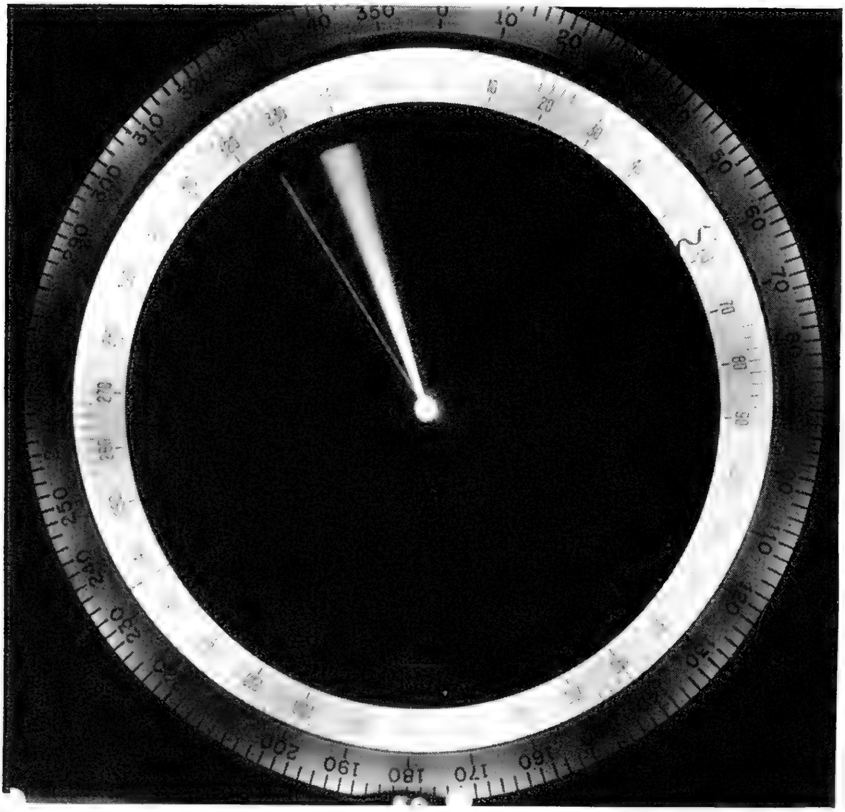


FIGURE 3-4.—PPI scope showing azimuth indication obtained from Ramark station.

adjustment by relatively untechnical personnel, and with facilities for automatic change-over to a spare equipment in event of failure of the operating one. Figure 3-5 shows an X-band (3-cm.) Ramark transmitter.

Power output requirements are extremely modest; present models radiate about 15 watts on the S-band, and ½ watt on the X-band. Even these low powers will deliver to the navigator's Radar receiver a stronger signal than the best of echoes from its own transmitter. The optimum power output for a Ramark is still somewhat problematical, but it would appear that the final choice will lie somewhere within these limits. A magnetron is used for the S-band 10-cm. RF power source while a standard reflex klystron is used for 3-cm. equipment.

In the development work to date, however, there have been certain problems. One is that of obtaining an equipment of construction sufficiently reliable to permit unattended operation. It is understandable, at this stage of progress in the microwave portion of the frequency spectrum, that this should be true. Solution of this problem would appear to lie simply in the general progress of the techniques in the microwave field. In the meantime the equipment will probably continue to require more technical supervision than might be desirable, but this should grow progressively less.

No means is provided at present for distinguishing between Ramarks, such as a coded signal characteristic. This is primarily due to the fact that only one or two stations will be operated in a given locality, and therefore these should be readily distinguishable by their relation to other objects. Should

Figure 3–5.—X-band Ramark transmitter.

the need for coded identification of a particular beacon arise, however, this can eventually be accomplished without too much difficulty.

It will be appreciated that any beacon for general use must be easily utilized by the surface navigator, and also without appreciable, and preferably no, modification of the user's navigational Radar. This precludes the adoption of any of the several existing responder-type systems which require elaborate and expensive modification or auxiliary equipment before the service may be utilized.

RACON

An example of the responder-type beacon is the RACON, which was used extensively during the war by military aircraft. Briefly, beacons of this type transmitted only when called, or interrogated, by coded pulses from the Radar of the aircraft desiring the service of the beacon. When so interrogated, the RACON would reply by sending out a set of coded pulses which would indicate its bearing on the PPI scope of the aircraft's Radar. Also, responding beacons of this type provide range as well as azimuth by permitting measurement of the elapsed time between the triggering of the beacon and the arrival of its response pulse at the aircraft.

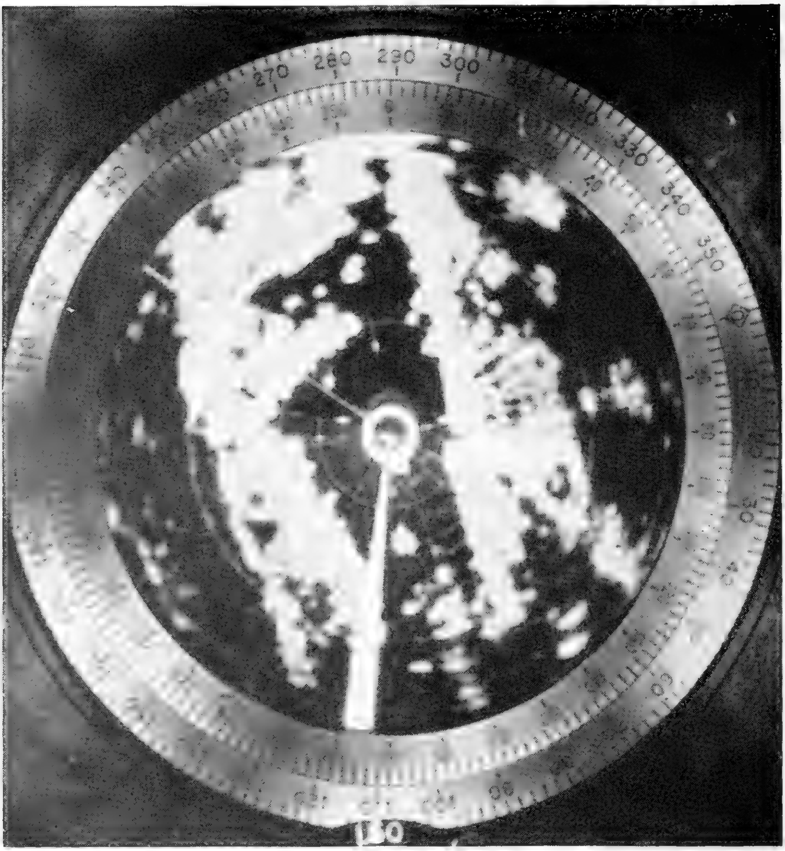


FIGURE 3–6.—Ramark beacon signal superimposed on Radar view of New London Harbor.

Not only are RACONS much more expensive than other types of beacons, but they can be used only by Radars capable of sending out the proper interrogating pulses, which increases the complexity and cost of the Radars also. With the peacetime trends toward simplicity and economy, RACON is now limited to use only by military aircraft on special routes.

MARINE RADAR

INTRODUCTION

The Coast Guard, by virtue of its close association with the maritime world in performing the functions of saving life and property at sea, and maintaining and operating aids to navigation, is especially interested in Radar for use at sea. Long before the secrets of Radar were released to the American public, its application as a safety feature on merchant ships had been realized by the Coast Guard by reason of their use and reliance on this equipment. This remarkable technological achievement, conceived long before the war but brought to practical success only by the impact of war, has become one of the most important single safety features put to use on merchant ships. As time goes by, it can be reasonably expected that Radar scopes on the bridges of ships will be as common sights as gyrocompasses.

FIGURE 4–1.—Typical Radar presentation superimposed on a navigational chart showing entrance to New York Harbor.

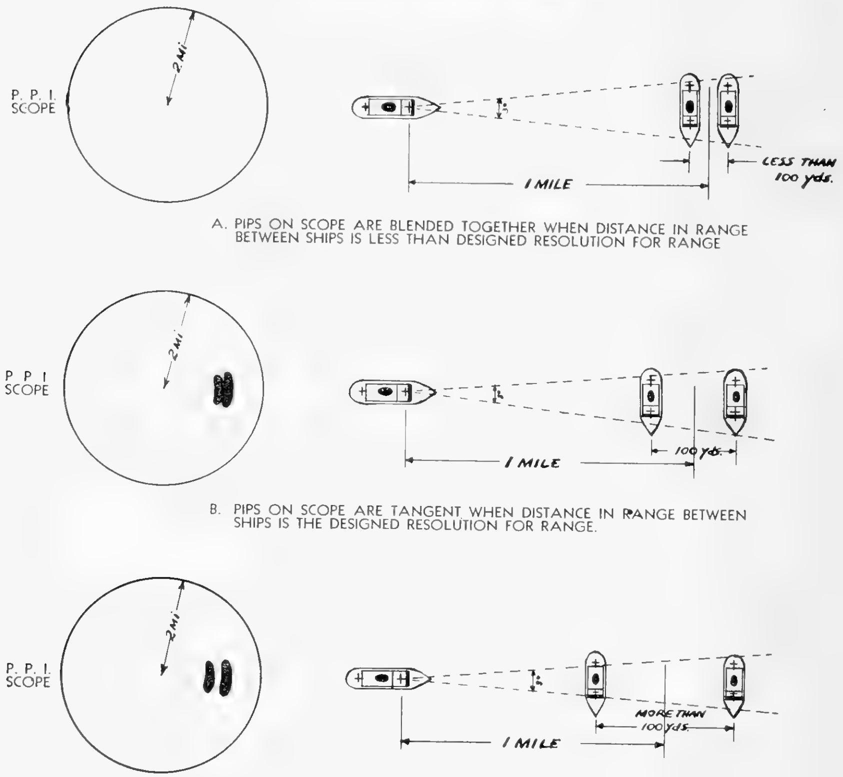
CONSIDERATIONS INVOLVED IN THE SELECTION AND INSTALLATION OF A MERCHANT MARINE RADAR

Two factors are most important in selecting a merchant marine Radar: (1) the use to be made of the equipment, (2) the installation problem encountered on the ship to be equipped. Commercial Radars have been purposely designed to be somewhat versatile and some compromises have been necessary. Due, however, to the many factors involved in the design of any Radar equipment, each type offers certain advantages. It is the purpose of the advisory specifications to outline the characteristics considered desirable for various commercial shipboard applications. The following paragraphs, therefore, are intended to point out the considerations involved in the selection and installation of a commercial-type Radar, and to indicate the reasons for some of the requirements contained in the advisory specifications.

RESOLUTION: Owing to the type of presentation on a PPI scope, resolution is divided into two components: resolution in range and resolution in bearing. Resolution in range is the ability to distinguish between two targets on the same bearing and closely spaced in range. (See fig. 4–2.)

Resolution in bearing is the ability to distinguish between two targets at the same range having slightly different bearings. (See fig. 4–3.)

