RAYDIST IN HYDROGRAPHY AND SURVEYING

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Introduction.

The art of electric surveying has been developing very rapidly since the war. Pulse and radar type techniques as exemplified by Shoran have already found much use and have been proven as accurate surveying tools. Continuous-wave, heterodyne, phase-comparison systems such as Raydist show promise of becoming even more valuable in this field of electronic surveying because of their simplicity, reliability, considerably higher accuracy, and their suitability for operation at ranges beyond line of sight.

Phase-comparison systems without the advantages of the heterodyne principle have been widely used throughout Europe for the past ten years. They have been used for precise distance and position measurement and also for general air and marine navigation. These continuous-wave systems are rapidly gaining acceptance throughout large areas of the world in preference to the pulse systems generally advocated by this country.

All electronic surveying systems have one obvious advantage over optical methods of surveying in that they can be operated regardless of weather or visibility conditions. Continuous-wave techniques have, in general, marked advantages over the pulse-type electronic systems in that they offer considerably higher accuracy and are suitable for operation beyond line of sight, whereas the pulse type systems are seriously limited in this respect. Raydist, by the incorporation of the heterodyne principle, has not only the advantages common to all continuous-wave systems, but offers still higher accuracies with a minimum of frequency requirements.

Raydist within the past few years has been able to prove these advantages in field operations and to establish its value as a surveying tool. First-order surveying accuracies have been obtained under some of the most unusual and exacting field conditions. Raydist has been used on a 24-hour basis, day in and day out, by both Governmental and commercial users. Propagation paths have included sea water, fresh water, dense tropical growth, rugged mountainous regions, and virtually all combinations thereof. Ranges in excess of 250 miles have been achieved without the necessity for high altitude flights. Systems have operated in excess of 100 miles at night, have operated well beyond line of sight, and throughout all types of weather including severe thunderstorms. Increased ranges are of course practical with increased power, higher antennas, and lower frequencies.

These results are not limited to our own operations. As will be discussed later, the Bureau of Standards recently used Raydist techniques (Reference 1) to measure a distance of 1500 meters (less than 1 mile) and reported better than 1 part in 90,000 probable error. Mr. J. Th. Verstelle of the Netherlands Navy also recently reported that by the use of phase measurements in Europe they were able to measure lines of 162 kilometers, 157 kilometers, and 171 kilometers with absolute accuracies of 1 part in 54,000, 1 part in 63,000, and 1 part in 90,000 respectively, (Reference 2). Mr. Verstelle's opinions regarding the accuracies obtainable with phase-comparison, continuous-wave systems are essentially the same as those expressed herein; namely, that early inabilities to obtain high accuracies for overland distances measurements resulted from insufficient experience with early equipment and lack of knowledge of propagation considerations and data evaluation rather than from any inadequacies of the basic phase-comparison techniques.

Before discussing the individual jobs in which we have successfully used Raydist during the past few years, let us first consider just what Raydist basically is and how it is used in the various types of applications.

Fundamental Principles of Raydist.

I shall make no attempt here to discuss at length the technical details of Raydist systems. Much information of this type has already been published (References 3, 4, 5, and 6), and is available from the writer for those desiring more technical information.

