LORAC

A RADIOLOCATION SYSTEM HAVING LONG RANGE ACCURACY

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GENERAL.

LORAC is a radiolocation system which enables an accurate determination of position to be made at long and short ranges. The system has been named "LORAC", taken from the words LOng RAnge ACcuracy.

Conventional surveying and electronic war-born aids have proved inefficient and inaccurate in long distance off-shore surveying operations in connection with geophysical work. As a result of their inadequacy, LORAC was developed to provide a system with distance limitations governed primarily by the ground-wave coverage of the transmitters. There are no limitations upon the number of users participating in the operation, since receivers only are utilized at the recording positions.

The LORAC radiolocation system operates on long or medium wavelengths. These waves follow the curvature of the earth and therefore the mobile receiving units can be below the horizon — out of the "line of sight". The frequency channels required are extremely narrow and need not be selected in a harmonic or other definite frequency relation. Two independent unrelated frequency channels are all that are required for a complete "fix" of position.

SYSTEM OPERATION SUMMARY.

The LORAC system consists basically of four radio transmitters. The radiations from these transmitters form two hyperbolic interference patterns which are used as a coordinate system. A special radio receiver transforms these interference patterns into two dial readings, and these dial readings in turn give a direct determination of the position of the receiver in the coordinate system. Position is determined by reading the two dials and finding the intersection of two corresponding lines on a chart which has been specially prepared for this purpose (see Fig. 2).

BASIC LORAC PRINCIPLE.

The basic principle employed in the LORAC system is essentially that of measuring the phase difference of the radio waves received from two continuous-wave transmitters. The radiations from these transmitters produce a hyperbolic interference pattern, the transmitters being at the foci of the hyperbolas. Constant phase difference exists along any hyperbola.

If a phase meter, capable of indicating phase difference, were moved along one of these hyperbolas, no change of indication would take place. However, if the phase meter were moved across the hyperbolic lines, a change in its reading would take place. A phase change of 360 degrees is referred to as a *lane*, the latter having a width of one-half wavelength along the straight line joining the transmitters. The number of lanes crossed is read on a counter mechanism which is an integral part of the phase meter.

Position with respect to the hyperbolic lines is thus obtained but, in order to obtain a "fix", additional information must be supplied. Accordingly, the transmitters are duplicated and the second pair is placed so that its hyperbolas will intersect those of the first pair, thus forming a grid. Reading a second phase meter, to determine the phase difference of the waves received from this latter pair, enables a position fix to be made. The two dial readings thus give a position determination in a hyperbolic coordinate system. The latter is prepared as an overlay chart on a geographic map.

The basic principle is illustrated by considering installations at two separated fixed shore positions and one mobile ship installation, as shown in Fig. 3. At shore position 2, a continuous-wave transmitter T_2 emits a signal at frequency f_2. This signal