RANGE RESOLUTION



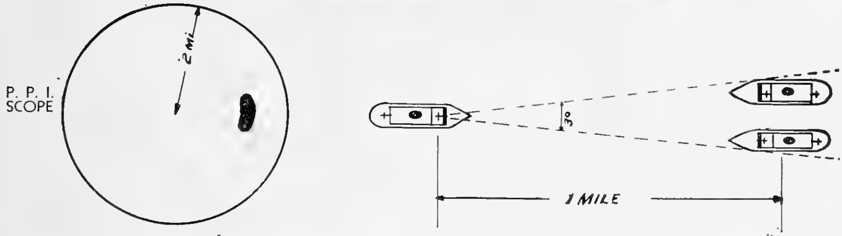
A. PIPS ON SCOPE ARE BLENDED TOGETHER WHEN DISTANCE IN RANGE BETWEEN SHIPS IS LESS THAN DESIGNED RESOLUTION FOR RANGE

B. PIPS ON SCOPE ARE TANGENT WHEN DISTANCE IN RANGE BETWEEN SHIPS IS THE DESIGNED RESOLUTION FOR RANGE.

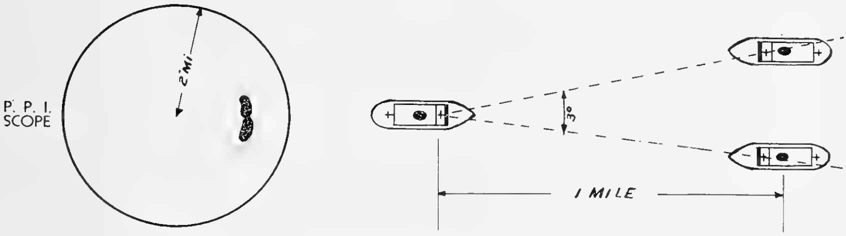
C. PIPS ON SCOPE ARE DISTINCT FOR EACH SHIP WHEN DISTANCE APART IN RANGE IS GREATER THAN DESIGNED RESOLUTION FOR RANGE.

FIGURE 4–2.—Range resolution.

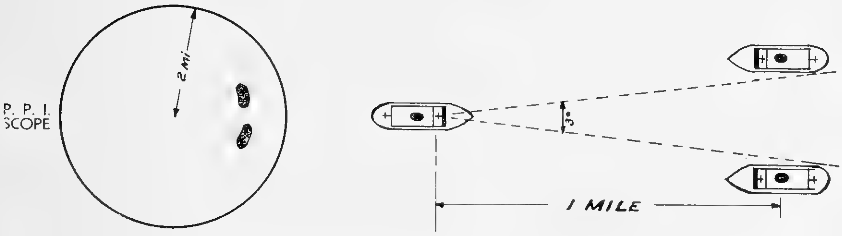
BEARING RESOLUTION



TWO TARGETS WITHIN THE BEARING RESOLUTION APPEAR AS A SINGLE PIP.



TWO TARGETS SEPARATED BY THE BEARING RESOLUTION ANGLE APPEAR AS TWO TANGENT PIPS.



TWO TARGETS SEPARATED BY MORE THAN THE BEARING RESOLUTION ANGLE APPEAR AS TWO SEPARATE PIPS.

FIGURE 4–3.—Bearing resolution.

While the result of good resolution in range and bearing is a clear, sharply defined PPI picture, giving an accurate contour of land and definite pips for small targets, a Radar of poor resolution would have a blurred and fuzzy appearance with targets blending together on the scope.

The resolution in range is a function of pulse length, pulse shape, and receiver fidelity. The returning echoes are successively amplified by each of the intermediate-frequency and video circuits of the receiver; should these circuits modify the returning echoes, poor range resolution will result. The optimum band pass of the receiver should consequently be from 1.2 to 1.5 times the reciprocal of the pulse duration in microseconds. As the pulse duration T in microseconds is equivalent to 164T in yards any targets separated by less than this value will appear as a single target.

The resolution in bearing is directly dependent on antenna beam width. For any set frequency, beam width is a function of the antenna dimensions, decreasing as the antenna dimensions increase. Fortunately, as we narrow beam width to improve resolution we increase the over-all gain of the antenna system. However, there is a practical limit of about 1° or 2° where further narrowing of the beam causes targets to be missed due to the small number of pulses that will strike it as the antenna scans the target.

Fanning or spreading of the beam in the vertical plane is desired to eliminate any necessity for mechanical stabilization of the antenna, that is, to retain energy on the surface as the ship rolls. This in turn considerably reduces the vertical dimension of the antenna. The wide beam in the vertical plane will result in some loss of azimuth resolution ahead as the ship rolls, and abeam as the ship pitches, which again brings out the futility of decreasing the horizontal beam width beyond about 1° or 2°. If the PPI is not stabilized in azimuth (true bearing presentation) there will be an appreciable decrease in bearing resolution and a smearing of the picture as the ship yaws. Another limitation, though relatively unimportant with antenna beam widths above 2°, is the consideration of how closely the PPI scan can be made to follow the antenna.

It is extremely difficult to design a reflector that will direct the radiated energy in a pencil beam. There are generally some side lobes of radiation. The lobes in the horizontal plane should be sufficiently small to be relatively unimportant as compared to the main lobe. In most cases, if these side lobes are from 25 to 35 decibels down, no difficulty will be encountered. No harm results from side lobes in the vertical plane other than wasted energy directed skyward.

In addition to the above, both range and bearing resolution will be limited to the size of the spot of light on the scope caused by the electron beam. Because of this spot, which is not pin point and is the same on all range scales, the range and range scale at which the desired resolution is expected should be stated. For example, in figures 4–2 and 4–3, the resolution is illustrated at 1 mile on the 2-mile scale.

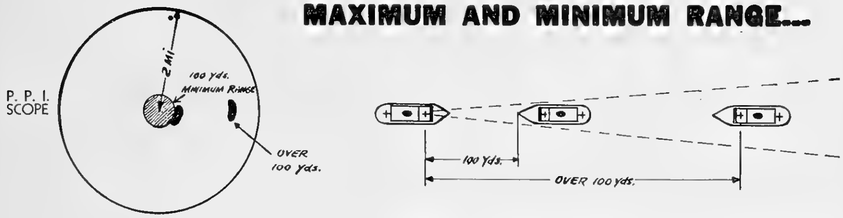
Because of the many factors entering into resolution it is generally expressed as the result to be expected providing the equipment has been designed properly for these factors.

COVERAGE.—Because of the fundamental nature of the electromagnetic waves employed in Radar the coverage of a surface Radar will be improved by increasing the antenna height. Increase in frequency will improve resolution. At the present time, however, there is a practical limit to which the frequency may be increased. The attenuation of electromagnetic waves by the atmosphere is a function of frequency and increases at an amazing rate at frequencies corresponding to wavelengths below 3 centimeters. Likewise at the higher frequencies such conditions as rain, snow, and fog, appreciably reduce coverage. Over-all consideration indicates the most desirable wavelength insofar as reliable coverage is concerned is in the area embracing 3 to 10 centimeters.

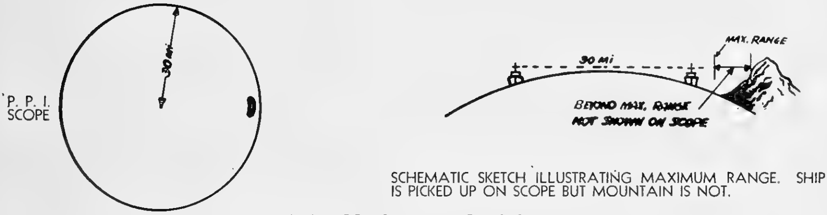
In general, a Radar is limited in coverage to about 15 percent beyond the visible horizon, and has a minimum practical range limit of approximately 100 yards. (See fig. 4–4.)

The maximum range is increased by increasing the height of the antenna and in a like manner a higher object will be observed at a greater range. It is not unusual for a good Radar to pick up objects as far away as 100 miles providing they are above the visible horizon. Atmospheric conditions play an important part in range coverage at distances greater than 10 or 15 miles. However, we are primarily interested in vessels located in the area between the minimum range of the equipment and the horizon. The subject of the vertical beamwidth has a bearing on range coverage. The beam must be sufficiently wide in the vertical to illuminate with electromagnetic energy all targets from the minimum range to the maximum in order that all ships will be indicated.

Power output has a considerable bearing on range coverage. It is well known that the reflected energy from the target to the antenna is an inverse fourth power function, increasing to a much higher power inverse function at a distance somewhat short of the horizon. Hence small increases in power do not mean much in increased efficiencies. At the same time, the realized power is considerably affected by the losses in the transmission line and antenna, the antenna gain, the receiver gain, and other factors. A large amount of power is essential to insure the indication of all above-water objects in the vicinity of the Radar. The real target illumination will also be a function of the pulse rate and speed of antenna rotation as the Radar is pulsed at the same time that the antenna rotates. Electromagnetic waves cannot pierce conducting surfaces of any practical thickness. Therefore, masts, stacks, and other obstructions will give shading effects, and objects located in the shade of these obstructions will not be indicated. The desir-



SCHEMATIC SKETCH ILLUSTRATING MINIMUM RANGE. ANY OBJECT CLOSER THAN THE MINIMUM RANGE WOULD NOT BE PICKED UP.



SCHEMATIC SKETCH ILLUSTRATING MAXIMUM RANGE. SHIP IS PICKED UP ON SCOPE BUT MOUNTAIN IS NOT.

FIGURE 4–4.—Maximum and minimum range.

able speed of antenna rotation is tied in with the cruising speed of the vessel and the retentivity of the PPI tube. One might reason that by increasing the frequency and repetition rate, more desirable coverage might be obtained with a small antenna. This, however, is not true. We cannot pulse faster than the time required for the return of echoes.

With too low a pulse repetition rate, targets will be passed over as the surrounding area is scanned, while too slow a scanning rate will not keep a continuous picture on the PPI scope because of fading of the illumination after the beam has swept by the target. Therefore, with a slow antenna rotation a low pulse repetition rate should be used and conversely, with a fast antenna rotation, a high pulse repetition rate would be needed. A compromise is consequently necessary. A speed of antenna rotation from 6 to 15 times per minute and a pulse repetition rate greater than 800 pulses per second produces the best results.

INDICATOR DISPLAYS.—On the indicator is presented all the information collected by the Radar. Although there are many ways of presenting this information the PPI is considered the most advantageous and desirable from a mariner's point of view. While the distance from the center of the scope to the outer edge represents the range from the Radar to the Radar horizon, this range may be set to suit the individual needs of the user depending upon the areas in which he will operate and possible use to the scale of the navigational charts. Generally a number of different range scales are available to be selected at will. The choice of the lowest range scale, although dependent on magnification desired for operating in confined areas, has a lower limit dependent largely on the resolution.

