THE APPLICATION OF RAYDIST TO HYDROGRAPHIC SURVEYING

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INTRODUCTION.

Radio surveying or radio position determination, when used in conjunction with sonic depth finders, provides complete information for hydrographic surveys. Such a system requires a minimum of time and effort, and is independent of atmospheric conditions. The Raydist system has been developed for precise two-dimensional tracking of a small continuous-wave radio transmitter which may be transported in a boat and which is sufficiently compact and light in weight to be carried in a small suitcase. Raydist equipment has already proven its dependability to military services and to other Government agencies for navigation, tracking and position plotting over both long and short ranges. Accurate data have been constantly obtained from over-water Raydist operations carried out in driving rain and fog. The overall accuracy of the Raydist system for offshore surveying is 20 feet at a range of 25 miles, and at this range the sensitivity of the system is sufficient to detect a motion of one foot.

The ideal radio position-indicating system, to be most useful for hydrographic applications should not be limited to line-of-sight operation ; should be automatic, to avoid operator fatigue and error ; and its indications should be capable of being recorded as a permanent record. Furthermore, the mobile portion of the equipment should be light and the ground equipment should be highly mobile and free from complex or bulky antenna structures. To satisfy all these requirements the Raydist system has been developed and manufactured by the Hastings Instrument Company, Inc.

Raydist is a continuous-wave radio system in which the position of a small transmitter in a moving object is measured continuously and automatically with respect to fixed stations. It is necessary to place only a small continuous-wave transmitter in the ship and to set up a reference transmitter and two or three ground stations, depending upon whether one or two-dimensional data is desired. The indicating station will continuously track and indicate or record (or both, if preferred) the position of the moving airplane or ship.

In the specifications for a Raydist system developed for the Navy Bureau of Ships, the requirements called for both recording and indicating the data, stating that the equipment was to track a moving ship and to automatically record at a shore station, as well as indicate on the ship, the motion and position of the ship at all times. The specifications also included the accuracy requirement that "within a six square mile area, indication of the motion of the mobile unit shall be detectable and repeatable to within two feet on the indicators and within five feet on the recorder". The Raydist system more than satisfied these strict requirements. Figure 1 is a photograph of this equipment.

Equipment of the type described, intended for permanent installation at a fixed location, is of course constructed in keeping with the type of installation. The equipment can be constructed in portable form and, in fact, portable indicators have been constructed weighing as little as 32 pounds. Figure 2 is a photograph of an early type portable master station, constructed for field use for the Photographic Mapping and Charting Branch of the Air Materiel Command at Wright Field. (See Reference 1.)

Radar has been used for survey work of this type, but the difficulty of accurately recognizing targets on the shore, the line-of-sight limitations, and the low accuracy at short distances were unfavorable factors. Radar beacon-type systems have also been used. The accuracy of these systems is said to be suitable for most hydrographic work, but the weight, the complexity, and the line-of-sight limitations have been serious handicaps.

Raydist, on the contrary, is light, portable, and operates automatically, requiring no highly trained operators or technicians. It is not limited to line-of-sight operation as are most radar pulse systems. It requires a minimum of frequency assignments and these frequencies need bear no fixed relation to each other. Its over-all accuracy for over-water work is 20 feet at a range of 25 miles, but this by no means represents the limitations of the system, as it is not limited to line-of-sight operation. If greater range is required, only the transmitters need be converted to higher power, standard R.F. amplifiers being satisfactory.

TYPE E SYSTEM.

Raydist systems with precision comparable to the Navy installation referred to above are now available to commercial organizations who need equipment for accurate survey and position finding work. The Type E Raydist system, developed for precise two-dimensional tracking of a small continuous-wave radio transmitter, is uniquely flexible and allows the application of one set of apparatus to a number of problems. The mobile transmitter can be transported in a boat, automotive vehicle or airplane for purposes of navigation, surveying, or position plotting. Figure 3 is a typical Type E Raydist installation. Figure 4 shows a block diagram of this equipment.

This system has been specifically designed to meet the severe requirements imposed on radio equipment to be used in survey work with regard to portability, rugged construction, ease of operation and, above all, accuracy and dependability of data.

The entire apparatus for the Type E Raydist system consists of three fixed radio relay units, or "stations", one mobile transmitter, one reference transmitter, and one set of recording or indicating apparatus. It is not necessary to use all of these components for each application, however.