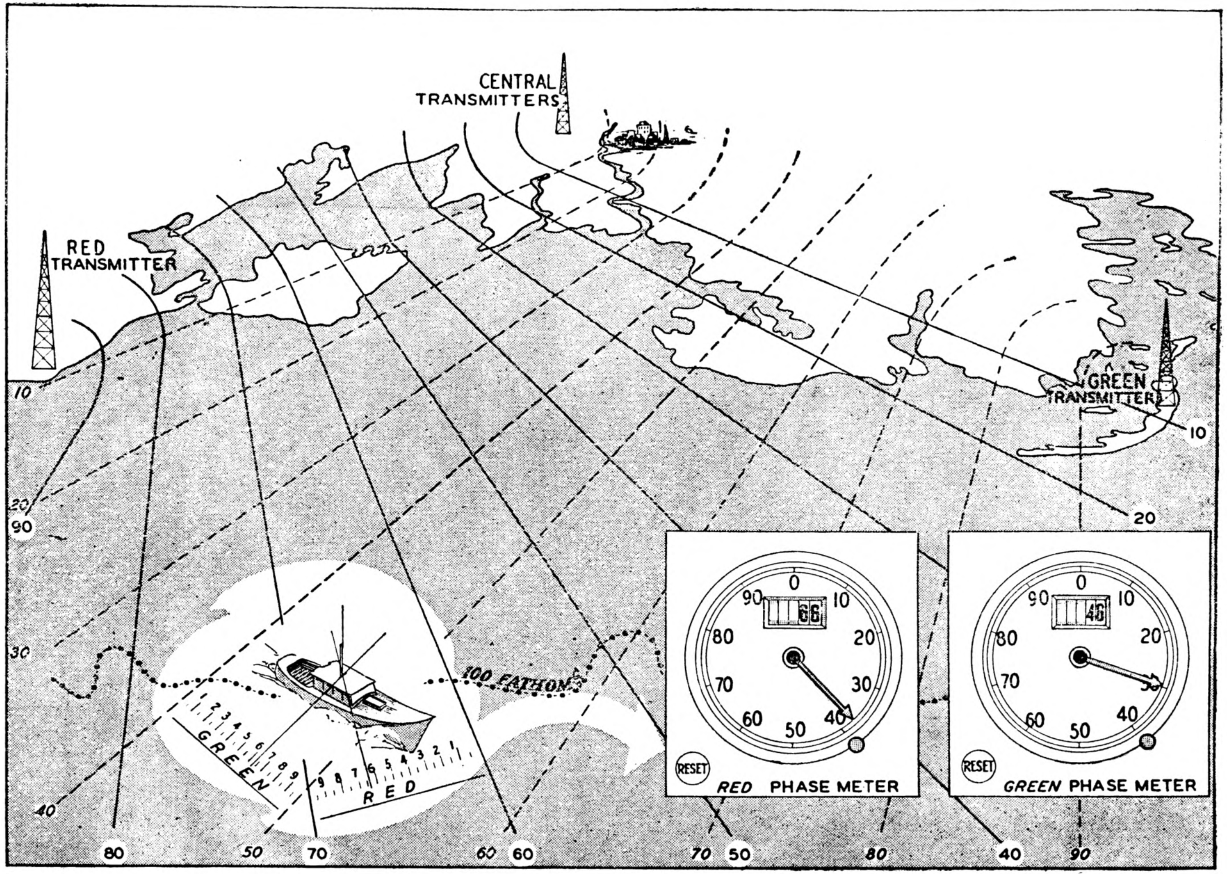

FIG. 1

General Principle of LORAC Radiolocation System. "Fix" is obtained from the Red and Green phase meter readings. "Red" dial reads 66.38 lanes. "Green" dial reads 46.30 lanes. Observer reads dials and finds intersection of lines on map corresponding to the dial readings.

is received at shore position 1 by receiver R_1 and at the ship by receiver R_b. At the same time a continuous-wave transmitter T_1 at shore position 1 emits a signal at frequency f_1, which differs from frequency f_2 by an audio frequency. This signal from transmitter T_1 is received by receiver R_1 at the same position and by receiver R_b on the

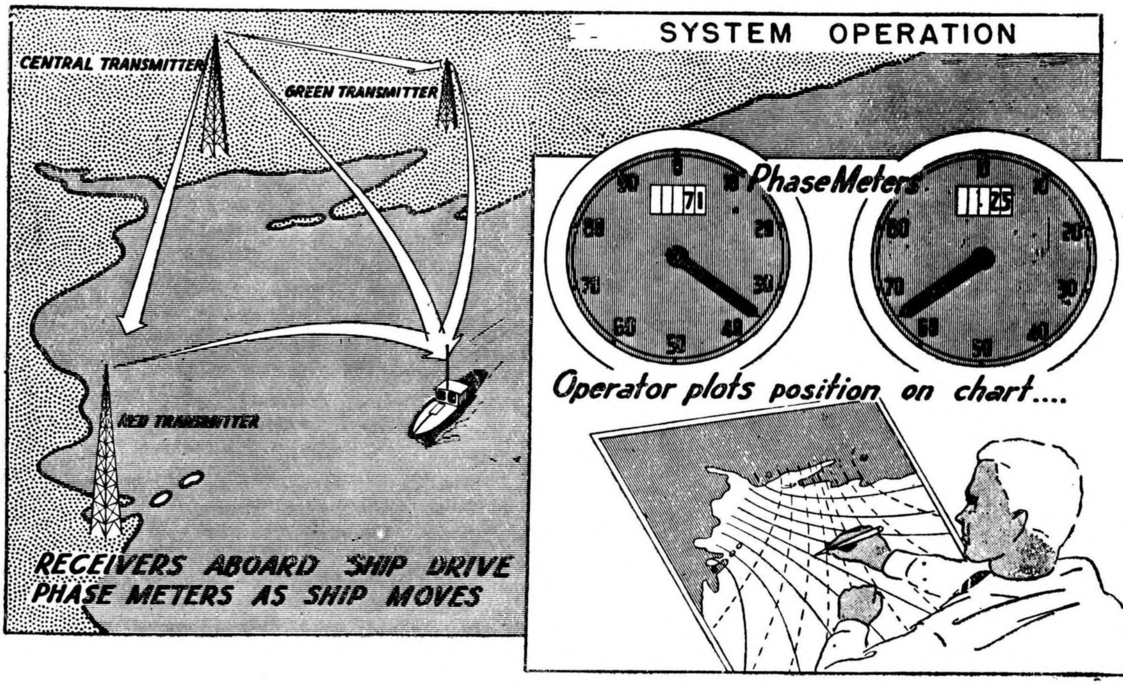

FIG. 2 — *System Operation.*

Ship position is obtained by indirect measurement of the time required for radio waves to travel from land stations.

ship. The two signals received at receiver R_1 heterodyne to produce an audio beat frequency $(f_1 - f_2)$ which is used to modulate a reference transmitter T_L located at shore position 1. Transmitter T_L, operating at a frequency f_L and modulated by $(f_1 - f_2)$, is used as a means of transferring the beat note of receiver R_1 from the shore position 1 to the ship. On the ship, receiver R_L is used to demodulate the signal and obtain the beat frequency. Meanwhile, receiver R_b on the ship has been receiving the signals from transmitters T_1 and T_2 and has been heterodyning them to produce the beat frequency $(f_1 - f_2)$.