The size of the PPI scope will to some extent govern the range scales that should be used. The size of the scope, however, is essentially a matter of individual preference. As the Radar provides an excellent means of precisely measuring range and bearing it is believed that range and bearing knobs should be provided with precise means of determining these factors, particularly on the better type Radars. Even less expensive Radars should retain the means for precise bearing measurement, as this factor is predominant in determining whether or not two ships are on a collision course. The methods of determining range generally used are by means of a movable range ring geared to a dial or counter and by using fixed range markers (circles) to which the range of an object may be referred. Means should be provided to eliminate the range circles when not in use.

In measuring bearing, there are two methods available, the first of which is by considering the top of the scope as being in line with the bow of the ship and measuring the bearing relative to the bow of the ship. This method has distinct disadvantages: As the ship turns in one direction, the pips on the scope move in the opposite direction causing a trail to be left on the scope due to its persistence. In addition, the PPI must be closely observed during the turn or later confusion will result in the new placement of objects about the scope. In the second method of bearing indication which has won favor with the Navy, the PPI is stabilized in azimuth so that the top of the PPI is always north. A marker is then flashed when the antenna is pointed toward the bow to indicate true heading. This method enables both true and relative bearings to be determined readily, preserves the resolution of the equipment and does not have the undesirable feature of the relative bearing presentation. The picture on the scope is then similar to a chart with the addition of the movable objects. For this latter method, however, the ship must be gyrocompass-equipped.

INSTALLATION.—To meet the varying requirements for installation, commercial Radars have been broken into 2, 3, or 4 packages. One package, for example may be the indicator alone, or the indicator and receiver. The transmitter-modulator unit may be a separate package to be installed in any convenient location; or the indicator, receiver, modulator, and transmitter may be combined in a single package. The antenna is generally a separate unit, but in some cases may have the transmitter and modulator units mounted with or near it in a watertight cabinet. On direct-current ships a converter or motor generator is required which can be located where it may receive proper attention.

Locating the antenna is a special problem. While in the case of naval installations antennas were mounted on the masts, this may present difficulties on a merchant vessel due to the use of the masts to support rigging for cargo handling. It is desirable however, from the standpoint of coverage that the antenna be located as high as practicable. It is also desirable that the antenna be located so that 360° azimuth coverage is provided. A satisfactory solution in some cases has been to place the antenna on a short tower or platform mounted above the pilot house. In any event it is poor economy to pay a relatively large amount for a Radar and then limit its capabilities by failing to install the antennna in a good position.

BRIEF DESCRIPTION OF RADAR COMPONENTS

Basically Radar employs very short electromagnetic waves and utilizes the principle, that these waves can be beamed, that they travel at a definite speed in a straight line, and that they will be reflected from any discontinuity in the medium through which they are transmitted.

The typical surface Radar consists of five components: the transmitter, modulator, antenna, receiver, and indicator. In addition to these components, the power supply is an important factor to be considered in determining the actual characteristics of any Radar set. While the physical form of each of these parts may vary widely from one type to another, all Radars contain them. Figure 4–5 illustrates the arrangement of the fundamental components in a block diagram.

The transmitter consists of the radiofrequency oscillator which produces the electromagnetic waves of energy. Because of the necessity for beaming this energy, while at the same time being able to receive suitable echoes, the oscillator generates very high-frequency energy. The development of a suitable oscillator with sufficient power has been one of the major accomplishments of the Radar technicians.

In order that range may be determined accurately, electromagnetic waves are emitted in the form of pulses and each pulse is transmitted for a very short period of time, one-millionth of a second (1 microsecond) or less. After each pulse the transmitter is silent while echoes from that emitted pulse are being received. The procedure is then repeated about 1,000 times a second. The modulator, or keyer, is the unit which turns the transmitter on and off and forms these pulses.

The antenna assembly is so designed as to beam the energy at the target, normally being accomplished by the use of an antenna and reflector in much the same manner that the headlights of an automobile are directed. The echo is received back through the same antenna and directed to the receiver. The antenna must be directional and concentrate the radio energy into a well-defined beam, since this is the method by which the direction of the detected objects is determined. It must also be capable of being rotated or trained in order that the surrounding area can be properly scanned.

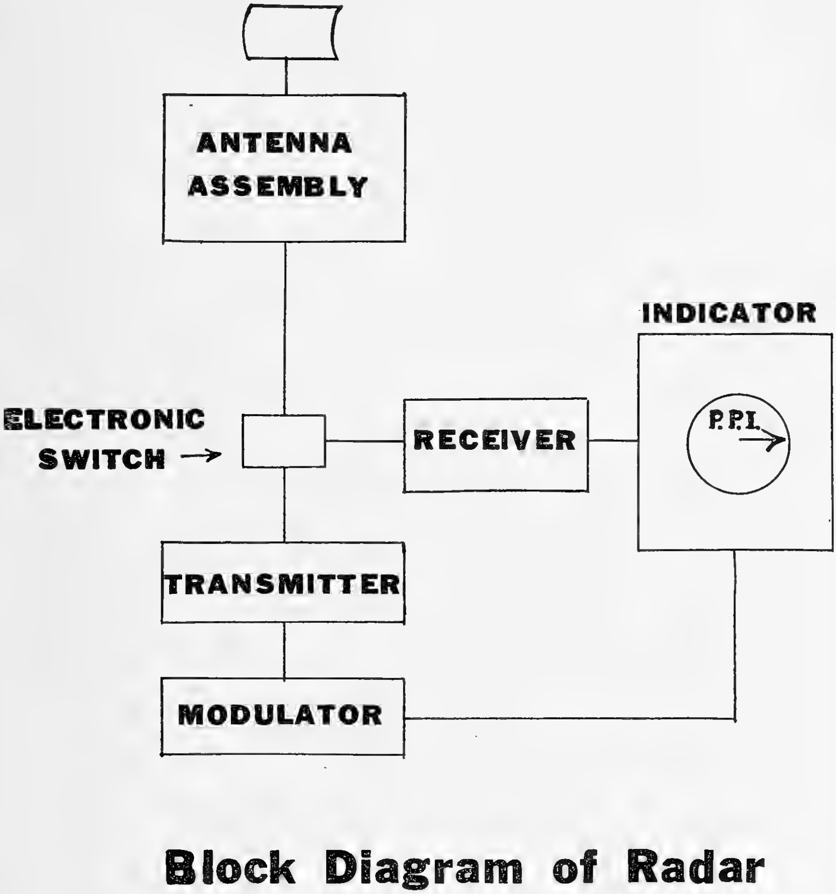


FIGURE 4–5.—Block diagram of Radar.

In the receiver, which employs the superheterodyne principle, the radio energy reflected back from the target is converted into a form that may be presented visually on an indicator or scope. Since a very small amount of power is reflected by an object the receiver must amplify it many times. Because the same antenna is used for outgoing and incoming signals a method of disconnecting the receiver from the antenna is needed during intervals when the transmitter is operating. Due to the rapid switching that is necessary, an electronic switch is used.

It is the indicator of a Radar that presents the information collected in the form best adapted to efficient use of the equipment. The indicator commonly used in navigation is the plan-position-indicator, commonly abbreviated PPI, which presents on the scope a continuous polar picture of the surrounding area.

RADAR FREQUENCY BANDS

The following bands are now provided in the United States for merchant marine Radar and associated beacon:

	Radar	*Beacon*
10-centimeter	3000–3246 MC.	3256 MC.
5-centimeter	5460–5650 MC.	5450 MC.
3-centimeter	9320–9500 MC.	9310 MC.

The 5-centimeter band has been allocated in order that the opportunity be provided to determine whether Radars operating in this band might combine many of the desirable features of those in the other two bands. Equipment operating in the 5-centimeter band is not yet generally available, and no advisory specifications have been prepared for equipment in this band.

ADVANTAGES AND LIMITATIONS OF RADAR

Radar is definitely not a "cure-all" to replace other devices and methods of navigation, but is rather a supplement to such devices and methods. The chief advantage of Radar is that it succeeds in those conditions where other methods are impossible; i. e., in fog, heavy rain, and other conditions of poor visibility. These conditions, however, do have a decided effect upon any Radar set and it is well to have an understanding of these effects in order to utilize the Radar to the fullest extent when it is most needed. An understanding of the effect of wind on Radar is also important. These and other conditions, of course, tend to impose limitations on any Radar, and are therefore discussed in some detail in the following paragraphs. The extent to which these things affect the usefulness is, of course, dependent upon the design of the particular equipment and the experience of the user, but all Radars are affected to some extent.

In the open water the effects of wind are most pronounced. The wind by itself gives no trouble but the attendant sea results in an obscuration of the Radar known as "sea return." The waves present myriads of targets for the Radar signals to detect, with the most pronounced effect being in the direction of the sea. (See fig. 4–6.)

Sea return may be visible up to 10 miles, depending upon the sea conditions and the design of the Radar set. Merchant marine Radar sets are now equipped with devices for minimizing the effect of sea return and permitting more or less normal operation of the set. While such devices are quite effective they do not wholly remove the sea clutter in bad weather. With careful conning of the ship it is usually possible to pick up large targets such as ships, before they get close enough to get into the sea return. It is also possible in most cases to properly manipulate the receiver gain control and sea return suppressor to detect ships inside the range of the sea return because a ship normally gives a larger concentrated echo than do waves. The Radar set in this condition is operating at reduced sensitivity and will, of course, miss small targets which may still be a source of potential danger to the ship.

As an example of failure to pick up a small target, a ship on a southerly course standing into a harbor with a southerly wind of 30 to 40 miles per hour, observed that the small buoys at the breakwater entrance could not be detected, regardless of how the Radar controls were manipulated. The breakwaters themselves and the shoreline, however, were easily visible, thus permitting safe navigation. The effects of wind are somewhat reduced on the Great Lakes, when compared to ocean travel, in that the ship master usually can and does lay his course to take advantage of any lee afforded by the surrounding land.

Rain, snow, sleet, and clouds are generally observed to have a somewhat similar effect on the picture observed on the scope. If the ship is in the midst of a general rain, Radar operation will probably be normal or there will be a slight haze on the screen. In the case of heavy concentrations of precipitation, usually local in nature, the actual area and location of the storm will be seen on the scope. During this time the Radar detects normally in the other areas of the scope and will probably see targets on the same azimuth as the storm but either closer to or beyond it. (See fig. 4–7.)

Present experience on the Great Lakes indicates such storms to be of relatively short duration. Radar detection of clouds, heavy precipitation, cold fronts, etc., is being exploited by meteorologists in weather predictions.

The operation of Radar in fog is usually good and can be relied upon although there may be a reduction in the range at which targets are first detected. It is reiterated, however, that all other safety precautions must be continually used by the nagivator.

It is apparent, therefore, that the navigator must always, be particularly vigilant during periods of inclement weather, and must use more care in operating the Radar and in studying and using the data obtained from it.

FIGURE 4-6.—PPI picture showing sea return when no anticlutter or sea return suppression devices are in use (special 3 cm. Radar).

Other factors which more or less impose limitations on Radar are tabulated and briefly discussed below:

(1) Objects cannot be readily identified unless additional electronic devices (Radar aids) are used in conjunction with the Radar itself. Identification, however, can quite often be accomplished by implication such as movement, relation to other objects, shape (coastline), and sometimes initial range of detection.