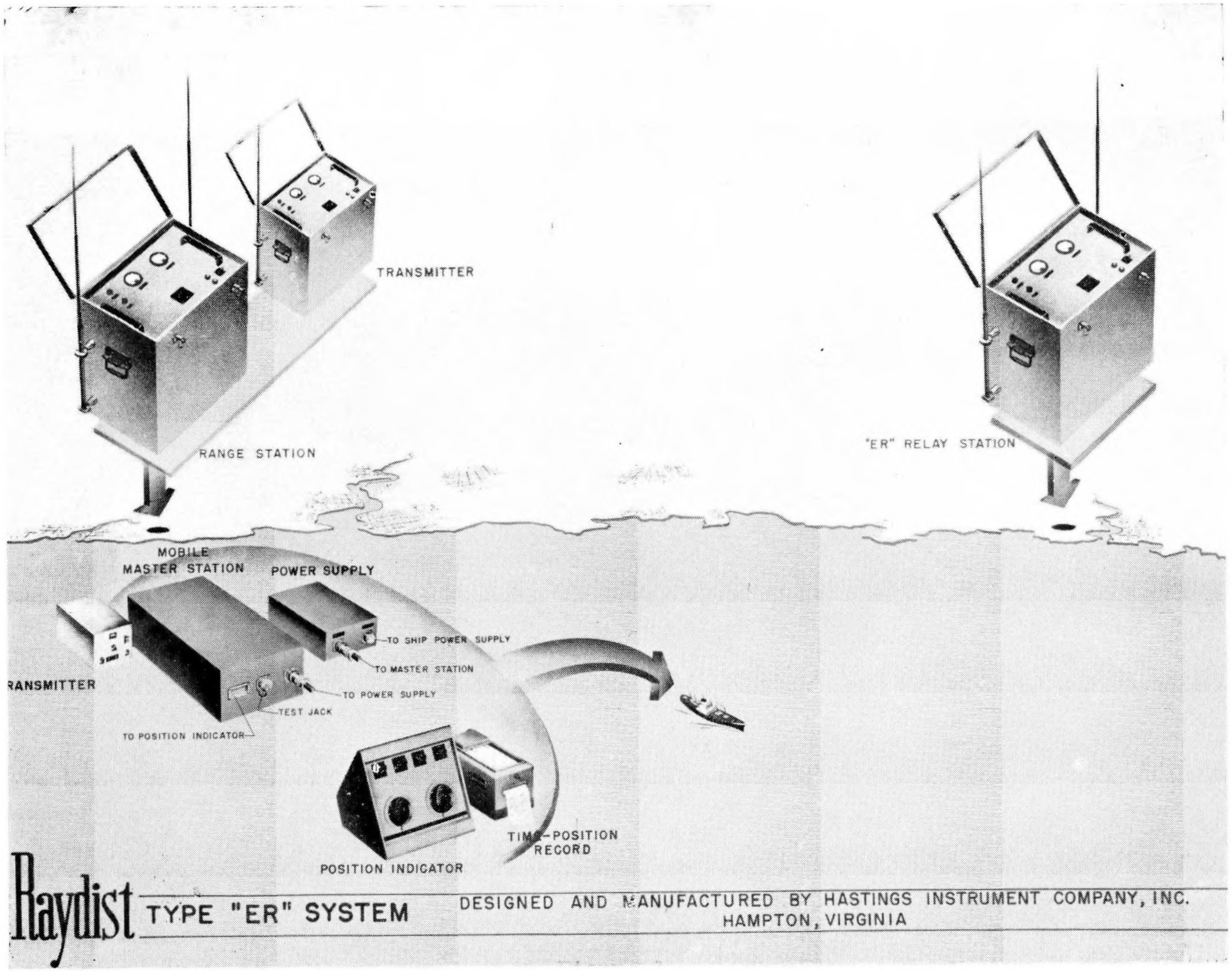
Let me just say, simply, that Raydist is a primary method of determining distances or differences in distance in terms of phase shift. Basically, continuous-wave transmitters emit continuous radio signals which differ from each other by audio frequencies. These heterodyne audio frequencies are received at two or more points. By comparing the phase of the signal as received at the various points, accurate distance determinations can be made. Determination of precise distance to several points allows determination of position, either in a plane of three-dimensionally in space.

System configurations and equipment arrangement vary depending upon the application and the type of data presentation desired. Some Raydist systems are hyperbolic lines of position. Other Raydist systems are not hyperbolic and data are presented directly in terms of range. Some systems are « saturable », meaning that only a limited number of users may obtain data from a given system simultaneously.