The equipment for each fixed radio relay station includes a receiver, a constant output amplifier and a radio transmitter. These are compactly arranged in a single unit, equipped with a collapsible whip antenna.

To set up a relay station for operation it is only necessary to place the unit at the desired location and extend the whip antenna. The power supply is normally 6-volt storage battery but 115-volt A.C. supplies are easily adapted. The mobile transmitter is a continuous-wave transmitter and can sometimes be the standard communications transmitter already installed in the aircraft or ship. The reference transmitter is a similar continuous-wave transmitter placed at any convenient location such that it can be readily received by each of the relay stations being used. The indicating station can be installed in the moving object or the indicating and recording can be made available at a fixed location. The latter arrangement would allow the position of a helicopter to be recorded continuously with only a transmitter weighing one pound (less power supply) being required in the helicopter.

For the measurement of the distance between two islands, it is necessary to use only two of the fixed relay stations, placed on the survey points on each of the islands. Close by one of the relay stations, a reference transmitter and a set of indicating or recording equipment can be located. It is then only necessary to carry the mobile transmitter from one of these island stations to the other to establish the distance between them. The path over which this mobile transmitter travels is unimportant and it need not be a straight line.

Since the same meter reading is obtained anywhere on the line of extension behind the station as would be obtained if the mobile transmitter were exactly at the fixed relay station, it is just as satisfactory and usually much more convenient to completely circle the islands with an airplane or boat as it would be to go directly from station to station. When the mobile transmitter crosses the extension of the line between the two fixed stations, the indicator passes through a minimum and reverses its direction.

As it crosses the line behind the other station it passes through a maximum and again reverses its direction of rotation. The difference between these maximum and minimum readings indicates the distance, each complete revolution of the indicator being equal to a distance equivalent to one-half wavelength of the frequency of the mobile transmitter. Thus, each complete circle around the island gives two complete sets of data, one from minimum to maximum, and the other from maximum back to minimum. The system automatically checks itself as the indicator should return to the original minimum as it returns to the first extension line.

In order to indicate two-dimensionally the position of the mobile transmitter at any time, it is only necessary that a third relay station be placed in operation. The signal transmitted by the mobile transmitter is received at each of the three relay stations. A reference transmitter, placed anywhere on the ground also transmits a continuous-wave signal which is received by each of the relay stations, and heterodynes the mobile transmitter. The heterodyne signals are each retransmitted to the indicating station, where the phase relationship of each is continuously compared. The position of the mobile transmitter with respect to each of the relay stations is determined by these phase relationships.

The standard indicator used on the Raydist equipment is shown in Figure 5. The reading of the indicator indicates continuously the hyperbolic line of position on which the moving transmitter is located at any instant. These data may be simultaneously recorded on a direct-inking oscillograph which provides a permanent, instantly available record on chart paper. A typical record of the motion of an airplane in flight is shown in Figure 6. Each peak on the record represents a distance travelled of 38.22 feet, or one-half of a wavelength for the radio frequency employed by the moving transmitter. Figure 7 is a two-dimensional record of a ferry boat crossing Hampton Roads. The roll of the boat can be clearly seen on this record.

By placing the indicating equipment at a fixed point, it is possible to keep the equipment in the mobile object down to a minimum (one small transmitter). If the system is to be used for navigation, however, the indicator can be placed in the moving object. It is also possible, with one additional indicator or recorder, to have simultaneous recording or indicating at both places.

In the case of offshore hydrographic surveys it seems most reasonable to place the indicating equipment in the boat and to place the relay stations along the shore.

THEORY OF OPERATION.

The Raydist system accomplishes the equivalent of setting up standing radio waves in space and enables the number of these waves set up within a given distance to be counted. The uniqueness of Raydist lies in the method of obtaining these radio waves with simplicity and reliability. The continuous-wave transmitter is moved between the two points. A second transmitter heterodynes the moving transmitter and is held at a fixed position in such a way that the heterodyned signals can be received at both ends of the distance being measured. The signal received at one receiver is then retransmitted to the other point so that the two received signals can be mixed. Each beat between these signals represents a distance travelled by the moving transmitter equal to one-half wavelength of its transmitted frequency.

One way to describe the operation of Raydist is to consider it from the point of view of the Doppler effect. When one transmitter is moved, receivers at the two points receive the heterodyne signal differently because the frequency of the moving transmitter is apparently increased with respect to the receiver it is approaching and is decreased with respect to the receiver from which it is receding. By mixing the heterodyne signals received by the two fixed receivers, the beat frequency obtained is proportional to the speed of the moving transmitter or, in other words, the number of beats obtained is proportional to the distance travelled. A radio link, or other suitable means, such as a telephone line, brings the two signals received to a single position for mixing. This method of counting half wavelengths of the signal from the moving transmitter allows the recording to be accomplished at a stationary location.