Each of the two beat frequencies arrives at the ship with a phase value governed by the difference in the distances the original carriers have traveled before reaching the heterodyning receivers to form the beat notes. At the receiver R_1, the waves from transmitters T_1 and T_2 heterodyne and the resultant beat note $(f_1 - f_2)$ has a phase value dependent on the relative distances the carriers have traveled before heterodyning. Since the positions of the antennas of T_1, T_2 and R_1 are not changed, the phase of the beat note does not change. The beat note is transferred to the ship by means of the reference transmitter T_L, with a phase value which for all practical purposes is constant. Because of this constant phase value, it is called the "reference beat note". At the receiver R_b on board ship, the beat note $(f_1 - f_2)$ received directly from the transmitters T_1 and T_2 also has a phase value which is dependent on the relative distances between each of the shore transmitting antennas and the ship receiving antenna.

If the ship is stationary, the $(f_1 - f_2)$ beat note at the beat receiver R_b will maintain a constant phase value. A phase meter, connected to measure the phase relationship of the two beat notes, will show a reading but the reading will not

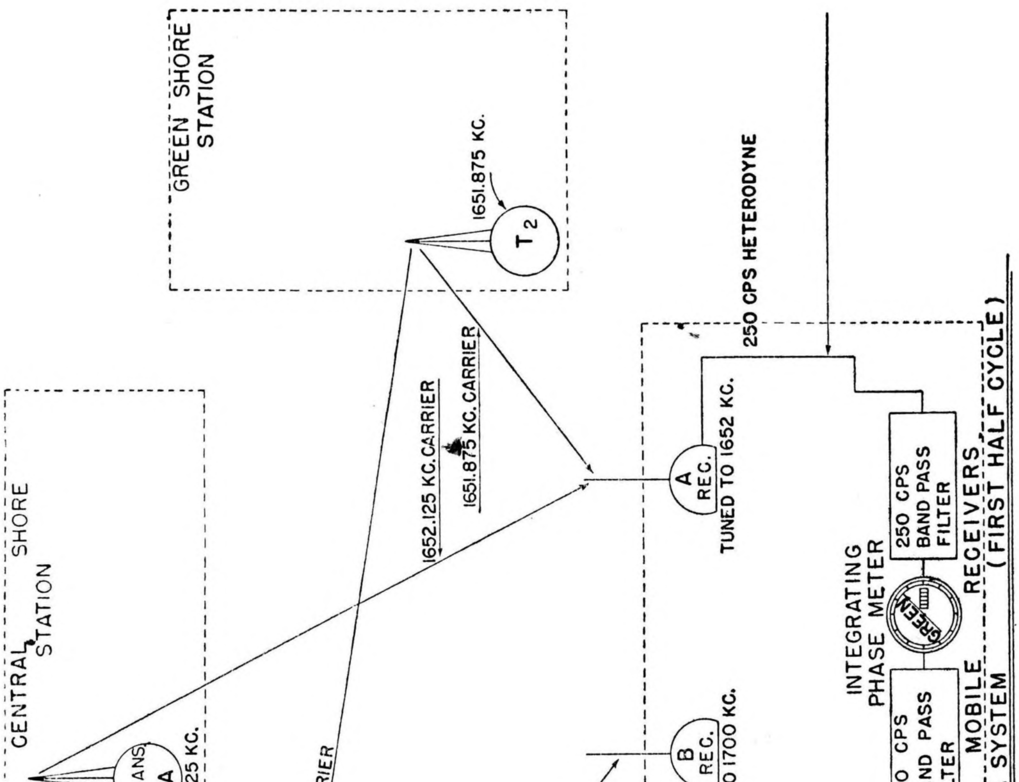

FIG. 4

Essential equipment and functions during first half of switching cycle.

