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Raydist on Georges Bank

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This series of Technical Bulletins was inaugurated to present to the personnel of the Coast and Geodetic Survey and to others the results of research and development in the various fields of the Bureau's activities. Since many of the bulletins deal with new practices and new techniques, the views expressed are those of the authors and do not necessarily represent final Bureau policy.

Technical Bulletin No. 5 describes and evaluates the phase-comparison, survey-navigation system known as Raydist which was used by the Coast and Geodetic Survey on its offshore surveys of Georges Bank in 1957 and 1958. Raydist control for hydrographic surveys is a supplement to that furnished by Shoran and the Electronic Position Indicator.

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Raydist on Georges Bank

CAPTAIN GILBERT R. FISH

U.S. Coast and Geodetic Survey

AT THE end of World War II the Coast and Geodetic Survey obtained several sets of shoran from the U.S. Air Force and used them to control hydrographic surveys in the Aleutian Islands, Alaska. Shoran is a pulse-type electronic control system developed for U.S. Air Force use during the war and it has proved to be a very adaptable substitute for the nonelectronic control methods previously used by the Bureau. From this initial beginning in 1946, the use of shoran by the Bureau has increased until this method of control practically superseded other methods, except for the immediate inshore areas and the areas beyond its range.

As shoran uses high frequency radio waves, the range of the equipment is limited to slightly more than the line-of-sight distance between the antennas. To overcome this limitation of shoran, the Coast and Geodetic Survey developed a system called the Electronic Position Indicator (EPI). It is also a pulse-type system, but uses a lower radio frequency than shoran and therefore has considerably more range. The increased range makes EPI very suitable for small-scale offshore surveys, but it is not suitable for controlling medium- to large-scale surveys.

In 1957, a resurvey of Georges Bank, which lies about 100 miles east of Cape Cod on the Massachusetts coast (see fig. 1), was scheduled to begin and a method of control was needed that would position the sounding lines on the medium- to large-scale surveys required to adequately develop the sand ridges and shoals found in this area. Shoran was not practicable because of the long distances involved and the EPI was not suitable due to the requirement for the large-scale surveys.

To solve the control problem the use of Raydist was considered. In 1954, the Coast and Geodetic Survey had leased an ER-type Raydist equipment from the manufacturer and used it on a trial survey in the vicinity of Sarasota, Fla. The results of the test[1] showed that the Raydist was well suited to control large-scale surveys. Therefore, if such equipment could be procured that had sufficient range, there was no reason why equally satisfactory results could not be obtained in the Georges Bank area. In May 1957, an agreement was made with the manufacturer to install, on a trial basis, a Raydist system on the survey ship *Hydrographer*, the vessel assigned to the project. The agreement also provided for the lease of the equipment if it proved suitable for our purpose and for its purchase should funds become available. The equipment was purchased in September 1957. This Bulletin is based on information and experience obtained during the 1957 and 1958 survey seasons during which approximately 17,000 miles of Raydist-controlled hydrography were accomplished.

DESCRIPTION AND PRINCIPLES OF OPERATION

The Raydist purchased by the Coast and Geodetic Survey and used on the ship *Hydrographer* was a DM model using 100 watts of power. To obtain distances from the ship to two shore, or fixed, stations four radio transmitters with four separate frequencies are required. It is a range-elliptical system wherein the direct distance to each station appears on the phasemeter dials. The distance to the second station, however, is not obtained direct but depends on the sum of the distances from the ship to each station minus the distance to the first station.

The Raydist system used on the Florida coast in 1954 was an ER model using 20 watts of power. It was a range-hyperbolic system that also required four radio frequencies. The distance to one station was read direct on the phasemeter dial but the distance to the second station had to be computed from the hyperbolic reading portrayed on the dial.

[1] ER-Type Raydist System of Position Control by T. C. Hickley and R. C. Bolstad, in *The Journal, Coast and Geodetic Survey*, October 1957.