Not only do the systems vary, but the locations of the Raydist components often vary within the same type of system. In the hyperbolic system, for example, the Raydist components have been arranged to determine the position of a boat or aircraft and to record this position either in the moving object or at some fixed remote ground station. Systems have been supplied with duplicate indicating equipment so that the position data recorded at the ground station were also simultaneously indicated in the moving object. Tracking applications naturally require an arrangement with the data recorded at a ground station while navigation requires position data in the moving vessel. Location of the equipment depends primarily upon the end results desired by the user.

Newest Raydist System — Type ER.

The newest Raydist System, Type ER Raydist, is probably the most suitable for hydrography and surveying applications, and is therefore the only system I shall discuss in detail at this time. For more complete details see Reference 3.


TRANSMITTER
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TO POWER SUPPLY
TEST JACK
TO POSITION INDICATOR
RANSMITTER
TIME-POSITION
RECORD
POSITION INDICATOR
Raydist
TYPE "ER" SYSTEM
DESIGNED AND MANUFACTURED BY HASTINGS INSTRUMENT COMPANY, INC.
HAMPTON, VIRGINIA

Fig. 1.

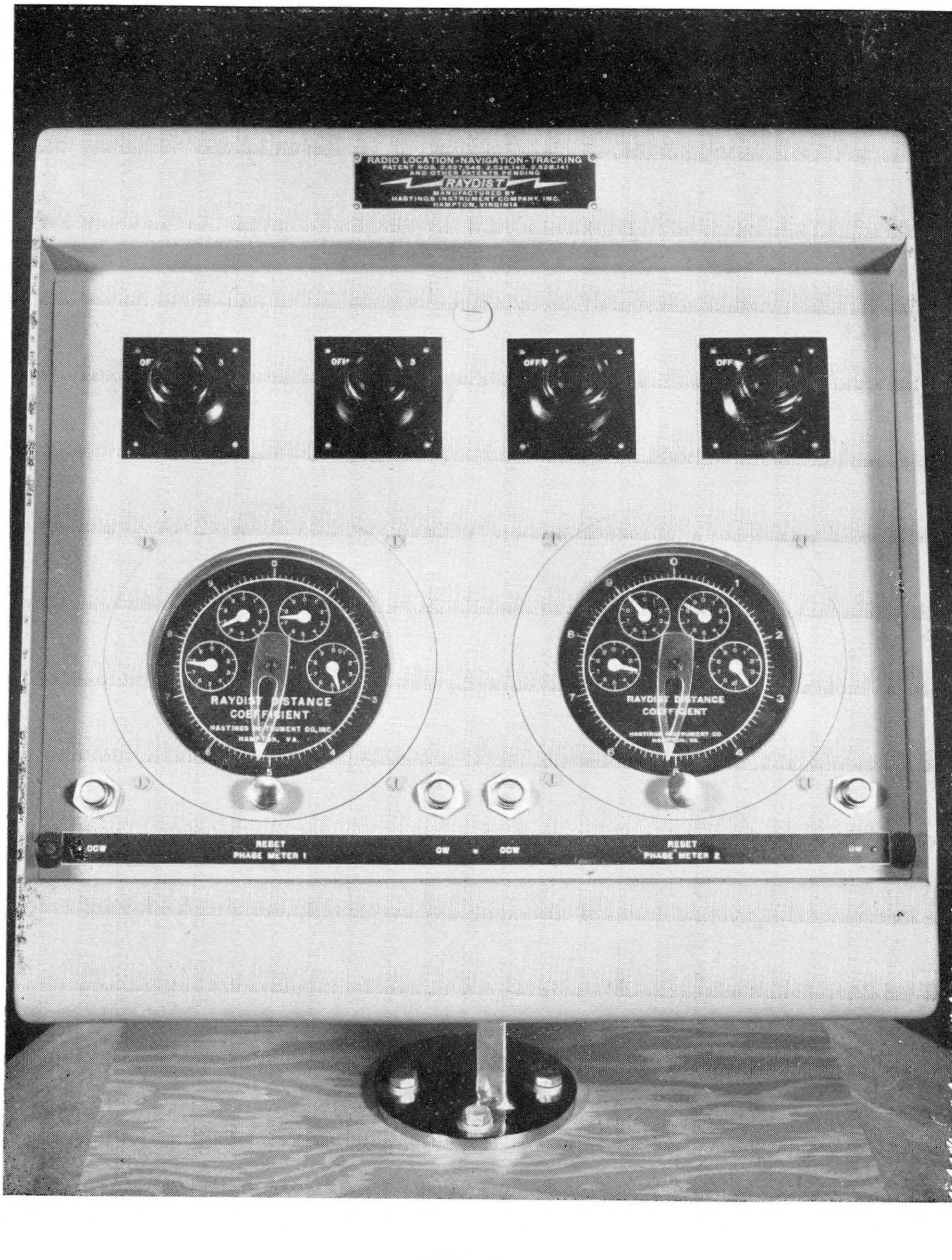

RADIO LOCATION - NAVIGATION - TRACKING
AND OTHER PATENTS PENDING
RAYDIST
MANUFACTURED BY
HASTINGS INSTRUMENT COMPANY, INC.
HAMPTON, VIRGINIA
OFF
RAYDIST DISTANCE
COEFFICIENT
HASTINGS INSTRUMENT CO., INC.
HAMPTON, VA.
CCW
RESET
PHASE METER 1
CW
CCW
RESET
PHASE METER 2
CW

Fig. 2.

The Type ER Raydist is not hyperbolic but furnishes the user position data directly in terms of range from two known points. No hyperbolic computations or overlays are required, and the plotting of points may be performed on maps of any scale.

The system consists of two shore relay stations and the ship-borne equipment, as shown in Figure 1. Figure 2 shows a typical Raydist Position Indicator for use with Master Station or at some remote location. All of the equipment is light, portable, and requires very little installation time. The shore stations are set up at any convenient locations along the coastline. The ship-borne equipment normally consists of a continuous-wave transmitter, the Raydist Master Station equipment and the desired indicating and recording equipment. However, the Master Station equipment may be located at a fixed shore point if it is desired to record the position at a shore station rather than use the data for navigation purposes.