The phase meter and counter is a device similar to the electrical power house type synchroscope geared to a revolution counter and is used as an indicator of wavelengths travelled. The rotor and stator windings of the synchro are energized by the signals received at the two ground locations. The synchro will indicate the phase relationship between the two signals impressed or, in other words, the fractions of a wavelength travelled by the moving transmitter. The number of revolutions of the counter attached to the synchro will represent the number of one-half wavelengths travelled. If the direction of motion is reversed, the synchro will subtract rather than add the number of counts. Regardless of the direction and path travelled by the mobile transmitter, the reading will be the same every time the transmitter reaches a given point in space. By the use of this counting device, any path may be travelled between two fixed points and the resulting readings between the fixed ground stations will indicate the air-line distance between the two points. The readings of the synchro will allow a small fraction of a wavelength to be determined. This system not only has the advantages of indicating direction of travel but also reduces the possibility of erroneous counts caused by radio interference.

The accuracy of the system depends on the frequency of the mobile transmitter but not on the difference in frequency between it and the reference, because any drift in this beat frequency will be cancelled at the two receivers. There is thus no need to synchronize the two transmitters either in frequency or in phase. Any phase errors that might be introduced in the receivers will be almost completely cancelled due to the fact that both signals would be shifted equally.

At the receivers the phase measurement problem is simplified and made more accurate by the reduction of the signals from radio frequencies to audio frequencies. The phase measuring system becomes in effect a narrow-band pass filter. Only signals which are split in phase supply torque to the synchro. Static or stray signals within this band have the effect of first driving the synchro in one direction and then in the other but inertia in the synchro causes these effects to damp out. This system is thus made extremely free from difficulties from static of all kinds.

Actually, the imaginary standing waves set up in space from a single-dimensional system are hyperbolas. If one transmitter moves in such a manner that the rate of change in distance from each receiver remains constant, no difference in the two signals received will be recorded. This type of path is a hyperbola with the receivers at the foci. A family of such hyperbolas represents what can be considered standing waves as far as the records are concerned. At any particular instant, the dial reading indicates on which hyperbolic line of position the transmitter is located. By the use of an additional fixed receiver at another location and by recording the difference between this signal and the signal received by one of the other receivers, the equivalent of a second system of hyperbolas is formed in space. This second system of hyperbolas will furnish a means of determining the position of the moving transmitter in a two-dimensional system. Furthermore, the position of the transmitter in space can be calculated by recording a third set of data obtained by adding still another receiver.

The position of a ship may be determined with a two-dimensional Raydist installation as shown in figure 8. For this type of measurement the master station may be installed at one of the shore stations or on the ship, or duplicate indicators and recorders can be at both locations if desired.

Each of the two Raydist indicators shows the position of the ship on one of the two families of hyperbolic line-of-positions. The numbers on the hyperbolic lines shown on the chart represent the number of half wavelengths of the basic carrier frequency. The zero line passes through the two baseline stations A and C and, reading from left to right on the horizontal axis, A-C, the numbers 10, 20, 30, etc. represent half wavelengths of distance with station A taken as the zero reference.

The four small dials on each indicator represent these hyperbolic lines in units of thousands, hundreds, ten and unit half wavelengths, reading from left to right. The transparent pointer on the large dial reads in tenths of half wavelengths, the smallest division being one hundredth of a half wavelength. At 5 megacycles the smallest division represents a distance of approximately one foot.

The readings of the indicators shown are 152.6 and 124.2 and these mark the position of the ship with respect to coordinate axes A-C and A-B respectively, as shown on the chart.

A section of a continuous strip chart record is also shown in this figure. Vertical deflections on the chart are in direct ratio to the motion of the large transparent pointer on the indicator, and each sawtooth on the record corresponds to one revolution of this pointer. The upper record line represents coordinate axis A-B and the lower line axis A-C. The exact location of the ship for the condition shown by the indicators has been marked on this chart. It will be noted that it is easily possible to read the chart to a small fraction of a half wavelength.

For the simplest surveying problem, that of measuring a linear distance between any two points, equipment is placed at two relay stations located conveniently adjacent to the distance to be measured. A transmitter is then moved over any convenient path from a point at one end of the distance to be measured to a point at the other end.