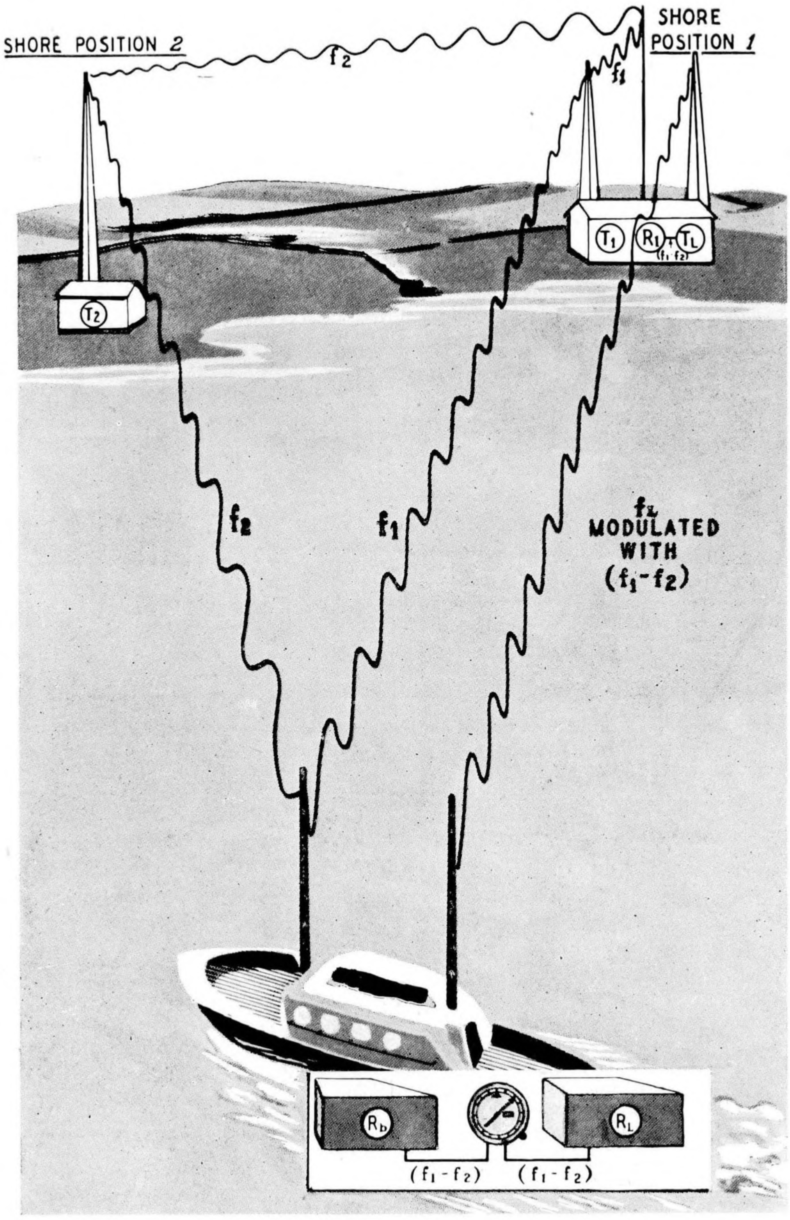

FIG. 3 — *The LORAC Principle.*

The radiation at frequencies f_1 and f_2 from two transmitters form a hyperbolic interference pattern.

The heterodyne frequency (f_1 - f_2) is used for measurement of the hyperbolic pattern.

change as long as the ship is motionless. If slight electrical changes take place at either shore transmitter, resulting in slight variations in phase, both beat notes will vary an equal amount so that the effects will be cancelled and the phase meter reading will not change. *This is an important feature of the system since it completely obviates phase synchronization problems.*

When the ship moves so there is a change in its relative distance from the two shore transmitting antennas, the phase value of the $(f_1 - f_2)$ beat note at receiver R_b will change but, as explained above, the phase value of the reference beat note will not change. Consequently the continuous integrating phase meter (called phase meter for simplicity) will record the change in phase relationship between the two beat notes and its pointer will move to the appropriate new position. The beat notes are used only as a means of transferring the hyperbolic pattern information to the phase meter.

As the ship continues to move relative to the transmitters, the phase meter pointer continues to indicate the position until a complete lane has been crossed. At that time the integrating counter mechanism of the phase meter adds or subtracts a digit to identify the new lane the ship has entered and the pointer continues to indicate the precise position within the new lane. If the moving ship is steered so there is no change in reading of the phase meter, the course followed will be along one of the hyperbolas of the coordinate system.

From the standpoint of determining absolute position, such a single phase angle measurement is not sufficient since the same phase indication may be obtained at any point along a given hyperbolic line. Accordingly, the entire set of equipment is duplicated and a second pair of fixed shore stations is so placed that its hyperbolas will intersect those of the first pair to form a grid of hyperbolic equiphase lines which blanket the area in which position information is desired. Then, by obtaining a phase relationship indication on the ship from this second pair of transmitters, a position determination may be made since the ship must then be at the intersection of the two hyperbolas defined by the readings of the two phase meters.

LORAC TYPE A SYSTEM.

Two separate transmitters are used at the Central shore station with transmissions taking place alternately from them at a rate of several times per second. The transmitters at the Green shore station and the Red shore station are in continuous operation, but their functions in the system change with each change of transmitters at the Central shore station.

Fig. 4 illustrates the operation when Central transmitter A is transmitting. Fig 5 indicates the operation when Central transmitter B is transmitting. For clarity, only the significant units in operation during each half cycle are shown in the respective illustrations. Fig. 6 shows the complete cycle of operation.

In Fig. 4 Central transmitter A is transmitting on 1652.125 kilocycles, while the Green station transmitter is simultaneously transmitting on 1651.875 kilocycles. These are thus so close together that a radio receiver tuned to 1652 kilocycles will detect the heterodyne wave of 250 cycles per second. The mobile receiver A detects this heterodyne or beat note. The phase of the beat note will depend on the respective distances the two waves have traveled before reaching the receiver A.

At the Red station, receiver R_1, tuned to 1652 kilocycles, will also detect this beat note. But, since R_1 remains at a fixed distance with respect to the Central and the Green transmitters, the phase relationship of the two waves will be constant. To compare the variable phase wave that arrives at the mobile receiver A with the constant phase wave received by receiver R_1 at the Red station, the latter wave as received by receiver R_1 is used to modulate the carrier wave of 1699.700 kilocycles being radiated by the Red transmitter. Mobile receiver B detects the 1699.700 kilocycle signal from the Red station and separates the modulation from the carrier wave.

For purposes of phase difference measurement, the beat note now available at receiver B is the same as that received originally at the Red station receiver R_1. For all practical purposes, the receiver B obtains a constant phase beat note originating from the Central and Green transmitters. The receiver A simultaneously detects the same beat note directly from the Central and Green transmitters in a phase that will vary with the position of the mobile unit as it moves about. Therefore a variable phase wave is available for comparison with a constant phase wave.