As a surveying tool, this Type ER Raydist allows distances to be determined quickly and easily without hyperbolic calculations or overlays, offers increased precision over greater areas because it is not subject to the severe geometric dilution of precision of hyperbolic systems at the greater ranges, and offers real advantages in savings of time, money and effort.

Range and Accuracy.

Similar to the comparison between the equipment and techniques necessary for first-order triangulation nets and ordinary surveying, simple light-weight Raydist equipment is sufficient for general surveying work and heavier equipment and more care are required for long ranges and highest possible accuracies.

From the fundamental equations of the mathematics of Raydist (Reference 4) it can be shown that the accuracy of Raydist measurements depends essentially upon two factors; the stability of the frequency transmitted and the velocity of propagation of radio waves. A third factor, the accuracy of the actual phase measurement, would only become important at very short ranges or at extremely low frequencies. Frequency stability can easily be controlled to a few parts per million, leaving the correct value of the velocity of propagation of radio waves as the only factor in question.

The uncertainty of the exact correct value of the velocity of propagation and the determination of the relative effects of such constants as terrain, humidity, etc. on this value has probably been the biggest difficulty encountered in quickly adapting these phase-comparison techniques to first-order accuracies.

As early as 1948 the Bureau of Standards recognized the value of applying Raydist techniques to high-precision methods of studying these constants and at that time they awarded us a contract for work in the field of velocity of propagation measurements. Since then the Bureau has done considerable additional work along these lines and they have recently published some of the results of their studies (Reference 1).