A phase relationship exists between the signals from the mobile and reference transmitters as these signals are received at the two relay stations. As long as the mobile transmitter remains stationary, the phase difference between the signals received at these stations is fixed. As the mobile transmitter moves closer to one station and away from the other, however, the signals received at the two relay stations from the mobile and reference transmitters go in and out of phase at a rate proportional to the velocity with which the mobile transmitter is moving with respect to the two relay stations.

If the mobile transmitter is approaching one relay station and receding from the other and moves one-half wavelength, the signal as received at the relay station is increased 180° in phase and at the master station it is decreased 180° in phase. Therefore, the difference in phase between the two stations is increased by 360° for each half wavelength distance moved by the mobile transmitter on a straight-line path between the stations. A synchro-operated phase comparator counts the number of complete 360° changes in phase and also indicates the final phase relationship of the signals received at the two stations at any instant. Each complete revolution equals a distance travelled by the moving transmitter equal to the half wavelength of its transmitted frequency. The dial reading gives the fractional change in phase and therefore the fractional part of the half wavelength distance. The position of the indicating or recording equipment is unimportant. The phase shift in the signals being transmitted to the indicating equipment is negligible since the wavelength of a 400 cycle modulation is several hundred miles.

The application of the heterodyne principle results in considerable simplification of apparatus and an increase in accuracy over systems that do not use this principle.

Typical frequencies for the mobile and reference transmitters would be of the order of 2 to 15 mc., sufficiently low to avoid phase errors due to multiple transmission paths but high enough to allow readable phase indications to represent precise measurements of distance. The nominal difference in frequency between the mobile and reference transmitters would be approximately 400 cycles.

The true limitation of the accuracy of the system lies only in the consistency of the velocity of radio propagation over different types of terrain and as affected by atmospheric conditions. Raydist, unlike radar, detects motions of less than one foot, whereas pulse radar type equipment normally does not detect motions of less than 100 feet. It further provides continuous indication of the position of the moving transmitter. A recording unit can be installed in the mobile unit or at a fixed station whenever a permanent record is desired.

The system has been used successfully during the past few years by branches of the Army and the Navy. Raydist has been proven to be inherently the most accurate radio means for measuring short distances yet developed. The accuracy of the system is attested to by a review of the applications which have been made. The fundamentals of the system, involving the heterodyne principle, were first used by the author as early as 1940 at the laboratories of the National Advisory Committee for Aeronautics at Langley Field, Virginia, to determine the velocity of aircraft by obtaining time-distance records of the motion of the airplane. (See Reference 2). The National Bureau of Standards is currently sponsoring measurements of atmospheric effects on radio propagation conducted with Raydist equipment.

CONCLUSION.

The advantages of the Raydist system over other systems now in use for hydrographic operations lie in a combination of unique features which result in greater utility and dependability.

a. Raydist is not limited to line-of-sight operations. The system is good for several hundred miles.

b. The over-all accuracy of this system for over-water work is one foot at one mile and twenty feet at a range of 25 miles.

c. The system is fully automatic, to avoid operator fatigue and error.

d. Position is indicated on an easily-read dial and may be simultaneously recorded as a permanent record.

e. Indicators and recorders may be installed on a moving boat or on a shore station, or at both locations.

f. The mobile portion of Raydist equipment may be made very light and the ground equipment can be made highly mobile and free from complex or bulky antenna structures.

g. The system requires a minimum of frequency assignments, and these frequencies need bear no fixed relation to each other.

Considerable interest has been demonstrated by organizations that have learned of the equipment from the military services. In view of the simplicity and flexibility of the Raydist system and its unique ability to obtain precision with facility it is believed that it will prove a major contribution to today's surveying and position determining methods.

References :

1. Hastings, Charles E., Raydist—a Radio Navigation and Tracking System. Tele-Tech, June 1947.

2. Hastings, Charles E., Radio Ground—Speed System for Aircraft, NACA A.R. Feb. 1943.

FIG. 1
Indicating and recording Raydist system. The two dials continuously indicate the position of the moving transmitter while a continuous strip recorder transfers the data to a permanent record at a fixed station. A Raydist remote indicator is also located on the boat.

FIG. 2
Early model of a portable Raydist master station. This model was built for field use and the heaviest unit weighed thirty-two pounds.