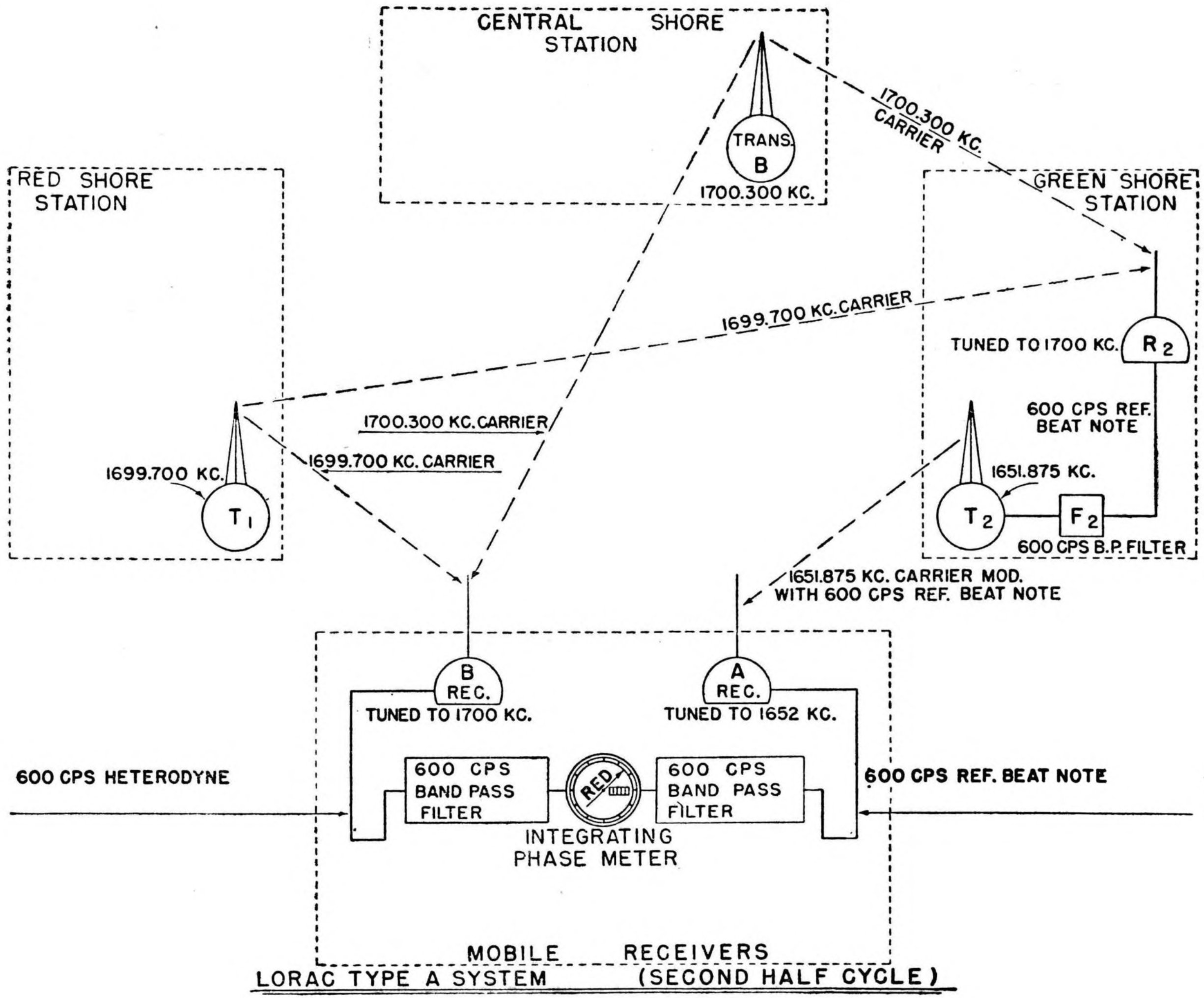

FIG. 5

Essential equipment and functions during second half of switching cycle.

The variable phase beat note of 250 cycles per second from receiver A is applied to one side of the Green phase meter ; the constant phase beat note of 250 cycles per second from receiver B is applied to the other side. This meter was originally preset at a known position. Thereafter, as the mobile unit moves about, the Green phase meter compares and measures the difference in phase between the two beat notes.

With the dial counter recording the nearest whole co-ordinate number and the meter hand indicating the fraction of a wavelength, the position of the mobile unit is known with reference to a known green hyperbolic line on the map. This is one-half of the information necessary to determine the position of the mobile unit. The problem remaining is to determine its position with reference to a known red hyperbolic line on the same map. To obtain this information, the transmitter B at the Central station is energized and transmitter A is stopped.

Central transmitter B now emits a signal at 1700.300 kilocycles. The Red station transmitter continues to transmit at its regular 1699.700 kilocycles, but without any modulation on its carrier wave. Receiver B stays tuned to 1700 kilocycles, but it is now detecting a 600 cycle beat note that will vary in phase according to changes in the position of the mobile unit with respect to the Central and Red stations.