(2) Radar chart presentation on the scope requires interpretation due to line-of-sight characteristics which give shadow effects. In other words, larger intervening objects may blank out objects behind them.

(3) Radar can be used reliably for only slightly over line-of-sight distance.

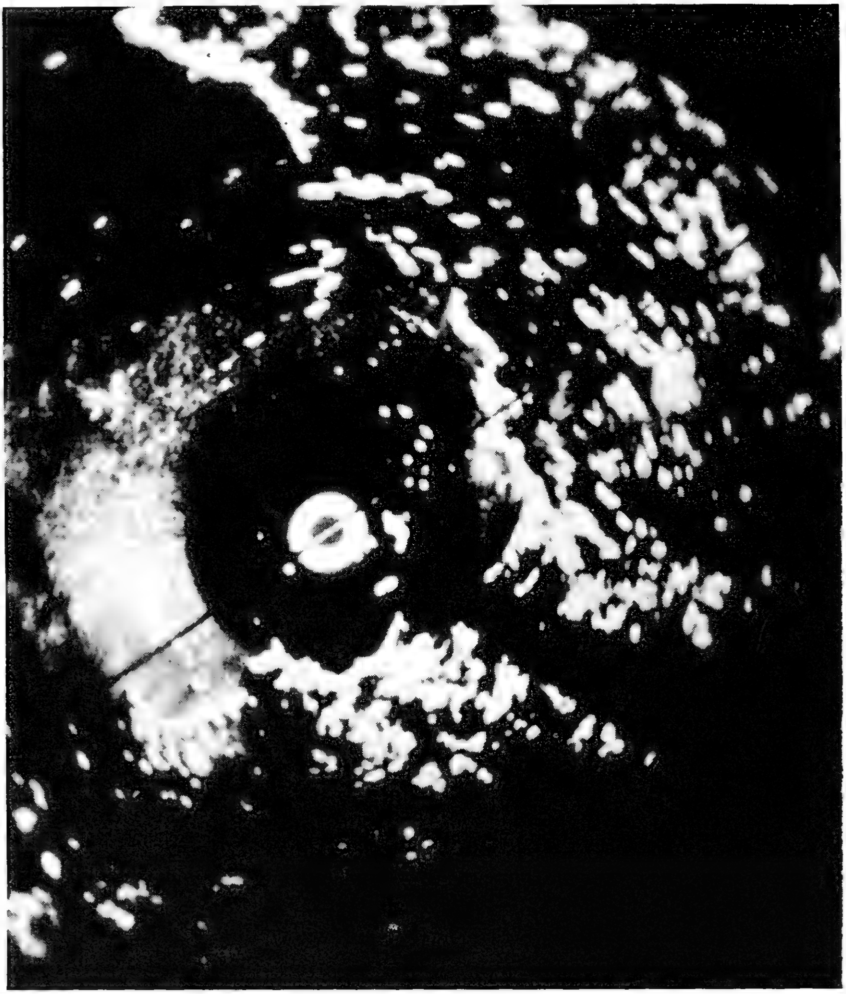


FIGURE 4–7.—PPI picture showing portion of sea area (left-hand portion of picture) obscured by a heavy rain squall which is local in nature (special 3 cm. Radar).

(4) Certain types of objects, because of their characteristics or motion, may go undetected. For example, the Coast Guard's study of Radar detection of floating ice has revealed that while icebergs can ordinarily be observed, pieces of ice large enough to damage a ship may go undetected. Ice and some other things, therefore, due to physical characteristics and reflecting properties, are relatively poor targets. A low-lying point of land is another example of a relatively poor target. The motion of small objects, such as small buoys and boats, caused by bobbing up and down in a seaway tends to reduce the echo returned to the Radar. These considerations become particularly important when such things as sea return and rain, are present to reduce the Radar visibility.

While Radar has limitations, its advantages more than compensate for these limitations. The distinct operational advantages are summarized below:

(1) It is the best anticollision device yet perfected.
(2) It makes for greater safety while piloting or making landfalls during periods of low visibility.

FIGURE 4–8.—Typical marine Radar equipment produced by United States manufacturers.

(3) It indicates continuously instantaneous ranges and bearings of objects.

(4) It presents a chartlike picture of the surroundings, the presentation being in the nature of a polar chart with PPI presentation.

(5) By observation of the scope, movement of objects may be noticed.

STUDY OF RADAR BY THE UNITED STATES COAST GUARD

As the war progressed and the existence of Radar became known publicly, the Coast Guard was approached by commercial ship operators with requests as to how Radar could be used for commercial navigation. While the information could not be released under wartime restrictions, the need for such a study was realized and an extensive program to collect data was undertaken. The United States Coast Guard cutter *Mackinaw* was Radar-equipped specifically for study of conditions on the Great Lakes. Additional ships and planes were equipped and specialized personnel assigned for a study of conditions on the Grand Banks during the 1945 Ice Patrol. Various harbor craft were equipped and studies on the employment of Radar in harbors were made. To coordinate activities a Radar study group whose sole purpose was to disseminate existing information and accumulate new data was established at Coast Guard Headquarters in the early part of 1945. The employment of

Radar as a collision-prevention device and as an aid to navigation was evident immediately.

The Coast Guard has determined a set of recommended minimum specifications for Radar installation aboard merchant vessels that has served as a mutual starting point and impetus for future study and development of this equipment to further ensure the safety of lives and property at sea. Realizing its possible use in conjunction with other electronic aids to navigation, the Coast Guard felt that favorable consideration should be given to arriving at uniformity of design and standardization and that every effort should be made to provide simplicity of operation with optimum performance. The problem, however, is broad in its scope because of the varying operational requirements of the ship operators and the expense involved.

In carrying on this work consideration was given to the experience and knowledge gained during the war, to the employment of a merchant marine Radar with present and contemplated navigational aids, and to the possible future effect that such installations would have on the revision of present navigational laws and possible reduction of insurance rates. As a result, three sets of minimum specifications were prepared by the Coast Guard, with the cooperation and assistance of the Navy Department and Radiation Laboratory. The specifications were submitted at a conference of Radar manufacturers and representatives of the maritime industry as a basis of discussion. As a result of this meeting a new and more complete set of recommended specifications was issued.

Nothing in the revised specifications is to be considered as a limitation upon the number of improvements or innovations which may become desirable as the art of microwave detection and navigation is developed. As in the past, the Coast Guard will revise these suggested specifications to reflect additional knowledge acquired through investigations of new equipment, contact with engineering representatives of manufacturers, contact with shipping interests and conferences with developmental agencies and interested nations. The specifications are purely recommendatory in nature and have no administrative statutory relationships to other merchant vessel equipment required by the Coast Guard. They are promulgated in the public interest and serve only to further that interest.

The Advisory Minimum Specification Briefs are to be found in the appendix.

APPENDIX A

HISTORICAL OUTLINE OF RADIOBEACON, LORAN SYSTEMS AND RADAR

The sea or coast may be blanketed in fog, visibility may be reduced to zero due to rain or snow, sound warnings may be completely drowned out by storm, and yet, in this day of available navigational aid systems, the navigator may obtain with confidence positional information or actually fix his position through the medium of electronics.

For over 2,000 years there have been lighthouses to guide ships, and for more than 200 years there have been sound fog warnings of some sort to aid the mariner in thick weather, but until the introduction of electronic navigational aids he did not have a practicable method of taking accurate bearings on invisible objects. Electronics has supplied this most urgent need of navigation by allowing the navigator to locate his vessel without depending on visual methods.

Today the navigator may take bearings on established marine radiobeacon stations which provide reliable service from 10 to over 200 nautical miles and may by the use of Loran fix his position, when in the service area of the stations, up to 1,400 nautical miles offshore. The present day electronic navigational aid systems contribute greatly to the safety and operational efficiency of transportation whether it be on or over the high seas or in coastal or lake waters.

MARINE RADIOBEACONS [1]

United States marine radiobeacons were first placed in regular operation in May 1921, when three installations were placed in commission in the vicinity of New York Harbor on Ambrose Channel Lightship, Fire Island Lightship, and at Sea Girt Light Station. The system has expanded from the original three installations in 1921 to 186 United States radiobeacons in 1949.

The present United States marine radiobeacon system includes installations on the Great Lakes, along the coasts of the United States, its territories and at outlying bases. The most northerly and westerly radiobeacon in the United States system is on St. Paul Island, Alaska, in the Bering Sea; the radiobeacon at Point Tuna, P. R., is situated farthest east; and the installation at Cape Mala, C. Z., is most southerly.

LORAN SYSTEM [2]

The Loran system has its roots directly in the vast program of development in the field of electronics which has been unfolded with dramatic import during World War II.

With the outbreak of hostilities in Europe in the latter part of 1939, the probability of our ultimate military involvement became apparent. We were thoroughly unprepared to meet the demands of a new and rapidly changing technology of modern warfare, and no mechanism existed for the mobilization of civilian scientific resources to meet wartime technical problems.

The first step to remedy this situation was taken in June 1940, when President Roosevelt appointed the National Defense Research Committee to mobilize our great scientific resources for research and development of weapons of war.

In June 1941, the Office of Scientific Research and Development was established by an Executive order of the President. This group was vested

[1] The word "radiobeacon" was coined by an official of the former U. S. Lighthouse Service (now U. S. Coast Guard) and is now generally listed in dictionaries.

[2] The word "Loran" was coined by a Coast Guard officer and was officially adopted by the U. S. Navy in 1942.

with the responsibility of coordinating the activities of the National Defense Research Committee with those of the Committee on Medical Research and of assuming general responsibility for the over-all coordination of the country's industrial technical program.

The Loran program was an outgrowth of a special division of the National Defense Research Committee working with the armed services. The initial techniques were closely allied to those of Radar. When the Navy began to work closely with National Defense Research Committee it was recognized that an accurate and reliable long distance navigational aid would be invaluable to insure coordination and control in carrying out a myriad of military operations both offensive and defensive. It was of prime importance to minimize losses of ships, aircraft, and the crews aboard as the result of enemy action. Culminating a following period of intensive research and laboratory investigation, Loran was born.

The early beginnings were in 1941 at the Radiation Laboratory of the Massachusetts Institute of Technology and by the end of 1942, the first of the Loran transmitting stations which were later to lace the world with electronic lines of position were placed in experimental operation. These first units were set up in the North Atlantic area by the United States Navy in cooperation with the National Defense Research Committee, the Royal Canadian Navy and the United States Coast Guard, and later were taken over in their entirety by the United States Coast Guard and the Canadian Navy. Coast Guard officers and men were actively associated with the project from its earliest applications to the war effort.

The dramatic growth of the operating Loran system was intimately connected with the progress of military and naval operations against the enemy. During the bitter cold of midwinter of 1942 and the hazards of the Battle of the Atlantic the North Atlantic Loran chain was established to serve our men and ships.