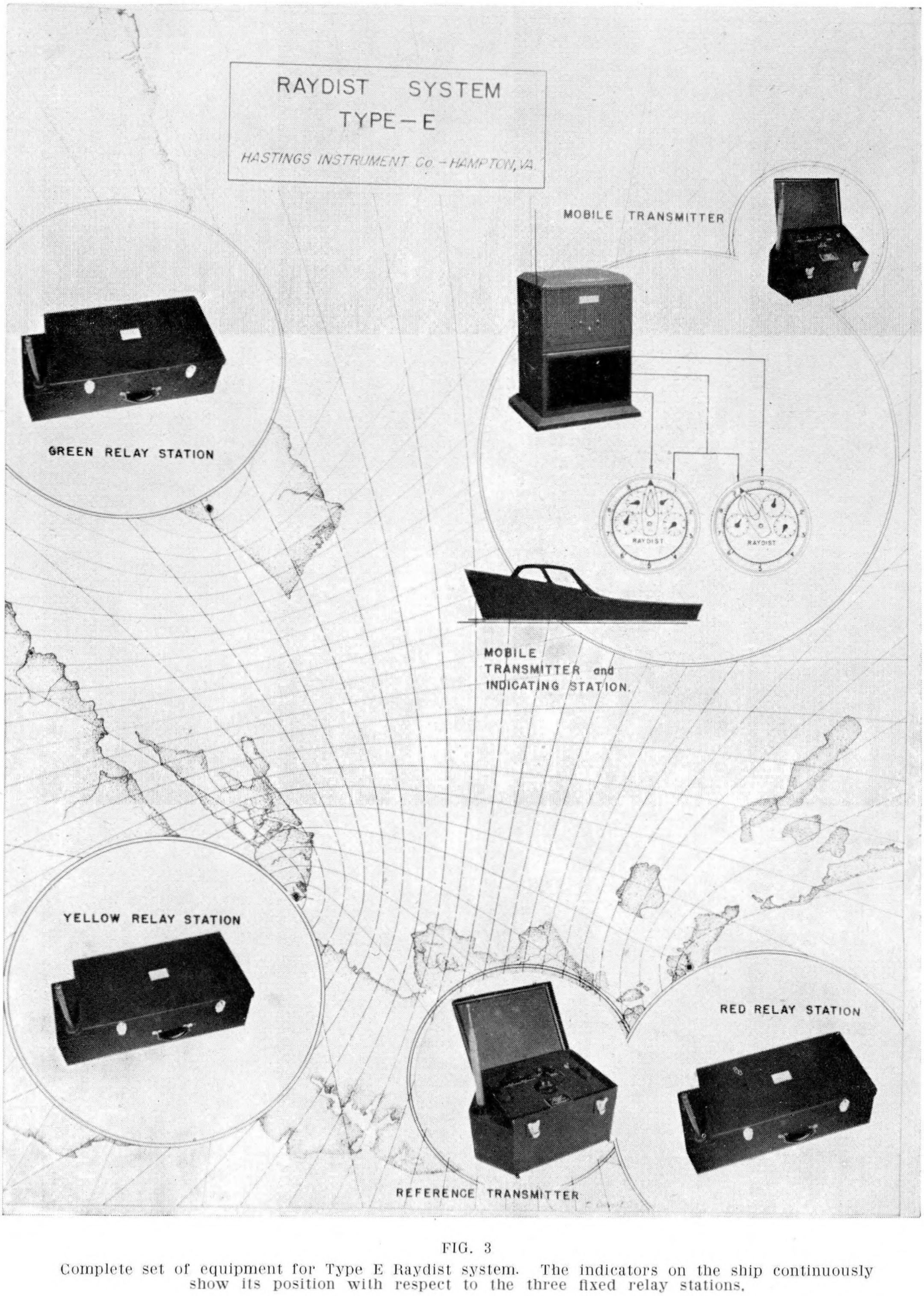

FIG. 3

Complete set of equipment for Type E Raydist system. The indicators on the ship continuously show its position with respect to the three fixed relay stations.

Figure 4. A block diagram of the Type E Raydist system.