Meanwhile at the Green station, receiver R_2 functions for the first time. Tuned to 1700 kilocycles, it detects the constant phase 600 cycle beat note from the combination of the Central B and Red transmitters (constant phase because the Green receiver remains at a fixed distance from the Central and Red transmitters). From receiver R_2 the constant phase 600 cycle beat note is fed into the Green transmitter and modulates the latter's carrier frequency of 1651.875 kilocycles. This constant phase beat note is detected by receiver A, and the modulation, separated from the carrier wave.

The same two mobile receivers are functioning, tuned to the same frequencies as before. The only difference is that now receiver B is obtaining the variable phase beat note and A the constant phase or reference beat note ; just the reverse of their former functions. These beat notes are applied to the Red phase meter for comparison ; while the Green phase meter momentarily stops registering. The Red phase meter, now functioning, has also been preset at a known position.

Just as was previously the case with the Green, now the Red phase meter records the difference of phase in the two waves as the mobile unit moves about and, every time the waves are in phase, the Red counter will add or subtract one number, depending on which direction the mobile receivers move.

With the information available to locate the position of the mobile unit with reference to a red line on the map, its exact position can be determined since the red line at some point will intersect the previously-determined green line.

In the lower portion of Fig. 6 is shown the schematic layout of the mobile receiving equipment for a complete switching cycle. When the receivers are obtaining the 250 cycle heterodyne and reference beat notes during the first half of the cycle, the notes can only enter the Green phase meter because the 600 cycle band pass filters block them from the Red phase meter. Similarly, when 600 cycle notes are being received during the second half of the switching cycle, they can only be applied to the Red phase meter. Thus the two band pass filters automatically channel the alternating cycles of beat notes into the proper phase meters.

The frequencies as illustrated for the Type A system are representative only and any available frequencies having the same general relationship may be used.

ACCURACY.

The accuracy provided by any surveying system is a function of several variables and cannot be expressed by one simple and constant value.

Absolute distance is obtained with pulsed systems while only differential distance is measured by continuous-wave systems. In pulsed systems the total travel time of a pulse is measured and a very high precision of measurement is required to determine this total time with the necessary accuracy. In continuous-wave systems the number of wavelengths, which must be integers, is counted and then the fraction measured. The potential accuracy of continuous-wave systems is thus very high.