Likewise, activity of the Japanese in the Aleutian Campaign led to the establishment of the Aleutian Loran chain in the latter part of 1942 and the spring of 1943. These installations were made in the face of very severe weather and were located at strategic points in treacherous terrain. The landing of men and equipment and the ensuing construction program proved to be an exceptionally hazardous operation.

These early Loran installations proved to be well worth their cost in effort, sweat and dollars—because, by virtue of these achievements, navigators aboard naval craft sailing the northern routes were given "electronic eyes" to combat the intensely bad weather and other hazards of the sea at a critical time of the war, when uncertainty of position at sea would in all probability spell disaster at the hands of the enemy.

As the war against the Japanese was pursued with increasing vigor and our forces began their long and successful offensive, Loran took its rightful place in these military developments. Joint planning of the attack by Army and Navy commands emphasized the need for adequate means of long range navigation to protect our supply ships and to aid our fleet and aircraft operations. As a consequence, Loran "system building" became a program of ever-increasing tempo.

In rapid succession Loran stations were placed in operation in the many island chains of the Pacific; Hawaii, the Phoenix, Caroline, Marshall, and Admiralty groups—were covered, and thus Loran lines of position were extended over many millions of square miles of the Pacific. All of these installations were made by the United States Coast Guard and some others on the outer fringes of the combat areas were made by other military services.

In the fall of 1945, a joint release was made to the public by the United States and its allies of the secrets of Radar and Loran, so that the public transportation services could henceforth make use of these developments.

In December of 1945, Science Service named "Development and use of Loran which allows determination of exact positions at sea and in the air through use of exactly timed radio signals" as one of the Ten Most Important Advances in Science Made During 1945. The same lists contains the "atomic bomb" and explains that "some of these developments were actually made before 1945 but on account of war secrecy were not announced before."

Although Loran had its inception and growth as a product of technological warfare, the extensive "system building" program of wartime leaves a valuable heritage to the art of peacetime navigation in that, today, a nearly world-wide Loran system is an operating actuality.

RADAR [3]

The basic principle of Radar is not a difficult one. In 1886 it was proved that radio waves are reflected from solid objects. In 1904, a German engineer was granted a patent in several countries on a proposed way of using this property as an obstacle detector and a navigational aid for ships. A discovery which led to the actual development of Radar was made in 1922 by two scientists working at the Naval Aircraft Radio Laboratory, Anacostia, Md. Testing plane-to-ground communications, they noticed that ships moving in the Potomac River distorted the pattern of radio waves, causing a fluctuating signal. From this discovery, development was pursued almost continually after that until 1935, when Congress provided a $100,000 appropriation to the Naval Research Laboratory for the development of Radar. A rather crude Radar was tested successfully in 1937 aboard the U. S. S. *Leary*, and a greatly improved one was given extensive sea trials on the U. S. S. *New York* in 1939. Before that, experimental work conducted from the ground employed a variety of ships and aircraft and the dirigible *Akron*.

Probably no scientific or industrial development in the history of the world has so expanded in all phases simultaneously, and on such a scale. Research, development, production design, actual production, field trials, training of thousands of operators and installers—all of these had to go on at the same time, and they did. Most significant of all, the use of Radar with the armies and the air forces in the field, and the ships at sea, was so widespread that nearly every responsible commanding officer had to be educated to an appreciation of the capabilities and the limitations of the new equipment through the trial and error of combat operations. Further, they had to communicate the experience and knowledge thus gained to all other field commanders. All this was made more difficult by the necessity of maintaining the strict secrecy which must surround a new and important development.

The development of Radar moved so rapidly through the last years before the war and the early years of the war itself that only the Radar specialist had any real knowledge of its behavior and its capabilities. Yet the immediate demands of war made it necessary to expand suddenly and tremendously in all directions at once.

During the war only the armed forces employed Radar. For this reason, and because of its close connection with the maritime industry, the Coast Guard prior to the end of hostilities commenced a study of Radar for peacetime employment.

As the war progressed and the existence of Radar became known publicly, the Coast Guard was approached by commercial ship operators with requests as to how Radar could be used for commercial navigation. While the information could not be released under wartime restrictions, the need for such a study, was realized and an extensive program to collect data was undertaken. The United States Coast Guard cutter *Mackinaw* was radar-equipped especially for study of conditions on the Great Lakes. Additional ships and planes were equipped and specialized personnel assigned for a study of conditions on the Grand Banks during the 1945 Ice Patrol. Various harbor craft were equipped and studies on the employment of Radar in harbors were made. To coordinate activities a Radar study group whose sole purpose was to disseminate existing information and accumulate new data was established at Coast Guard Headquarters in the early part of 1945. These activities culminated finally in the public release of Radar information simulanteously with the releases on Loran and the publication of advisory specifications for Merchant Marine Radar equipment.

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[3] The word Radar was coined by a U. S. Navy officer and officially adopted by the U. S. Navy in 1941.

APPENDIX B

ADVISORY MINIMUM SPECIFICATIONS FOR MARINE RADAR EQUIPMENT

Advisory minimum specification Brief No. 1 (3-centimeter Radar)
Advisory minimum specification Brief No. 1 (10-centimeter Radar)
Advisory minimum specification Brief No. 2 (Search Radar)
Advisory minimum specification Brief No. 3 (Anti-Collision Radar)

The minimum Radar, Loran and radio direction-finder equipment advisory specifications constituting this appendix are to serve only as a guide, for voluntary use by mariners, airmen and manufacturers interested in electronic navigational aid equipment.

It is inescapable that the user's electronic equipment must be coordinated in design with the electronic navigational aids system, whether it be Loran, radiobeacon or Radar-beacon aids.

It is hoped that publication of the specifications will be of some value to both the producer and user of electronic navigational equipment to the end that the best possible use of the available navigational aid systems and equipment is realized.

ADVISORY MINIMUM SPECIFICATIONS FOR MARINE RADAR EQUIPMENT

Advisory Minimum Specification Brief No. 1 (3-centimeter Radar)

I. Designation.—

Surface search and navigational Radar.

II. General Description.—

This is to be a 3-centimeter surface search Radar, primarily designed for ocean-going vessels to provide early warning of approaching vessels and navigational dangers on the open seas as well as high resolution for navigation in restricted waters.

III. Operational Requirements.—

Designed for operation by bridge personnel with little or no technical training. The operation of this equipment must not cause interference with other aids to navigation or to communication equipment on board and should be adequately shielded to prevent interference to the Radar from other electronic apparatus normally carried. The indicator unit shall not cause appreciable error in a magnetic compass when located more than 6 feet from the indicator nor shall other components cause error when located a distance of more than 15 feet. Mechanical noise from the indicator shall not be audible for more than 20 feet in still air.

IV. Performance.—

Range:
- Maximum—30 miles.
- Minimum—100 yards.

Resolution:
- A properly designed Radar with pulse length and antenna beam width as elsewhere prescribed in this specification brief should give a range resolution of 100 yards and a bearing resolution of 2° on the shortest sweep scale.

V. Indication and Output Data.—

Indicator:
- At least 7-inch PPI Scope (plan-position-indicator). Sweep linearity shall not deviate more than ±2 percent except that the first and last 10 percent of the sweep may deviate by ±5 percent.

Range scales:
- Capable of being set as desired by purchaser within the following limits: 2–5 miles; 4–15 miles; 15–30 miles; a positive range scale indicator is to be provided.

Range indicator:

A variable range marker with a range of 500 yards to 30 miles, accuracy ±2 percent or ±50 yards, whichever is greater, or a direct reading range indicator.

Bearing indication:

Stabilized PPI presentation (true bearing display), bearing cursor; ship's head indicator; variable azimuth illumination.

VI. Performance Indicator.—

Positive means should be provided to indicate whether or not the over-all operation of the Radar is such that it may be relied upon to provide effective anticollision and navigational information.

VII. Antenna.—

Truncated parabola or equivalent.

Beam width:

Horizontal—2° maximum at half-power points.

Vertical—Such as to prevent the transmitted beam from leaving a target on the horizon during a roll of +7½°. To accomplish this the antenna may be stabilized or have a vertical beam width of 15° at half-power points.

Mounting:

Navy Standard Flange (16½ inch bolting circle with eight 13/16-inch holes equally spaced, two opposite holes on center line).

Rotation:

Continuous, 360° in azimuth, speed of rotation 6 to 15 revolutions per minute with the specified transmitter and modulator characteristics. In the event a higher speed of rotation is desired, peak power and other characteristics of the modulator and transmitter should be raised sufficiently to compensate for a decreased return due to fewer "hits" per revolution of the antenna. Control on main on-off switch. Antenna reversing switch may be provided for sector scan.

Side lobes:

At least 25 decibels down.

VIII. Transmitter.—

Frequency recommended—3 centimeter band, 9320 to 9430.

Radio frequency source—Magnetron.

Modulator—Hydrogenthyratron, hard or soft tube, or equivalent.

Main transmission line—the over-all attenuation from the radio frequency source to the radiator must not be more than 3 decibels one way.

Peak power—15 kilowatts minimum.

Pulse repetition rate—Minimum 800 cycles per second.

Pulse length—0.5 microsecond maximum.

Trigger—Positive 10 to 50 volts (across high impedance).

IX. Receiver.—

IF, RF, and video band pass—Optimum for pulse length chosen.

Over-all gain—120 decibels minimum.

Video output—2.5 volts ±0.5 volts (across 75 ohms).

Over-all noise above KT△—15 decibels maximum.

Features:

Automatic frequency control; fast time constant; sensitivity time control or equivalent circuits to minimize interference from sea return and adverse meteorological conditions.

X. Power Requirements.—

The equipment shall be designed to take power from a source of 115 volts, 60 cycles per second, single phase with a regulation of ±10 volts and ±2 cycles per second. In the case of direct-current equipped ships and ships with poor regulation, auxiliary power equipment will be necessary.

XI. Operator Controls.—

On-off switch (all power).

Bearing cursor knob.

Range marker knob.

Continuous gain control.

Limited intensity control; focus to be essentially independent of intensity.

Range selector (positive range scale indicator).

STC, FTC selector switch for varying degrees of any or all (sea return and interference suppressor).

Azimuth scale light control.
Antenna-reversing switch (optional).
Safety devices shall be incorporated to make it impossible for the operator to damage the equipment by manipulation of the controls.

XII. Construction Features.—

Replaceable units with chassis type assembly.
Fuse alarms.
Mounting tropicalizing and weather proofing shall be suitable for intended installation.

XIII. Installation Features.—

The antenna assembly must be so mounted as to provide 360° clearance to the horizon. The indicator is to be mounted in the pilot house. To facilitate this arrangement on all types of vessels it is suggested that the radio frequency components, the antenna assembly, and the indicator be manufactured in separate units.

XIV. Special Provisions for Future Modifications.—

As contemplated, 3-centimeter Radar beacon objectives will meet 3-centimeter commercial Radar design objectives on the common ground that the Radar will be able to transmit within the frequency limits and with peak radiated powers as specified herein, and further that it will be capable, as constructed or with minor modifications, of receiving beacon signals on 9310 megacycles.