The Bureau, in measurements made over flat arid country in the West using Raydist techniques obtained data which when evaluated in terms of distance by using the velocity of propagation generally accepted by the electronics industry, checked to within 1 part in 143,000. Using the velocity of propagation obtained by the new molecular method, their values checked to 1 part in 97,000. It is noteworthy that to have obtained these accuracies over the short baselines which they were using, their distances measurements with Raydist techniques would have had to be accurate to less than 2 centimeters or a little more than one-half an inch.

These results, as the Bureau points out, were obtained under carefully controlled field conditions. So, of course, are all first-order accuracies, whether optical or electronic. It appears certain, however, that as our knowledge of propagation factors increases, and our accumulation and analysis of empirical data increases, accuracies much higher than those required for first-order surveying are assured.

Ranges in excess of 250 miles have been obtained with light-weight equipment using medium-range frequencies. At low frequencies with greater power and larger antennas, ranges of 3,000 miles seem entirely practical. The stability of atmospheric propagation considerations has now established that first-order accuracies could be obtained even at these ranges, assuming the selection of appropriate operating frequencies. To achieve first-order accuracies at ranges in the order of 2,000 miles the frequencies would certainly have to be below 200 kc/s. At ranges of less than 1 mile, to obtain corresponding accuracies, frequencies above 100 mc/s and directive antennas similar to those used by the Bureau of Standards would be required.

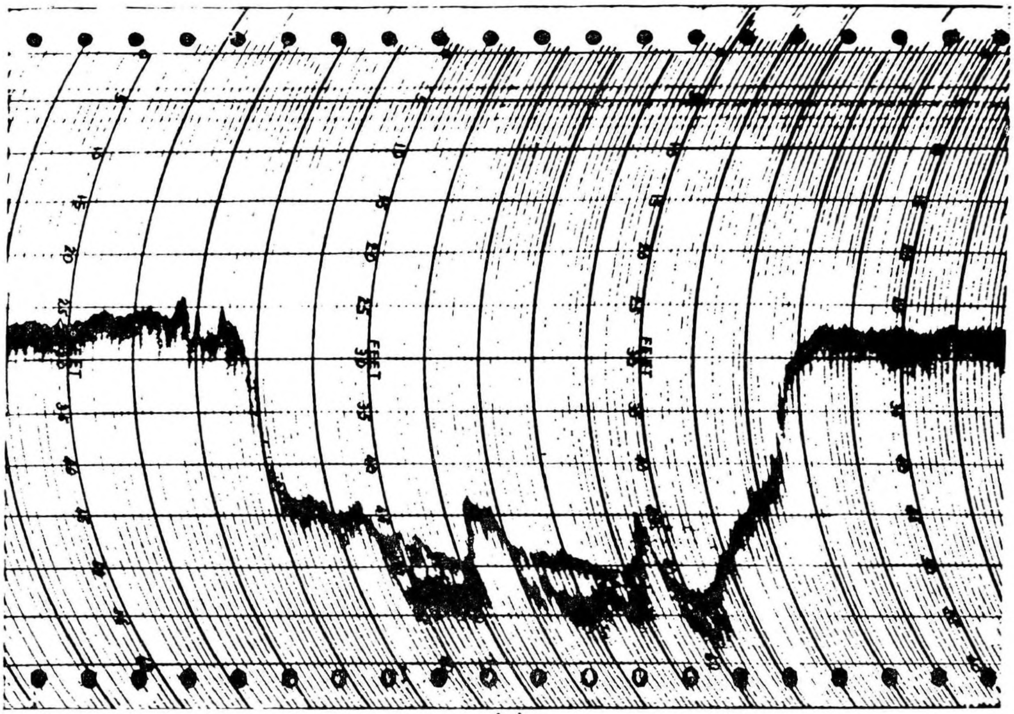
Some of the best data released to date relative to accuracies obtained with Raydist when tracking three-dimensionally the position of an aircraft in space were obtained by Patrick Air Force Base Missile Test Center (Reference 7). An evaluation of the accuracy of the Raydist data was made by determining the position of the aircraft simultaneously with Raydist and with optical measurements throughout the range of the optical instruments. Raydist, however, tracked the aircraft long before it got within range of the optical instruments and long afterwards. The Raydist data were considerably smoother and less erratic than the phototheodolite data, and the results are rather conclusive that Raydist was well within the checking accuracy of the theodolite optical data.