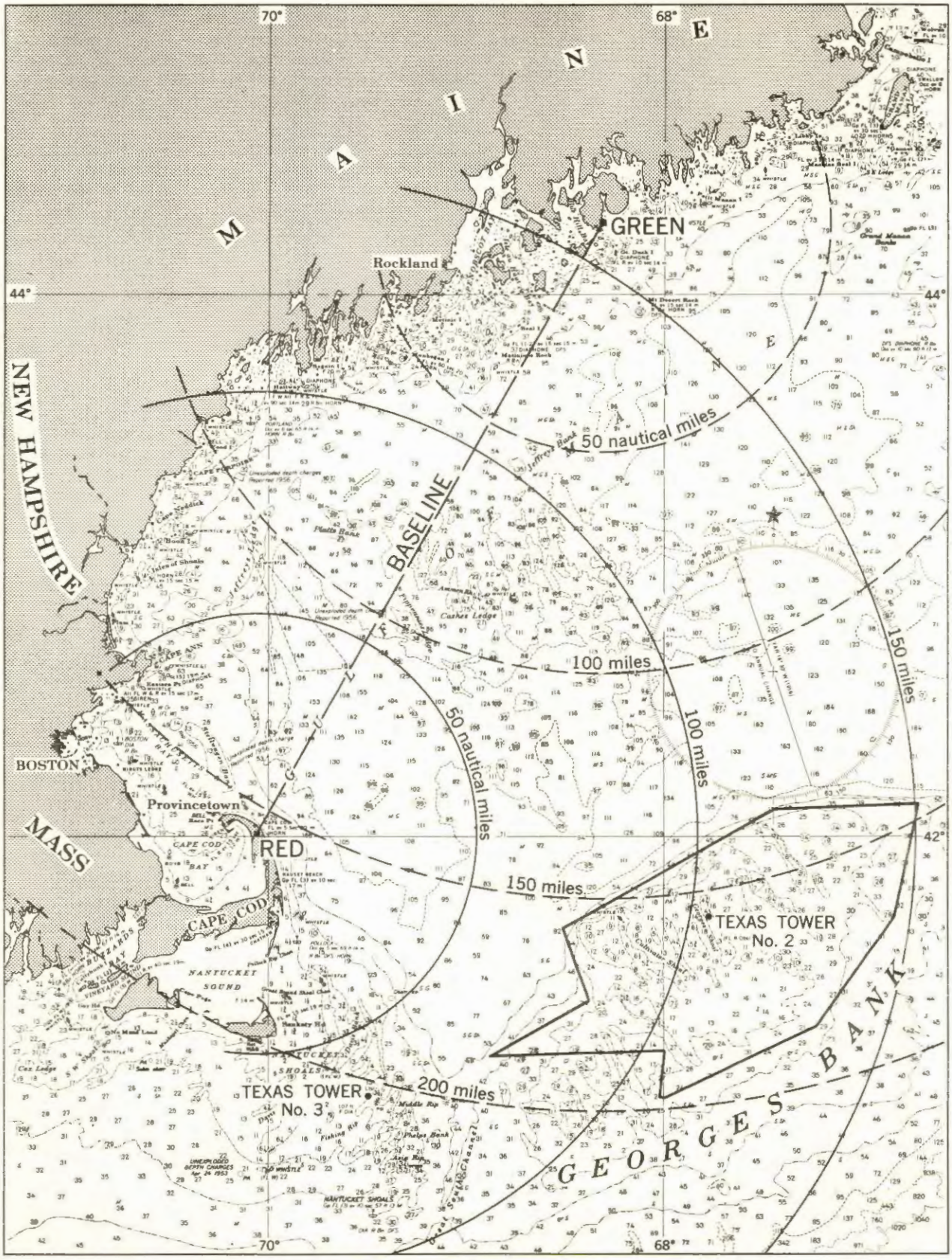

FIG. 1.--Project area of 1957 and 1958 Raydist-controlled survey of Georges Bank.

The readability of the dials has been improved on the DM model. Counters are now used to show full lanes to 10,000 lanes and a pointer indicates fractional lanes to the nearest 0.01 lane. It was found that readings to 0.1 lane were sufficiently accurate for purposes of hydrography. Figure 2 shows the phasemeter.

The System

Raydist is a phase-measuring instrument and the determination of distance is based on the measurement of a phase difference in two radio signals, one emanating from a transmitter on the mobile station--aboard ship--and the other from a transmitter at one of the fixed, or shore, stations. In order to obtain the distance of the ship from each of the two shore stations, it is necessary to measure the phase difference at three places, aboard ship and at each shore station. As long as the ship remains fixed in location the phase relationship between the two signals will not cause the dials to turn, but if the ship is moved, the phase relationship will change during the move which will cause the dials to turn and change the distance readings.