XV. Optional Features.—

Remote PPI's with controls independent of the indicator controls, for installation in the chartroom, commanding officer's quarters, etc., have obvious uses on certain classes of vessels. Such remote PPI's may have a means for comparison with navigational charts and/or giving an expanded presentation of a selected area of the PPI.

An "hours run" meter to facilitate the replacement within the required period of components which deteriorate with age.

XVI. Remarks.—

Standard Navy flange for antenna mounting, standard video output and standard trigger output are specified to facilitate ease of conversion for military use.

The phrase "or equivalent" is applicable to all the above items. As Radar is still in a progressive stage, these specifications are intended merely as a mutual, voluntary starting point. It is reiterated that nothing in these specifications should be construed as limiting development and improvement of Radar circuits or equipments extant.

Advisory Minimum Specifications Brief No. 1 (10-centimeter Radar)

I. Designation.—

Surface search and navigational Radar.

II. General Description—

This is to be a 10-centimeter surface search Radar, primarily designed for ocean-going vessels to provide early warning of approaching vessels and navigational dangers on the open seas as well as good resolution for navigation in restricted waters.

III. Operational Requirements—

Designed for operation by bridge personnel with little or no technical training. The operation of this equipment must not cause interference with other aids to navigation or to communication equipment on board and should be adequately shielded to prevent interference to the Radar from other electronic apparatus normally carried. The indicator unit shall not cause appreciable error in a magnetic compass when located more than 6 feet from the indicator nor shall other components cause error when located at a distance of more than 15 feet. Mechanical noise from the indicator shall not be audible for more than 20 feet in still air.

IV. Performance—

Range:
  Maximum—30 miles.
  Minimum—100 yards.

Resolution:

A properly designed Radar with pulse length and antenna beam width as elsewhere prescribed in this specification brief should give a range resolution of 100 yards and a bearing resolution of 4° on the shortest sweep scale.

V. Indication and Output Data—

Indicator:

At least 7 inch PPI scope (plan position indicator).

Sweep linearity shall not deviate more than ±2 percent except that the first and last 10 percent of the sweep may deviate by ±5 percent.

Range scales:

Capable of being set as desired by purchaser within the following limits: 2–5 miles; 4–15 miles; 15–30 miles; a positive range scale indicator is to be provided.

Range indicator:

A variable range marker with a range of 500 yards to 30 miles, accuracy ±2 percent or ±50 yards whichever is greater or a direct reading range indicator.

Bearing indication:

Stabilized PPI presentation (true bearing display), bearing cursor; ship's head indicator; variable azimuth illumination.

VI. Performance Indicator—

Positive means should be provided to indicate whether or not the over-all operation of the Radar is such that it may be relied upon to provide effective anticollision and navigational information.

VII. Antenna—

Truncated parabola or equivalent.

Beam width:

Horizontal—4° at half power points.

Vertical—Such as to prevent the transmitted beam from leaving a target on the horizon during a roll of ±7½%. To accomplish this the antenna may be stabilized or have a vertical beam width of 15° at half power points.

Mounting:

Navy standard flange (16½ inch bolting circle with eight 13/16 inch holes equally spaced, two opposite holes on center line).

Rotation:

Continuous, 360° in azimuth, speed of rotation 6 to 15 revolutions per minute; control on main on-off switch. Antenna reversing switch may be provided to sector scan.

Side lobes:

At least 25 decibels down.

VIII. Transmitter—

Frequency recommended—10-centimeter band, 3000 to 3246 megacycles (see par. XIV).

Radio frequency source—Magnetron.

Modulator—Hydrogenthyratron, hard or soft tube, or equivalent.

Main transmission line—the over-all attenuation from the radio frequency source to the radiator must not be more than 1.5 decibels one way.

Peak power—15 kilowatt minimum.

Pulse repetition rate—Minimum 800 cycles per second.

Pulse length—0.5 microsecond maximum.

Trigger—positive 10 to 50 volts (across high impedance).

IX. Receiver—

IF, RF, and video band pass—Optimum for pulse length chosen.

Over-all gain—120 decibels minimum.

Video output—2.5 volts ±0.5 volt (across 75 ohms).

Over-all noise above $KT\Delta f$—15 decibels maximum.

Features:

Automatic frequency control; fast time constant; sensitivity time control or equivalent circuits to give the operator optional control over interference from sea return and adverse meteorological conditions.

X. Power Requirements—

The equipment shall be designed to take power from a source of 115 volts, 60 cycles per second, single phase with a regulation of ±10 volts ±2 cycles per second. In the case of direct-current equipped ships and ships with poor regulation, auxiliary power equipment will be necessary.

XI. Operator Controls—

On-off switch (all power).
Bearing cursor knob.
Range marker knob.
Continuous gain control.
Limited intensity control; focus to be essentially independent of intensity.
Range selector (positive range scale indicator).
STC, FTC selector switch for varying degrees of any or all (sea return and interference suppressor.
Azimuth scale light control.
Antenna-reversing switch (optional).
Safety devices shall be incorporated to make it impossible for the operator to damage the equipment by manipulation of the controls.

XII. Construction Features—

Replacable units with chassis type assembly.
Fuse alarms.
Mounting, tropicalizing and weatherproofing shall be suitable for intended installation.

XIII. Installation Features—

The antenna assembly must be so mounted as to provide 360° clearance to the horizon. The indicator is to be mounted in the pilot house. It is suggested that the radio frequency components, the antenna assembly and the indicator be manufactured in separate units.

XIV. Special Provisions for Future Modifications—

As contemplated, 10 centimeter Radar beacon objectives will meet 10 centimeter commercial Radar design objectives on the common ground that the Radar will be able to transmit within the frequency limits and with peak radiated powers as specified herein, and further that it will be capable, as constructed or with minor modifications, of receiving beacon signals on 3256 megacycles. Beacon operation will be improved if the operating frequency of the Radar is in that portion of the Radar band as close as practicable to the beacon frequency.

XV. Optional Features—

Remote PPI's, with controls independent of the indicator controls, for installation in the chartroom, commanding officer's quarters, etc., have obvious uses on certain classes of vessels. Such remote PPI's may have a means for comparison with navigational charts and/or giving an expanded presentation of a selected area of the PPI.

An "hours run" meter to facilitate the replacement within the required period of components which deteriorate with age.

XVI. Remarks—

Standard Navy flange for antenna mounting, standard video output and standard trigger output are specified to facilitate ease of conversion for military use.

The phrase "or equivalent" is applicable to all the above items. As Radar is still in a progressive stage, these specifications are intended merely as a mutual, voluntary starting point. It is reiterated that nothing in these specifications should be construed to limit development and improvement of Radar circuits or equipments extant.

Advisory Minimum Specification Brief No. 2 (Surface Search and Navigational Radar)

I. Designation—

Surface search and navigational Radar.

II. General Description—

This is to be a 3- or 10-centimeter surface search Radar primarily designed for ocean-going vessels to provide early warning of approaching vessels and navigational dangers on the open seas as well as fair resolution for navigation in restricted waters.

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III. Operational Requirements—

Designed for operation by bridge personnel with little or no technical training in scope interpretation. The operation of this equipment must not cause interference to or be affected by other navigational and electronic equipment normally carried aboard ship.

IV. Performance—

Range:
- Maximum—30 miles.
- Minimum—400 yards.

Resolution:
- A properly designed Radar with pulse length and antenna beam widths as elsewhere prescribed herein should give a range resolution of 200 yards and bearing resolution of 6° on the shortest sweep scale.

V. Indication and Data Output—

Indicator:
- At least 7 inches PPI (plan position indicator) scope.
  - Sweep linearity shall not deviate more than ±3 percent except that the first and last 10 percent of the sweep may deviate by ±7 percent.

Range scales:
- Variable 2–5 miles; 4–15 miles; 15–30 miles; positive range scale indication is to be provided.

Range indication:
- Fixed electronic range markers; accuracy of ±2 percent or ±100 yards, whichever is greater; not more than five range circles appearing on the scope.

Bearing indication:
- True or relative bearing indication with bearing cursor; over-all absolute bearing accuracy from antenna to display ±30.

Positive means should be provided to indicate whether or not the over-all operation of the radar is such that it may be relied on to provide effective anticollision and navigational information.

VI. Antenna—

Truncated parabola or equivalent.

Beam Width:
- Horizontal—5° maximum to half power points.
- Vertical—15° minimum (7.5° either side of horizontal) to the one-half power points.

Mounting:
- Navy standard flange 16½ inch bolting circle with eight 13/16 inch holes equally spaced, two opposite holes on center line.

Polarization:
- Horizontal or vertical.

Rotation:
- Continuous, 360° in azimuth, speed of rotation 6 to 15 revolutions per minute; control on main on-off switch.
- Antenna reversing switch, may be provided to sector scan.

Sidelobes:
- 20 decibels down.

VII. Transmitter—

IF, RF, and video band pass—Optimum for pulse length chosen.
Frequency recommended—3000 to 3246 or 9320 to 9500 megacycles.
Radio frequency source—Magnetron.
Modulator—Hydrogenthyratron, hard or soft tube, or equivalent.
Main transmission line—the over-all attenuation from the radio frequency source to the radiator must not be more than 1½ decibels one way on the 10-centimeter band nor more than 3 decibels one way on the 3-centimeter band.
Peak power—15 kilowatts on 3-centimeter band and 7 kilowatts on 10 centimeter with the above transmission line attenuation limits.
Pulse repetition rate—minimum of 800 pulses per second.
Pulse length—1 microsecond maximum.
Trigger—Positive 10 to 50 volts (across high impedance).

VIII. Receiver—

Over-all gain—120 decibels.
Video output—2.5 volts ±0.5 volt (across 75 ohms).

Over-all noise above KTΔf—15 decibels maximum.

Features—

Automatic frequency control or equivalent. Fast time constant and sensivity time control equivalent.

IX. Power Supply—

The equipment should be designed to take power from a source of 115 volts, 60 cycles per second, single phase with a regulation of ± 10 volts ± 2 cycles per second. In the case of direct-current equipped ships and ships with poor regulation, auxiliary power equipment will be necessary.

X. Operator Controls—

On-off switch (all power).
Bearing cursor knob.
Range marker intensity knob.
Continuous gain control.
Limited intensity control; focus to be essentially independent of intensity.
Range selector (positive range scale indicator).
STC and FTC selector switch for varying degrees. (Sea return suppressor).
Azimuth scale light control.
Antenna-reversing switch (optional).

XI. Construction Features—

Replacable units with chassis type assembly.
Fuse alarms.
Mounting, tropicalization, and weatherproofing shall be suitable for intended installation.

XII. Installation Features—

The antenna assembly must be so mounted as to provide 360° clearance to the horizon. The indicator is to be mounted in the pilot house. To facilitate this arrangement on all types of vessels it is suggested that the radio frequency components, the antenna assembly, and the indicator be manufactured in separate units.