Lane Counts and Ambiguities.

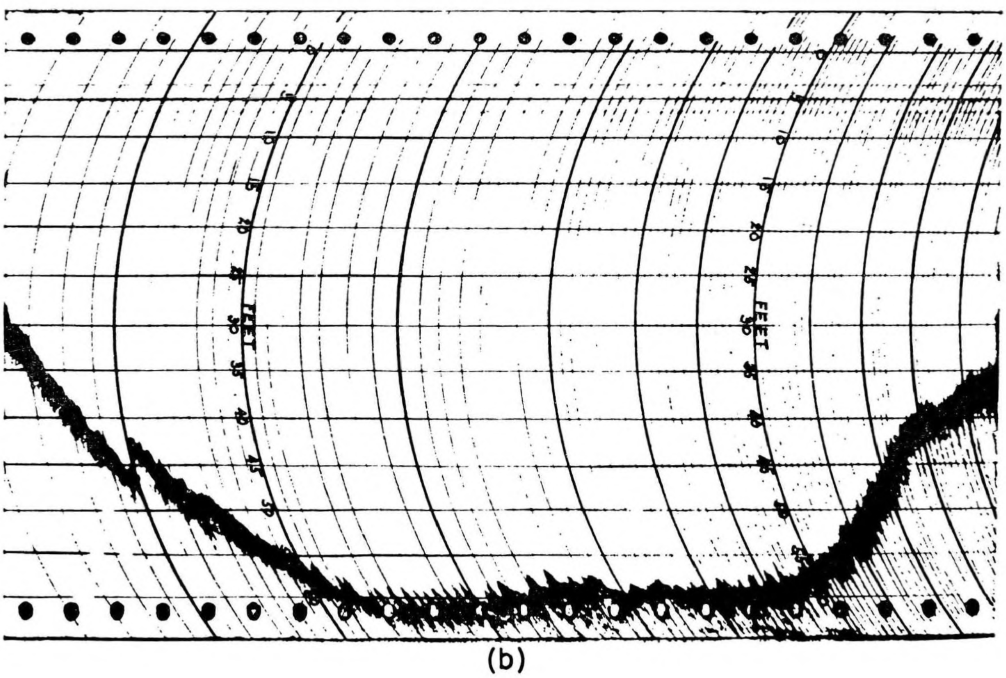
The very high accuracies obtainable with Raydist are in part due to the fact that the accuracy with which the shift in phase is measured does not have to be the equivalent of the accuracy to which the distance is being measured. In other words, the phase shift measurement is the equivalent of the vernier reading which is added or subtracted to the total number of lane count readings to obtain the distance. Thus, it is necessary to know both the number of whole counts or lanes and also the phase shift readings for the exact position in the given lane. .

There has been criticism of phase-comparison systems based on the fact that it is necessary to resolve ambiguities regarding the lane count to obtain the correct measurement, and resolving the ambiguities by actually counting the lanes might result in an error either because of an error in the counting process itself or because of an unreadable section of the record due to the failure of equipment or excessive interference at some particular time at or near maximum range.

A relatively simple method has now been proven practical for long lines where counting of lanes to determine whole count would prove burdensome or under conditions where questions might arise as to the correct number of whole counts. By making measurements on several frequencies and calculating the number of whole counts or lanes, it is not necessary to go through the tedious job of



(a)



(b)

Fig. 3.