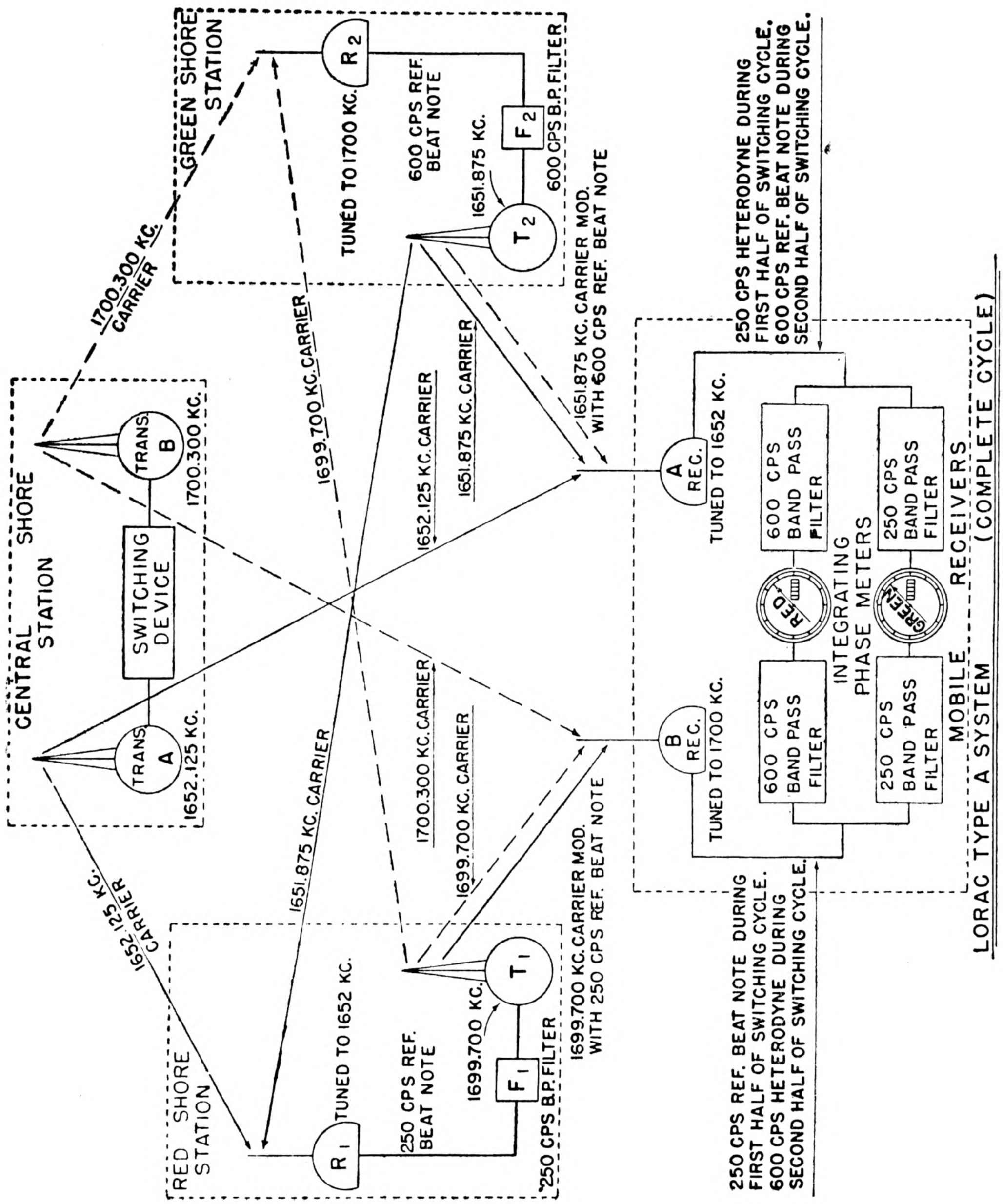

FIG. 6

Complete equipment and functions during entire switching cycles. The transmitting system operates with four transmitters and two receivers and requires only two frequency channels.

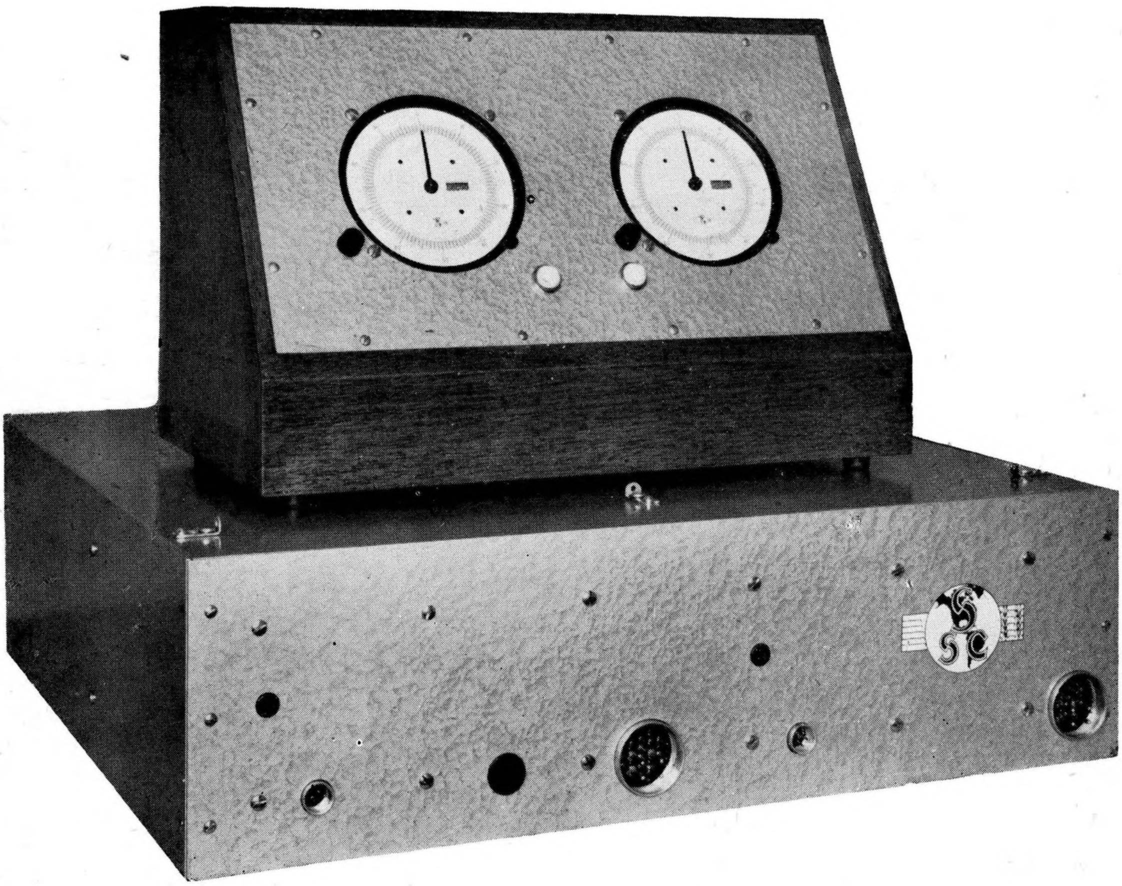

FIG. 7 — *LORAC Receiving Unit.*
LORAC Receiver (bottom) and Phase Meter (top).

The accuracy of all phase comparison systems is a function of the frequency employed. For frequencies in the order of 2000 kilocycles per second, the wavelength is approximately 500 feet. On the base line between transmitters, one-half wavelength or lane is approximately 250 feet. Since this constitutes a phase shift of 360 degrees, and an instrument accuracy of $\pm$ 3.6 degrees is not difficult to obtain, a reading accuracy of 1/100th of 250 feet, or $\pm$ 2.5 feet, is reasonable to expect with the LORAC system. The distance between the transmitters (within the limits of ground wave coverage) does not affect the fundamental accuracy of the system since, as the distance between the transmitters is increased, additional lanes are also added between them.