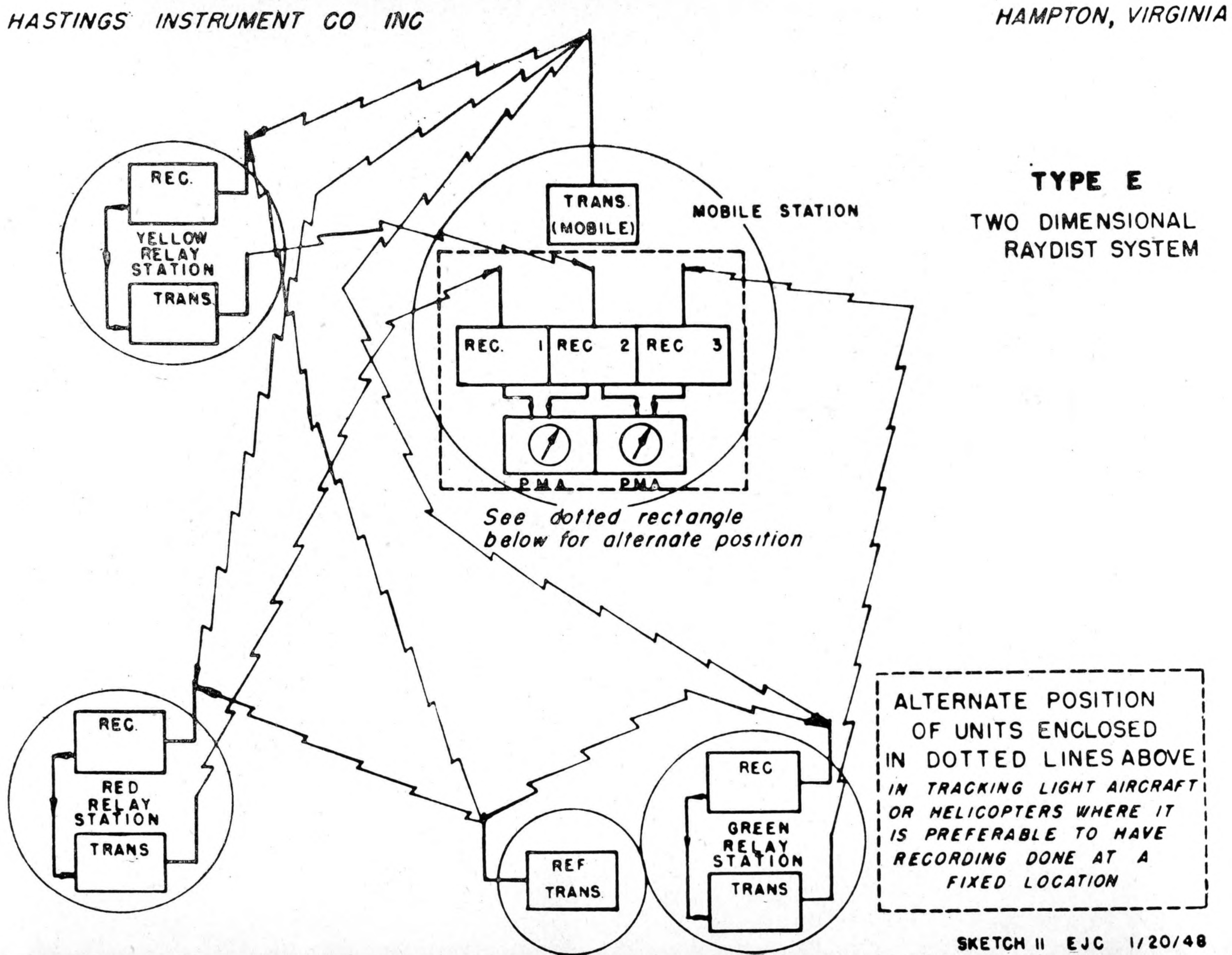

FIG. 5
Raydist Indicator.