SECTIONS OF ACTUAL RECORDS OBTAINED BY CORPS OF ENGINEERS SHOWING CROSS SECTIONS OF HAMPTON ROADS SHIP CHANNEL

The heavy lines represent depth as recorded by a sonic depth finder on a small boat crossing the Channel. The curved vertical lines represent the position of the boat recorded by raydist. The distance between successive fine lines represents 35.25 feet or 1/8 of the half wavelength at the raydist operating frequency (1738 kilocycles). The pilot on the survey boat follows a particular course by following one raydist indicator. A second indicator shows the distance traveled, which is simultaneously recorded directly on the chart. In figure (a) the boat traveled at approximately constant velocity; in figure (b) it traveled at increasing velocity.

counting them on the records. However, automatic counters have been developed and proven entirely reliable if satisfactory antenna arrangements can be made on the aircraft or vessel and sufficient power is available for the range over which the system is being operated.

Types of Raydist Applications.

Although it is necessary to take special precautions and use utmost care in order to obtain first-order accuracies, there are nevertheless many types of surveying work which do not require the ultimate in precision but in which such factors as portability, operation beyond line of sight, operation in all types of weather, and generally practicability of equipment are the important considerations.

One such type of application is that of hydrographic surveying. The precision of our hyperbolic systems has always been excellent and the Corps of Engineers Norfolk District have been using such a system for dredging channels in the mouth of Chesapeake Bay for some years and have found it highly satisfactory and very time-saving (Reference 8). They are, however, engaged in a continuing operation over the same area and it has therefore been practical for them to make up hyperbolic overlays with a scale of 1 inch = 200 feet in the critical channel areas. Sections of actual records obtained by Corps of Engineers showing cross sections of Hampton Roads ship channel are shown in Figure 3.

Very satisfactory Raydist hydrographic surveying operations have also been obtained over the past few years by the Hydrographic Office of the Portuguese Navy off the Bank of Sofala in Portuguese East Africa, Mozambique, and off the Colony of Guiné in West Africa (References 9 and 10, respectively).

Raydist has also been in continuous use for the past several years for precise surveying and positioning in the Gulf of Mexico along the coasts of Louisiana and Texas for oil exploration and well location operations for the oil industry (Reference 11).

Most hydrographic operations, however, are continuously moving along the shoreline or river and hyperbolic overlays are therefore expensive and cumbersome. The Coast and Geodetic Survey has felt that hyperbolic systems for their applications were impractical and not until we had satisfactorily developed our Raydist ER System which allowed the distances to be determined directly in terms of range did they feel it was worth their while to evaluate Raydist systems.

Late last summer at Sarasota, Florida, the Coast and Geodetic Survey used the Type ER Raydist System in some evaluation tests in the Gulf of Mexico. This area was selected because it was the critical location in relation to heavy thunderstorm conditions and radio interference. It was their feeling that if the system proved practical under these conditions, it would have passed the extreme tests. We were particularly pleased with their reports (Reference 12), which indicate that with small equipment and antennas radiating energies from small temporary installations on the beach with power of less than 20 watts, practical operation was obtained as far out as 20 miles in the Gulf, that for three weeks it was possible to operate on a 24-hour basis day after day without any failures of the Raydist equipment, and that in spite of severe thunderstorms completely satisfactory operations were obtained.

It was found that the differences between calculated values and Raydist indications never had any discrepancies greater than 5 meters and repeatability of the Raydist system from day to day was generally better than one-half of this amount.

There was considerable data in which the repeatability was better than 1 meter. Due to antenna structures in close proximity to the metal objects on the vessel and the fact that the antennas were not at a single point on the vessel, the apparent position of the boat in the system varied as much as 5 meters. From the data it seems that if a different effective center of the boat had been determined, the position error of the boat would have been less.