Regardless of distance from the transmitting stations, the LORAC system will give a high degree of local accuracy. Away from the interstation lines, the lanes widen and the accuracy of position determination is reduced by the curves from the two pairs of stations tending to become parallel. Nevertheless, the potential accuracy is high.

LORAC SURVEY RECEIVERS AND PHASE METERS.

The LORAC survey receiver with its associated phase meters (Fig. 7) is easily portable and designed for shipboard or automotive use. The LORAC receiver unit actually consists of two receiver channels mounted on one chassis. The receiver unit is remotely connected to the indicating phase meters so the latter may be mounted in a position most convenient to the operator. The receiver is fixed-tuned and hence no tuning or adjustment is required.

The LORAC phase meters integrate the received phase indications and accordingly keep constant records of the receiving position at all times. They must, however, be manually set at whatever point the survey commences within the cover of a system. If this is a harbor, then the coordinates are set up before leaving the harbor. Likewise, any other known point may be used at which to set the phase meters. It is only necessary to know the position within one lane, as the phase meters will automatically indicate the correct reading within any lane. The dials of the phase meters are divided into 100 parts, while the counter mechanisms will indicate up to 99,999 lanes.

OPERATION UNDER INTERFERENCE.

High-driving torque is only applied to a LORAC phase meter when phase-locked signals are being received. The effect of static crashes and other forms of interference is therefore to lower the driving torque for the instant that the static is stronger than the signals. Furthermore, the inertia of the phase meter mechanism reduces the response to high-peak short-duration impulses which characterize interference and static. The result is that the phase meter assumes the correct position whenever there is a small gap in the static or interference. The phase meters will thus operate at noise levels which would be too high for satisfactory communication. The receiver has been operated during electrical storms and the phase meters will function properly when the static crashes are several times as strong as the signals.

ADVANTAGES OF THE LORAC SYSTEM.

1. *Frequencies.* — LORAC frequency requirements are extremely elastic and are reduced beyond anything heretofore suggested ; i. e., two narrow, unrelated frequency channels are sufficient for a complete "fix". This minimizes the space required in the radio frequency spectrum. The frequencies used in continuous-wave systems have a direct bearing on the potential accuracy and range. Conflicting requirements dictate the frequencies which must be used. The LORAC system normally operates on medium frequencies which, because waves of these frequencies follow the curvature of the earth's surface, impose no special requirements on the heights of the receiving antennas.

2. *Simplicity of Instrumentation.* — Frequency synchronization is not required between the various LORAC transmitters. A constant and highly accurate frequency ratio between the transmitters is therefore not necessary. This also eliminates the need for frequency multipliers and dividers as well as frequency monitoring equipment and phase correcting circuits. The phase value of the waves does not require control, since phase shifts in the heterodyning transmitters are compensated by the double paths to the phase meters. This basic principle permits simplification of the entire equipment.

3. *Station Location.*— Because of the medium frequencies normally used, the locations of LORAC transmitting stations are not critical. It is generally practical for stations to be erected on convenient sites in inhabited areas adjacent to power and water sources and existing roads. In the case of other systems which radiate on high frequencies, coverage is limited by the optical range and stations must be placed on the highest available locations. The difficulty of access therefore places a great restriction on the use of such systems.

4. *Operation.* — The extreme simplicity with which the LORAC receiving equipment is operated is an outstanding advantage of the system. After the simple initial setting of the phase meters, position information is obtained by direct reading of coordinate figures from the phase meters which present this information continuously and progressively. The dial readings are translated immediately without computation into a precise position fix on the LORAC chart. No dial manipulation or "pip" matching is required. Thus the operator is free to move about at will and yet to record highly accurate fixes of position as often as may be desired. Operation may be satisfactorily carried out under conditions of heavy static or electrical interference.

5. *Accuracy and Range.* — The accuracy of the LORAC equipment is of a very high order, at least equal to, and in most cases better than, that provided by other electronic systems. Because of the medium frequencies used, the range is not limited by the "line of sight" between transmitting and receiving antennas as is the case with high frequency systems. The limiting factor with respect to range is the sky. wave reflection, which in turn is related to frequency and the accuracy requirements. The accuracy, range, station power and other factors are interrelated but highly accurate readings are expected to distances of 100 miles.

6. *Reliability.* — Medium frequency, low power and relatively low voltages reduce operational failures in the LORAC system. Duplication of units is insurance against transmitter failure. The need for presetting the phase meters and maintaining an accurate lane count is felt to be no handicap when supplying a service for surveying operations, since this work always commences by departure from some port and does not go outside a given service area. Precaution against service interruption is considered to be primarily a problem of adequate stand-by facilities.

7. *Number of Users.* — Any number of receivers may be used with a group of LORAC transmitters and, since no "triggering" of the transmitters is required from any recording position to fix a position, no interference is encountered between receiving units as each fixes its position. The equipment at the fixed installations cannot become "saturated" with users as may happen to triggered-type pulsed systems. Since the area of coverage is normally much greater than with other systems, the users have a greater flexibility of operations.

8. *Other Uses.* — The LORAC system may be used for navigation incidental to surveying operations in addition to its normal use in connection with surveying purposes, since the accuracy requirements for the latter are considerably greater than for navigation.