Four radio transmitters and frequencies are required to operate the system, the two distance measuring frequencies and two additional frequencies for a transmitter at each shore station to transmit the information concerning the phase relationship at the fixed station back to the ship. In referring to the shore or fixed stations, the station with the distance measuring transmitter is called the R-1, or "Red," station, and the other is called the R-2, or "Green," station.

Because it is difficult to measure phase directly at the radio frequencies the technique of heterodyning is used. This is a technique wherein if two radio signals are fed into a detector the issuing signal will have a frequency that is equal to the difference between the frequencies of the entering signals and will portray the phase changes that take place between the entering signals. In the Raydist the entering signals are separated by 400 cycles and after detection this frequency is fed into a phasemeter. Low frequency phasemeters are easier to build and are less critical than are those for the higher frequencies. This heterodyne technique enables the measurement of the phase of the high frequency signals to be made at a low frequency without a sacrifice in accuracy.

The distance from the ship to the Red station is measured by comparing the phase of the transmitter on the ship to the transmitter at the Red station. Distance is measured by knowing how many half-wave lengths of transmitter frequency

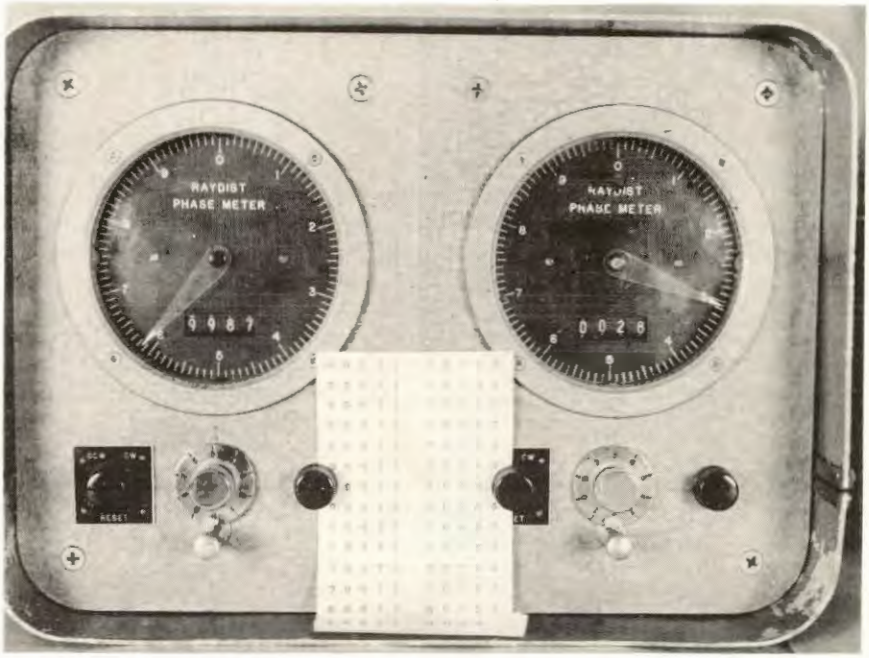

FIG. 2.--Raydist Phasemeter, section of Recorder tape has been placed between the dials to show the printed readings.

are between the shore station and the ship. Once this number is known and the phasemeter dial set to this value, the Raydist system keeps count of the number of half-wave lengths as the ship moves. These half-wave lengths are known as lanes and for the frequencies used in the Raydist aboard the *Hydrographer* are about 45 meters or 150 feet wide.

The ship and the Red station transmitters are crystal controlled. There is, however, a small change in phase with respect to each other since they are not phase-locked. The phase of the two transmitters are compared at the Red station and the phase information in the 400-cycle difference frequency is relayed back to the ship on one of the carrier frequencies. At the same instant the two transmitter frequencies are compared on the ship and the phase information appears in this 400-cycle difference in their frequencies. These two 400-cycle signals represent the difference in phase at each end of the R-1 line being measured. The arbitrary difference between the two transmitters, which may be the result of small fluctuations in frequency, are equal at each end of the line and hence cancel. The phase difference which do appear, and are used to turn the phasemeter dials, are the result of changes in phase caused by a change in the R-1 distance between the ship and the shore station.