A system has recently been completed for the Brazilian Hydrographic Office, in which we built equipment essentially the same as that used by the Coast and Geodetic Survey, but also supplied 100-watt amplifier units such that when the 10-watt transmitters were insufficient for the requirements, they could be used in conjunction with the amplifiers to supply 100 watts of transmitted power. This enables the user to have the advantages of the lighter 10-watt equipment for most applications, but the ability to use 100-watt power when necessary.

Considerable Raydist experimentation has also been done with helicopters. It has been found practical to indicate the position of a helicopter in the cockpit, or with only a small transmitter in the helicopter, position of the craft can be determined on the ground.

A little over a year ago we also were able to take Raydist data and feed it directly into the automatic pilot of a helicopter so as to give automatic two-dimensional control of the helicopter. The system was set up at Patrick Henry Airport near Hampton, Va. such that left-and-right and fore-and-aft signals were supplied to stabilize the helicopter and maintain it on a fixed vertical axis in space. During this experimental work the greatest problem was in the stability of the helicopter combined with the autopilot system, but with Raydist controlling the autopilot, it was found possible to control the position of the helicopter to within a 5-foot circle as the pilot ascended vertically up a straight line to 1100 feet, the highest altitude tested. This precision could be attained so long as the stability of the helicopter due to winds or other factors did not adversely affect the system.

Summary.

Raydist has proven itself capable of first-order surveying accuracies. Raydist offers, in addition, advantages of simplicity, reliability, minimum frequency requirements, and operation beyond line of sight.

Raydist has been successfully used for hydrographic mapping and charting, surveying of large over-water areas and difficult terrain, tracking of high-speed missiles and aircraft, and navigation and positioning services in connection with hydrographic exploration and seismic operations. Raydist systems are equally adaptable to all other types of applications where precise position or distance determination is required.

REFERENCES

1. Velocity of Light Redetermined, *National Bureau of Standards Technical News Bulletin*, Vol. 39, Number 1, January 1955.

2. An Evaluation of the Accuracy of Decca as a Means of Distance Measuring Over Land, by J. Th. VERSTELLE, *International Hydrographic Review*, Vol. XXXI, No. 2, November 1954.

3. Latest Development in Raydist for Precise Position Location in Marine Navigation, Hydrography, Dredging and Electronic Surveying, *International Hydrographic Review,* November 1954.

4. Raydist, A Radio Navigation and Tracking System, by Charles E. HASTINGS, Hastings Instrument Company, Hampton, Va.

5. Raydist, A New Navigation and Tracking System Which Shows Great Promise for Aviation, by Charles E. HASTINGS and Allen L. COMSTOCK, *Aero Digest,* July 1951.

6. Raydist System for Radiolocation and Tracking, by J. M. BENSON and J. E. SWAFFORD, *Electrical Engineering,* November 1953.

7. Final Engineering Report on Downrange Survey for AFMTC, Patrick Air Force Base, Cocoa, Florida, Report RN 4, Raydist Navigation Corporation, Hampton, Va.

8. Raydist for Shallow-Water Hydrography, by Harold H. WATERFIELD and Cecil HILLIARD, Survey Branch, Norfolk District Corps of Engineers, *The Military Engineer,* November-December, 1951.

9. Sofala Bank Survey by the Mozambique Hydrographic Survey, by Lt. Joaquim B. V. SOEIRO DE BRITO, *International Hydrographic Review,* November 1953.

10. Use of Raydist System in Portuguese Guinea Survey, by Cap.-tenente J. A. MONTEIRO DE BARROS and 1° ten. Eng. Hidrografo J. Luis DE OLIVEIRA, *International Hydrographic Review,* November 1954.

11. Raydist Applied to Off-Shore Exploration, by Charles E. HASTINGS, *Tele-Tech,* February 1954.

12. Initial and Final Reports of Raydist Equipment Tests, by Roswell C. BOLSTAD, Comdg. Officer Ship SOSBEE, U. S. Coast and Geodetic Survey, Washington, D. C.