XIII. Special Provisions for Future Modifications—

The Radar should be capable as constructed or with minor modification of receiving Radar beacon signals on 3256 megacycles for a 10-centimeter Radar or on 9310 megacycles for a 3-centimeter Radar. Beacon operation will be improved if the operating frequency of the Radar is in that portion of the Radar band as close as practicable to the beacon frequency.

XIV. Remarks—

Standard Navy flange for antenna mounting, standard video output and standard trigger output are specified to facilitate ease of conversion for military use.

The phrase "or equivalent" is applicable to all the above items. As Radar is still in a progressive stage, these specifications are intended merely as a mutual voluntary starting point. In using these specifications the constant improvement and development of Radar should be contemplated and kept in mind.

Advisory Minimum Specification Brief No. 3 (Anti-Collision Radar)

I. Designation—

Anticollision Radar.

II. General Description—

This is to be a surface search Radar primarily designed as an anticollision device with a limited value for navigational purposes.

III. Operational Requirements—

Designed for operation by pilot house personnel with little or no technical training but with specialized operational training in the interpretation of equipment data. The operation of this equipment must not cause interference to or be affected by other navigational and electronic equipment normally carried aboard ship.

IV. Performance—

Range maximum:

Equipment must be capable of absolute indication of the presence of a C2 type cargo vessel or equivalent at a distance of 7 miles.

Minimum—500 yards.

Accuracy—±5 percent or ±500 yards whichever is greater.

Bearing:

Equipment must be capable of giving an over-all bearing accuracy of ±5° using as a target a C2 cargo vessel or equivalent at a distance of 7 miles.

V. Indication and Output Data—

Indicator:

5 inch scope or larger; PPI (plan position indicator) preferred.

Range:

Electrical or mechanical to meet requirements of paragraph IV.

Bearing:

Mechanical dial or equivalent.

Positive means should be provided to indicate whether or not the over-all operation of the Radar is such that it may be relied on to provide effective anticollision and navigational information.

VI. Frequency—

Any channel authorized for use of commercial Radar.

VII. Antenna—

A motor-driven train is to be provided, with arrangements for shifting to manual train for bearing determination. Minimum speed of rotation, 5 revolutions per minute. In case an A scope is used, it is to be understood that it must be continuously manned by trained personnel if the anticollision features are to be realized. Should a PPI scope be used, the provision for hand train may be eliminated and the speed of the rotation may be increased to 15 revolutions per minute. The beam width in the vertical plane must be at least 20°.

ADVISORY MINIMUM SPECIFICATIONS FOR MARINE LORAN RECEIVER-INDICATOR EQUIPMENT

General.—These minimum advisory specifications are intended for the use of mariners interested in Loran receiving equipment for all types of vessels.

Application of Equipment.—The equipment herein specified shall be capable of furnishing accurate navigational information when used aboard vessels in Loran service coverage areas. It must be capable of being operated and accurate readings taken by persons having had limited training in its use.

Major Items of Equipment.—The entire equipment normally shall consist of the three component parts listed below:

(*a*) Receiver.
(*b*) Indicator.
(*c*) Power supply. If a separate power unit is provided, it is necessary that the connecting cable not contain high current leads which would limit the length of cable to a specific value.

The first two components should be included in a single package. A separate power supply is optional.

Physical Limitations.—For larger type vessels the equipment may be table, bulkhead, or deck mounted. For smaller craft the equipment should be as light and small as practicable, table or shelf mounting is recommended. The equipment should be rugged and designed in accordance with standard practice for electronic equipment for shipboard installation.

Receiver circuit.—Wideband superheterodyne capable of handling a 40 microsecond pulse width minimum distortion.

Frequency Range.—1800–2000 kc.; 2 switch-selected channels having discrete frequencies of 1950 and 1850 kc. The channels shall be marked: 1–1950, 2–1850. At least one spare RF channel shall be provided for 1900 kc.

Radio Frequency Tuning Stability.—The over-all radio frequency tuning stability shall be such that the center of the pass band will not deviate more than plus or minus 5 kc. from the channel frequency over the range of temperature and humidity specified.

Heterodyne Oscillator.—For each discrete frequency the frequency drift of the oscillator shall not exceed plus or minus 1 kc. over specified ranges of supply voltage, ambient temperature and relative humidity.

Bandwidth.—45 kc. over-all plus or minus 5 kc. at 6 db down and not more than 180 kc. over-all at 60 db down on all radio frequency channels.

Over-all Sensitivity.—Deflection on scope—1 inch for 3-inch tube, or 1½ inches for 5-inch tube for receiver input of 8 microvolts peak or less. Ratio of signal to internally generated noise—at least 3/1. At least 10 db additional gain to be provided, irrespective of signal/noise ratio.

Signal Amplitude Balance Ratio.—Continuously variable from 1/1 to 1000/1.

Maximum Signal Input Voltage.—Ten volts peak input to receiver terminals. A switched fixed attenuator may be employed in order to obtain the required range of gain.

Interfering Frequencies.—(*a*) As measured at the receiver terminal, interfering signals shall exceed the desired signal to provide equal and standard outputs by at least the following values:

Intermediate frequency	70 db
Image frequency	75 db

(*b*) At other frequencies, interfering signals shall be attenuated according to the below selectivity curve:

Total bandwidth	*db*
45 (plus or minus 5 kc)	6
90 minimum	20
130	40
180	60
250	80

Pulse Repetition Rates.—Basic 20 (S), 25 (L), and 33⅓ (H) pulses per second. Associated with each basic rate are to be eight specific rates of which the basic rate is one. The seven other specific rates are to be obtained by reducing the recurrence interval in steps of 100 microseconds. The specific rates are to be labeled "0" to "7", starting with the one having the longest interval (the basic rate). Example—Basic rate 25:

Rate	*Cycles*	*Microseconds*
0	25	40,000
1	25 1/16	39,900
2	25⅛	39,800
3	25 3/16	39,700

Time Difference Measuring Ranges.—Overlap the following limiting values:

For basic rate:	*Microseconds*
20	500 to 17,000
25	500 to 15,000
33⅓	500 to 11,000

Time-Difference Accuracy.—With signals of equal strength over a temperature range of —15° to +50° C. the accuracy of the time-difference measurement shall be within plus or minus 1 microsecond. With a signal input up to 10 volts (peak) and signals differing in strength as much as 1,000 to 1, the time-difference reading shall not vary more than 1 microsecond from the reading with equal signals.

Time Difference Presentation.—Direct reading by mechanical numerical meter. The mechanical electrical coupling between the meter and time delay circuits must be stable and simple to adjust for accurate prealignment.

Cathode Ray Oscilloscope.—Three inch or larger screen.

Timer Oscillator.—The timer oscillator shall have sufficient short-time stability to permit satisfactory use of the receiver indicator. Frequency variation for temperature excursion of —15° to plus 50° C. and variation in relative humidity of 15 to 95 percent shall not exceed 500 parts per million; and for correction of such variation a control whose range slightly exceeds the amount of variation shall be provided.

Framing (Left-Right) Switch.—The framing switch for positioning the received pulses on the indicator CRT screen shall provide suitable drift.

If fixed drift speeds are employed a satisfactory speed for the slow sweep is that equivalent to twice the difference beween two specific recurrence rates (4,000, 5,000, and 6,666⅔ microseconds corresponding to 20, 25, and 33⅓ pulses per second), while a drift speed of the order of 100 microseconds per second is suitable for the faster sweep speeds.

Pulse Height and Saturation.—The standard pulse height for the pulse matching operation (fast sweep) shall be approximately 1½ inches for a 5-inch CRT screen and approximately 1 inch on a 3-inch CRT screen. It is desirable that sufficient additional output shall be available from the video-amplifier to show a small degree of amplifier saturation on the screen on fast sweep.

Horizontal Sweep.—The horizontal sweep shall be reasonably linear. The approximate time lengths shall be as follows:

Slow sweep	½ recurrence rate period.
Intermediate sweep	1,000 to 1,500 microseconds.
Fast sweep	120 to 200 microseconds.

Power Supply.—Power-input for 50/60 cycles, 115 volts plus or minus 10 percent, consumption not to exceed 400 watts.

NOTE.—Aircraft Loran receiving equipment should meet the minimum requirements specified for marine Loran receiving equipment. The aircraft gear differs in package size, weight, and power supply. It is important that such equipment be designed in accordance with standard practice for electronic equipment intended for aircraft installation.

ADVISORY MINIMUM SPECIFICATIONS FOR MANUAL RADIO DIRECTION FINDER EQUIPMENT; TYPE I

The intent of this minimum specification is to serve as a general guide for use by mariners interested in marine radio direction finding equipment for navigational purposes when used on radiobeacons and on vessels where space availability is no serious problem and radio operator personnel are available for utilization of the direction finder for distress work.

The instrument covered by these specifications shall, in general, consist of the following:

(*a*) Loop antenna, suitably supported.
(*b*) Quadrantal error compensator.
(*c*) Directional indicating device.
(*d*) Receiver.
(*e*) Sense determining device.

Loop.—The loop should be ruggedly constructed and provided with means for rigid mounting. If the entire loop structure is a rotating device, it should be arranged for complete and continuous rotation about its vertical axis in such a manner that there is no observable lost motion between the loop and the indicator. The loop drive should function with precision and smoothness, and should be properly shielded and balanced electrically.

The loop should be designed for low wind resistance and should be easily rotated in a strong gale.

Indicator.—The scale or indicating device should include an azimuth scale (360°) which may or may not be used in conjunction with a gyro repeater. In any event the scale or indicating device shall be such that divisions can be read accurately to a portion of 1° of circular arc.

The quadrantal error compensator shall be capable of correcting plus or minus 15° of error.

Collector ring and brush assemblies, if used, shall be low-loss, designed to minimize noise and corrosion. Such assemblies are normally located in the indicator housing.

Cabinet.—Cabinet design should follow standard practice for shipboard electronic equipment. Provision should be made to prevent accumulation of moisture due to condensation or leakage.

Receiver circuit.—Tuned radio frequency or superheterodyne capable of CW and MCW reception.

Frequency.—275–515 kc. This frequency range will permit the reception of radiobeacon signals in the marine radiobeacon band (285–325 kc.) and on the international distress frequency (500 kc.). Dial calibrations should be direct reading in kilocycles.

Over-all Sensitivity.—The complete unit including loop assembly should be capable of developing an output of 6 milliwatts, with not more than 60 microwatts noise output when the loop is rotated for maximum signal in a ground wave field strength of 50 microvolts per meter.

Directional Sensitivity.—The directional sensitivity should be such that when a vertically polarized signal of sufficient intensity is received to induce 1 microvolt into the loop, and the receiver is adjusted to deliver an output of 6 milliwatts at optimum loop setting, the absolute null should be not more than 3° in width, this measurement to be made under conditions wherein any noise originating external to the receiver and picked up by the loop and sense antenna shall not be of sufficient magnitude to obscure the null.

Null Quality.—With a CW field of 50 microvolts per meter the null zones shall be diametrically opposite within 2°. It shall not be possible to shift the nulls by improper tuning or any normal manipulation of the controls. The minima should be crisp, well defined and entirely free of residual signal throughout the 360° rotation of the loop about its vertical axis.