In the range-elliptical Raydist system the R-2 distance is not measured direct but is derived from knowledge of the R-1 distance and the sum of the R-1 and R-2 distances. Measuring the R-2 distance in this manner prevents having to use more than four radio frequencies and helps to simplify the system. The phase of the ship and the Red station transmitters is compared at the Green station and the information is relayed back to the ship on the carrier frequency at that station. At the same instant the ship and the Red station transmitters are compared on the ship and the phase differences appear in the 400-cycle difference. The two 400-cycle signals are put into an elliptical phase resolver. The shaft position of this resolver is related to the sum distances R-1 and R-2. By combining the distance information from the Red station phasemeter with the elliptical resolver and by a proper gearing arrangement the Green phasemeter dial reads only the value R-2, or a direct distance to the Green station.

The inter-relation of the R-1 and R-2 distances as it affects the R-2 distance is discussed further when dealing with the operation of the equipment. More information about the manner in which the R-2 distance is measured is also given in the section concerning the antenna installations aboard ship.

The radio frequencies used in the *Hydrographer's* Raydist system were 3280.000 kc. aboard ship, 1639.800 kc. as the distance measuring frequency at the Red station, and 2492 kc. and 2496 kc. as the carrier frequencies. Before feeding the 1639.8 kc. signal into the detector the frequency is doubled to 3279.600 kc. so that it is 400 cycles less than the 3280.000 signal.

Fixed Station Installations

At the Red station three antennas are required, one for receiving the distance measuring frequencies (3280 kc. and 1639.8 kc.), one for transmitting the 1639.8 kc. signal, and one for the carrier frequency transmitter (either 2492 kc. or 2496 kc.). In 1957, three 100-foot tower antennas were used. They were placed in a southeast-northwest line with 250 feet between adjacent antennas. The center antenna was placed over the triangulation station marking the point from which the distances were measured. When using three tower antennas, it is necessary that the receiving antenna and the 1639.8 kc. transmitting antenna be symmetrical with respect to the point from which distance is measured in order to avoid applying corrections to the R-1 distance as the azimuth of the ship from the shore station changes. This condition was fulfilled by using the southeast tower for the receiving antenna and the northwest tower for the 1639.8 kc. transmitting antenna. The 2492 kc. transmitter was placed over the station mark. However, the use of three tower antennas arranged in this manner requires that a correction be applied to the R-2 distances. This is due to the fact that the R-1 distance in the sum of the R-1 and the R-2 distances used in measuring the R-2 distance is measured from the ship to the 1639.8 kc. transmitting antenna, while the R-1 distance subtracted from this sum in

the phasemeter is the distance from the ship to the mark denoting the location of the station, or the point midway between the 1639.8 kc. transmitting antenna and the receiving antenna.

In 1958, the antennas at the Red station were rearranged so that an azimuth correction to the R-2 distance would no longer be necessary. This was accomplished by placing a 35-foot whip antenna on top of the 100-foot tower antenna for the 1639.8 kc. transmitter and placing the duplexed antenna over the mark denoting the station location. The 2492 kc. transmitter was then shifted to the southeast of the three antennas. The position of this latter antenna has negligible effect on the distance measurement as long as it is in the immediate vicinity of the station.

Two 100-foot tower antennas are required at the Green Station. The antenna for receiving the 1639.8 kc. and the 3280 kc. signals was placed over the mark denoting the location of the station and the antenna for transmitting the carrier frequency, either the 2492 kc. or 2496 kc. transmitter, was placed about 250 feet distant. The distance is measured from the receiving antenna and the placement of the transmitting antenna has negligible effect on the distance as long as it is placed in the immediate vicinity of the station.

Ground planes with a radius of 100 feet were placed around each tower antenna. Care should be exercised to maintain the ground planes intact and well bonded. The Raydist will operate with considerable radio interference present, but it is well to keep down interference from all conditions over which there is control.

The Raydist components for the fixed stations are relatively small in size and are easily transported. They should be treated as a delicate instrument for rough handling may cause a loose connection or other damage which will be time consuming to find and repair. The components are installed at the bases of the antennas rather than in a central shelter. In 1957, the shelters constructed for the components were too small to permit the entrance of a technician for servicing the equipment, and they were not ventilated. In 1958, the size of the shelters was increased to 4 feet square by 6 feet high and louvers were installed for ventilation. They proved to be satisfactory.