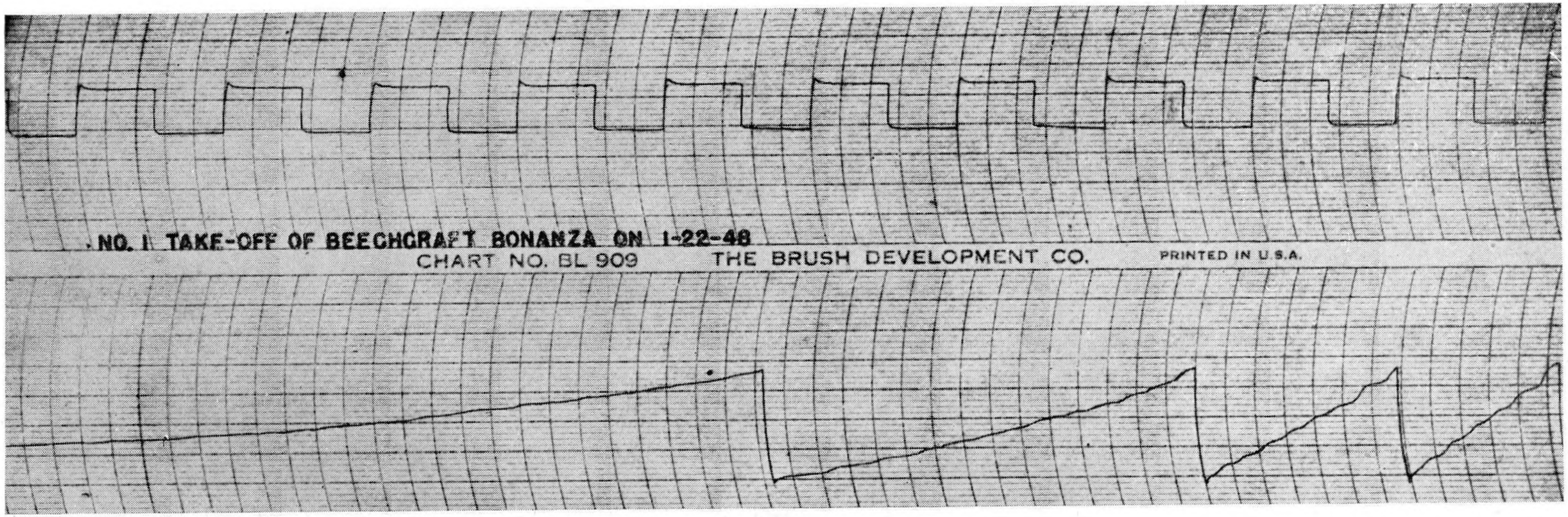

FIG. 6

Section of actual Raydist record of aircraft flight. This section, taken at the beginning of the flight, shows the distance travelled and the time interval involved. The upper strip records 1-second time intervals and the lower strip records distance, the distance between each peak being equal to 38.22 feet, or one-half wavelength of the frequency used (12.8625 mc.). From this record the velocity of the airplane or its position at any given time can be determined.

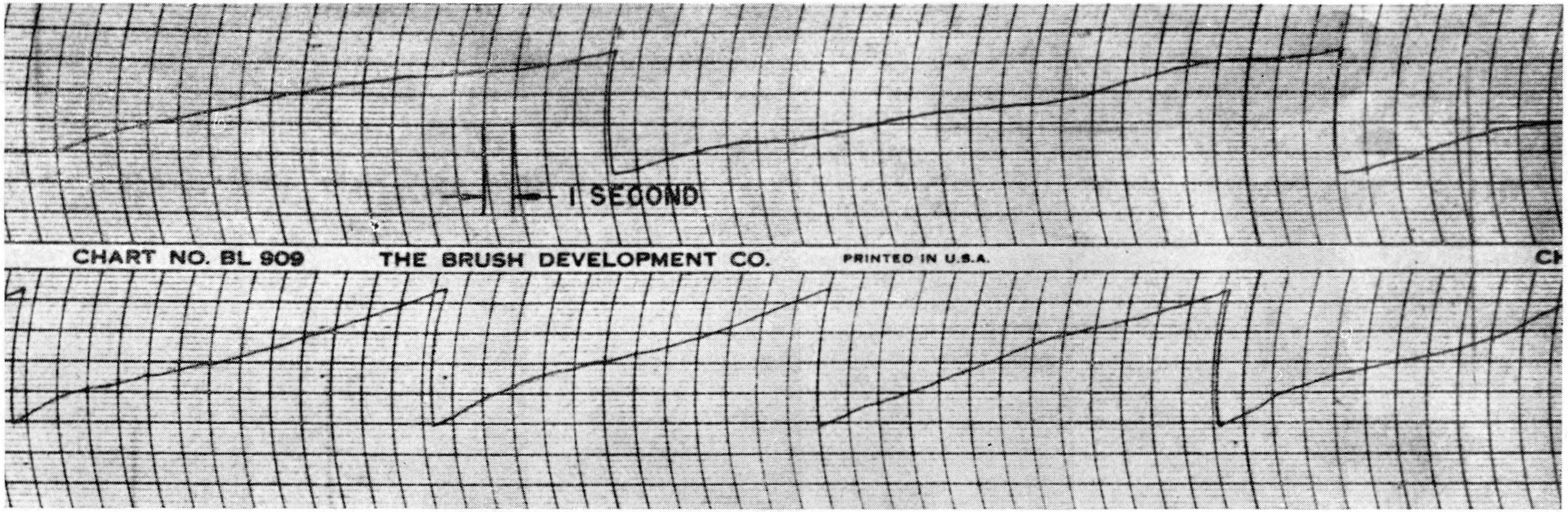

FIG. 7

A section of a two-dimensional record of a ferry boat crossing from Newport News to Norfolk, with the roll of the boat clearly visible. This is indicated by the waves in the sawtooth record.