Directional Sense.—Provisions shall be incorporated which will definitely permit the elimination of any ambiguity between the actual and reciprocal bearing.

Selectivity.—The ratio of over-all receiver and loop sensitivity at resonance, to sensitivity to signals off resonant frequency should be at least the following:

Ratio	*Percent frequency difference*
10	1
100	2
1,000	4

Image Frequency.—All image frequency response should be at least 60 db below the desired signal within the frequency range of the receiver.

Audio Output Power.—At least 6 milliwats across a 600- or 20,000-ohm load.

Output Impedance.—600 or 20,000 ohms at 1,000 cycles.

Installation.—Radio direction finder equipment should preferably be installed in a position easily accessible to the ship's navigator. Inasmuch as direction finder bearings are affected by objects in the path of approaching signals, consideration must be given to the location of the direction finder loop antenna. This antenna should not be located behind or near large metal objects such as vessel stacks, superstructure, trunks, etc. In most vessels the choice of loop antenna location will be a compromise, due to necessity. The ideal location aboard any vessel would be one where the loop antenna is well clear of all objects, permitting maximum use and accuracy of the direction finder equipment. An indicating device should be installed at radio operating positions to indicate when DF is in use. An interlock device to prevent radio operation during DF use may be desirable.

Power Requirements.—Inasmuch as marine direction finding equipment is used in connection with distress work, it is important that the equipment be available for immediate use at all times. It is therefore recommended the equipment be designed principally for battery operation. Provisions should be made for automatically recharging the batteries by rectifier, trickle charge, floating the battery across the d-c supply source, etc. The battery containers, charging equipment, etc. should be considered as part of the direction finder equipment. In event the equipment is designed with a self-contained a-c power supply, provisions for bypassing the rectifier and introducing necessary d-c potentials should be made by providing an easily accessible arrangement for emergency operation.

ADVISORY MINIMUM SPECIFICATIONS FOR MANUAL RADIO DIRECTION FINDER EQUIPMENT; TYPE II

General.—The intent of this minimum specification is to serve as a general guide for use by parties interested in marine direction finding equipment for small craft where personnel, space, and initial cost are important factors.

Loop.—The loop should be small, watertight, arranged for either inside or outside mounting, and be capable of being completely rotated around its vertical axis.

Indicator.—The indicator should be as simple as practicable and still give accurate bearing information. The device should be capable of being read to within 1° of circular arc. No mechanical compensation is required. Provisions should be made to provide a calibration card located readily available to the operator.

Receiver Circuits.—Tuned radio frequency or superhetrodyne capable of CW or MCW reception.

Frequency.—275 to 340 kc.

Over-all Sensitivity.—The complete unit including loop assembly should be capable of developing an output of 6 milliwatts, with not more than 60 microwatts noise output, when the loop is rotated for maximum signal in a ground wave field strength of 50 microvolts per meter.

Cabinet.—The cabinet size should be kept small, be spray-proof, and designed in accordance with standard practice for shipboard electronic equipment.

Power Requirements.—The equipment should be designed principally for battery operation, with the use of converter equipment at the option of the user desiring to use it on other power supplies.

ADVISORY MINIMUM SPECIFICATIONS FOR AUTOMATIC RADIO DIRECTION FINDER EQUIPMENT

NOTE.—Because exact engineering and operational requirements for marine automatic direction finding equipment are not available, the United States Coast Guard is not prepared to publish an advisory minimum specification for such equipment at this time. Practical and efficient marine ADF equipment has been developed for military use. When commercial automatic direction finder equipment is developed for the maritime industry, or when firm requirements for the equipment are established, advisory minimum specifications will be published.

The United States Coast Guard has converted and is operating for ADF and manual direction finding equipment use 16 marine radiobeacon stations. These stations provide continuous carrier toned keyed (CW signal emitted when station MCW identification characteristic not being transmitted) service.

GLOSSARY

FOR

ELECTRONIC NAVIGATIONAL AIDS

[Some of the most frequently used terms in discussing electronic aids or systems]

STANDARD LORAN SYSTEM.—A long-range system of navigation by radio providing accurate lines of position or fixes at sea by pulse time-difference measurement.

LORAN STATION.—A radio transmitting station radiating timed or synchronized pulse signals used in the Loran system.

STATION CIRCLE.—The great circle on the earth's surface passing through two synchronized transmitters.

BASELINE.—The segment of a station circle between the transmitters.

BASELINE EXTENSION.—The portion of the station circle not contained in the baseline.

LORAN HYPERBOLA.—A line on the earth's surface along which all points have a constant difference in their distances from two transmitters.

LINE OF POSITION.—A segment of an hyperbola.

CENTER LINE.—The hyperbola which is the great circle perpendicular to the baseline.

TIME DIFFERENCE.—The time interval between the arrivals of any two synchronized pulses. This value is read directly on the Loran receiver-indicator installed in the vessel or aircraft.

LORAN CHARTS.—Loran navigational charts published by the Hydrographic Office, Coast and Geodetic Survey, and the Aeronautical Chart Survey, USAF, for use aboard ships and aircraft.

LORAN TABLES.—Loran tables provide coordinate information from which Loran charts are constructed. The tables may also be used instead of the charts for Loran navigation.

RECURRENCE RATE.—The rate at which pulses are transmitted.

PULSE LENGTH.—The length of the pulse wave form expressed in microseconds, as measured at one-half peak amplitude.

SKY WAVE CORRECTION.—The amount of time to be added or subtracted from the indicated time difference to reduce a sky wave observation to the corresponding observation for the ground wave "line of position." Amount of correction required is indicated on the Loran chart.

RADIO DIRECTION-FINDING.—A radiolocation in which only the direction of a station is determined.

RADIOBEACON STATION.—A radionavigation station the emissions of which are intended to enable a mobile station to determine its bearing or its direction in relation to the radiobeacon station.

MARINE RADIOBEACON.—A radiobeacon station whose service is intended primarily for the benefit of ships.

SIGNAL TIMER.—A mechanical device controlled by clocks and used to control and program characteristics of radiobeacons.

WARNING DEVICE.—A device which warns the radiobeacon operator of beacon malfunction when the condition persists for more than 2 minutes.

RACON.—A radionavigation system transmitting, in response to a predetermined received signal, a pulsed radio signal with specific characteristics which provides bearing and distance data.

RAMARK.—A radionavigational system transmitting signals continuously which may be received by Radar. Provides bearing information only (experimental).

RADAR.—A radiolocation system where transmission and reception are carried out at the same location, and which utilizes the reflecting or retransmitting properties of objects in order to determine their positions.

"A" INDICATOR.—An indicator on which a time sweep produces a horizontal range scale on which echo signals appear as vertical deflections (also called "A" scan and "A" scope).

ANTENNA.—A conductor or a system of conductors for radiating or receiving radio waves.

AZIMUTH.—Angular position or bearing in a horizontal plane measured from 0° to 360°, relative or true north, to the target in a clockwise direction.

AZIMUTH-STABILIZED PPI.—A PPI presentation in which 12 o'clock on the tube face is made always to represent true north, irrespective of the heading of the vessel carrying the indicator. The stabilization is effected by introducing syncro voltages from the gyrocompass into the servo system that drives the PPI coils.

SWEEP BASE LINE.—The horizontal (or vertical) line formed by the movement of the sweep on a cathode-ray tube. Sweep usually used.

RADAR BEARING.—The direction of the line of sight from Radar antenna to target. Azimuth angle of train.

BEARING CURSOR.—Mechanical bearing line on PPI for reading target bearing.

BLIND ZONES.—Areas in which echoes cannot be received.

CALIBRATION MARKERS.—Indications on the screen of a Radar indicator which divide the range scale into accurately known intervals for range determination, or checking against mechanical indicating dials, scales, or counters.

RADAR CORNER REFLECTOR.—A device made in the form of three planes mutually perpendicular—as the three sides of a cube that meet at a corner. It is effective in returning a strong Radar echo.

RADAR ECHO.—The signal reflected by a distant target to a Radar set. Also the deflection or indication on the screen of a cathode-ray tube representing a target.

FACE.—The front or viewing surface of a cathode-ray tube. The inner surface of the face is coated with a material which gives off light under the impact of a stream of electrons.

GROUND CLUTTER.—Radar echoes reflected from terrain, which obscure relatively large areas of the Radar indicator.

HOOD.—A shield placed over the scope to eliminate extraneous light and thus make the image on the screen appear clearly.

INTERFERENCE.—Confusing signals accidentally produced on a radar indicator by the effects of electrical apparatus or machinery, or by atmospheric phenomena.

MARKER.—Electronic range or bearing indication on Radar indicator.

MICROSECOND.—One-millionth of one second.

PIP.—The figure presented on the oscilloscope of a Radar caused by the echo from an aircraft or other reflecting object.

PPI (PLAN POSITION INDICATOR).—An indicator on which echoes appear as bright arcs. The sweep moves radially from the center of the tube face, and the sweep line rotates synchronously with the antenna. Thus, the radial distance at which the echo appears is an indication of range, and the angular distance measured clockwise from 12 o'clock is an indication of bearing.

PPI REPEATER.—Unit which repeats PPI indication at a location remote from the Radar console.

PULSE DURATION.—The elapsed time between the start and finish of a single pulse.

PULSE REPETITION RATE (PRR).—The number of pulses transmitted per second. Pulse repetition frequency (PRF).

RADAR INDICATOR.—A unit of Radar equipment which provides a visual indication of the reflected energy received, using cathode-ray tube or tubes for such indication.

The Radar indicator comprises, besides the cathode-ray tube, the sweep and calibration circuit and associated power supplies.

RADAR RECEIVER.—An instrument which amplifies radio frequency signals, demodulates the r-f carrier, further amplifies the desired signal and delivers it to the indicator. It differs from the usual radio receiver in that it is designed to pass a pulse type of signal.

RADAR TRANSMITTER.—A unit of Radar equipment in which the radio-frequency power is generated and keyed. Corresponds to radio transmitter in communications.

RADOME.—A general name for Radar turrets which enclose antenna assemblies.

RANGE SELECTOR.—Control for selection of range scale.

RESOLUTION.—1. *Range.*—The minimum range difference between two targets on the same bearing that will allow the operator to obtain data on either target.

2. *Bearing.*—The minimum angular separation between two targets at the same range that will allow the operator to obtain data on either target.

3. *Elevation.*—The minimum angular separation between two targets at the same range and bearing that will allow the operator to obtain data on either target.

SEA RETURN.—The indication on a Radar indicator caused by radio waves being reflected by the surface of the sea.

SHIP HEADING MARKER (SHM).—An electronic radial sweep line on PPI indicating heading of own ship.

SWEEP CIRCUIT.—A circuit which produces at regular intervals an approximately linear, circular, or other form of movement of the beam of the cathode-ray tube.

TARGET.—Any object which will reflect a sufficient amount of signal to be evident at the search set.