Both shore stations were equipped with voice radios operating on 4160 kc. for communication with the ship. This is one of the frequencies assigned to the Coast and Geodetic Survey.

Power Supply.--The Raydist operates on 115-volt, 60-cycle, alternating current; 950 watts of power are required at the Red station and 700 watts at the Green station. The accuracy of the distances portrayed on the Raydist dials depends on continuity of operation after the ship leaves the point at which the dials are set, so reliable power is a necessity. A power failure at either shore station or aboard ship means that the dials denoting distance fail to turn while the ship continues to move. This often means that the ship has to return to a calibration point unless the power comes back on almost immediately and the missing lanes can be computed by time and distance methods.

Commercial power was used at both shore stations, and an auxiliary generator was installed at the Green station. Several times, when the power failed at this station, the generator was started in sufficient time to permit carrying the lane count forward and continuing the hydrography. It is desirable that each shore station has an auxiliary generator, if the commercial power is subject to frequent failure. When portable generators are used, a standby generator should be ready to start on short notice.

The lines carrying power to the Raydist components should be of sufficient size so that the voltage drop will not be excessive. At the Red station in 1957, the commercial power would frequently drop to a relatively low voltage and it was found that No. 16 wire would not provide the necessary voltage at the components. In 1958, the wire size was increased to No. 10 and no more trouble was experienced from this source. If there is much fluctuation in the voltage, a constant-voltage control should be used.

Shipboard Installation

Three 35-foot whip antennas are required aboard ship. Two receiving antennas, one for the 1639.8 kc. and 3280 kc. signals and the other for the 2492 kc. and 2496 kc. signals, were placed on either side of the top of the foremast. The antenna for transmitting the 3280

kc. signal was placed on top of the mainmast. To produce a stronger transmitted signal a 20-foot section of 1-1/2-inch aluminum pipe was attached to the top of the mainmast with insulated brackets, the top guyed, and the antenna secured in the end of the pipe. The top of this antenna was about 95 feet above the water and the receiving antennas were several feet lower.

The 3280 kc. transmitter was placed in the wardroom which is directly under the mainmast. This component is moderate in size and easily fits against the wall. The remaining equipment was placed in the plotting room aft of the bridge.

The equipment placed in the plotting room consisted of the Navigator, Power Supply, Monitor, Phasemeter, and Brush Recorder. The Navigator, the largest piece, is about 14 by 24 by 30 inches. Its function is to receive the radio signals from the shore stations and the 3280 kc. ship transmitter, and from them produce the 400-cycle current for the phasemeter. The Power Supply converts the 115-volt, 60-cycle alternating current from the main power supply to the voltages used in the equipment. The ship's Raydist equipment requires 1.3 kilowatts of power.

The Monitor is used to measure the frequency of the 400-cycle signals and to listen to the tone of these signals. Its hook-up is so arranged that it can be switched to the 400-cycle difference frequency emanating from either the Red station, the Green station, or aboard ship. This is a very useful function especially when radio interference is present or the power fails at one of the shore stations. The frequency of the 400-cycle signal is usually held between 390 and 410 cycles. If the frequency exceeds these limits the frequency of the 3280 kc. transmitter aboard ship is changed slightly to bring the value within the correct limits. The Phasemeter converts the phase differences in the 400-cycle difference frequency signals into half-wave length lane readings that register on its dials. The Brush Recorder, as used in the Raydist system, makes an inked record on a special tape of the lane changes shown on the phasemeter dials. It is especially useful when interference, or other causes, makes the dials operate erratically.

In addition to the basic Raydist components, a Recorder is used to print the phasemeter dial readings when fixes are desired. In 1957, a Clary Recorder was used. The connection between the phasemeter and this recorder required a large panel of electronic components; while the recorder worked well it was believed that a more simple arrangement would be as effective. In 1958, a Hewlett-Packard Printer was used. With this printer a mechanical-electrical sensing unit placed in the phasemeter provides the electric impulses for the printer. The rigid couplings between the shafts in the phasemeter and those on the sensing units gave some trouble and had to be replaced with flexible couplings, otherwise the printer gave very little trouble. One disadvantage with this printer was that it had a tendency to print erroneous figures when the reading ended in 0.9 lane. To guard against this defect it was necessary for the operator to compare the dial readings on the fix with the printed figures. The printer recorded up to 9999 lanes to the nearest 0.1 lane. In 1959, a Clary Recorder will again be used, but it will be operated from Coleman Digitizers installed in the phasemeter.