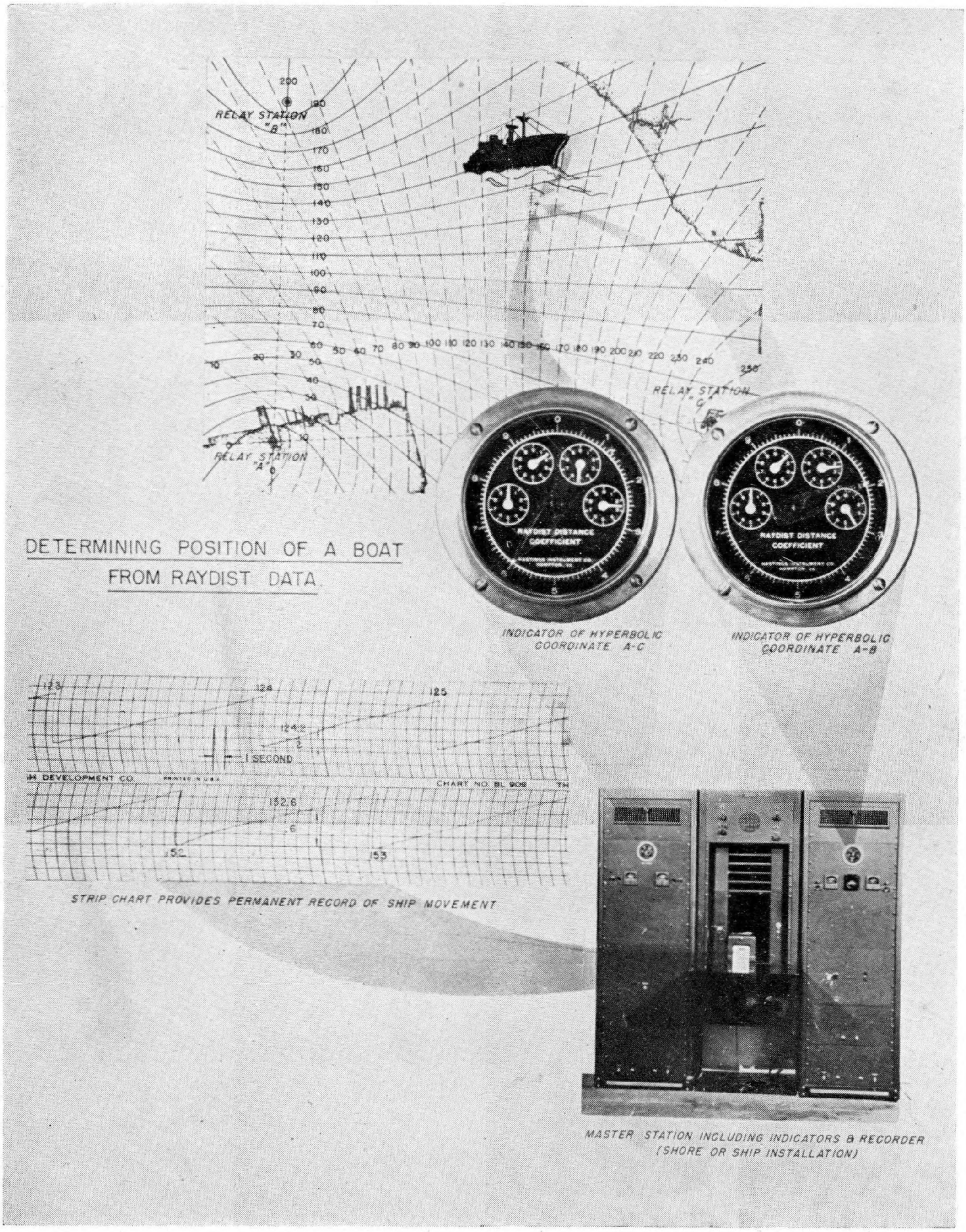

FIG. 8
Determining position of a boat from Raydist data.