In 1957 the shipboard components were placed on temporary shelves. During the winter of 1957-58 they were placed on permanent mountings in the plotting room. A shelf was built along the starboard side of the room, 29 inches above the deck, projecting out 28 inches from the inside edge of the 2 inch house framing, and extending 8 feet forward of the after bulkhead. The phasemeter is mounted on a stand 12 inches high at the forward end of the shelf, where the dials are easily visible to the Raydist reader and to the officer at the plotting table. The Brush Recorder is mounted in front of the phasemeter on a small shelf dropped 5-1/2 inches below the main surface and under a cut-out section 16 inches long and 8 inches wide. This makes it easy to write on the tape as it comes out of the recorder at table level. Then the tape runs along the tabletop for about 16 inches, under a removable plastic cover, before passing through a slot and onto an automatic winding reel fastened to the bottom of the shelf. The printer for the dial readings is mounted aft of the phasemeter on a

platform several inches above the table-top. The monitor for the Raydist is mounted on a small bracket over the phasemeter. The power supply is mounted under the shelf and the navigator just forward of the shelf.

The Raydist equipment takes up the forward 3 feet 9 inches of the shelf and the after part is used to mount two echo sounders, one on the starboard bulkhead and one on the after bulkhead. The electric clock, electric timer for soundings, switches for echo-sounder circuits, etc., are mounted in the corner between the echo sounders where they are readily available to the recorder. Figure 3 is a photograph of the installation.

The electric timer used for hydrography is so connected that it will mark the Brush Recorder tape and the fathogram and will cause the printer to operate. In order to do this the bell in the timing circuit had to be changed from a buzzer to a clapper type bell and a switch installed so that the recorder could select which sounding interval was to be used as a fix. Switches were also installed making it possible for the Raydist reader to cause the printer to print without depending on the recorder.

FIG. 3.--Raydist and echo-sounder installation aboard ship *Hydrographer* in 1958.

Radio Signals

It is necessary that the radio signals emitted by the four transmitters be received continuously if the lane count as portrayed by the phasemeter is to remain correct. Momentary breaks in the radio reception may not be harmful, but breaks of any considerable length will require resetting of the phasemeter dials at a known point, except in cases where the loss, or gain, of lanes can be computed.

When the first trial trip was made to test the Raydist it was found that the 2492 kc. and 2496 kc. transmitters at the shore stations were interfering with the reception of the 1639.8 kc. and 3290 kc. signals. This was evidenced by the instability of the phasemeter aboard ship, especially the R-2 dial for the ship was about 150 miles from the Green station. Filters were added in the receiving circuits at the shore stations to correct the trouble.

In 1958, a duplexed antenna was used at the Red station, a 100-foot tower antenna to transmit the 1639.8 kc. signal and a 35-foot whip antenna on top of the tower to receive the 3280 kc. and 1639.8 kc. signals. To get satisfactory results from the duplexed antenna, it was necessary to decrease the percentage of modulation and signal strength of the 2496 kc. transmitter at this station. This lessened the strength of the signal received aboard ship to the point where it did not have satisfactory strength at a distance of 100 miles. A second filter was then installed and the percentage of modulation and signal strength were increased to satisfactory levels. The signal strength of the 1639.8 kc. signal from the Red station was the same in 1958 as in 1957. During the first year, it was unusual for outside interference to affect the measurement of distance as shown by the R-1 distance dials in the phasemeter. In 1958, however, interference from outside sources and from atmospheric conditions was noticeable and it was found that a useable signal was not received from the Red station at a distance of 175 miles. While at the same time a strong signal was received from the Green station at a distance of 225 miles. Therefore, if the Raydist is to be used at distances of over about 125 to 150 miles from the Red station, the antennas at that station should not be duplexed.

Aboard ship with the two receiving antennas on the foremast and the transmitting antenna on the mainmast, a cor-

rection is applied to the R-1 and R-2 distances as the angle between the ship's head and a line to either shore station changes. This is due to the eccentricity of the antennas from the mean point of radio emission and transmission. (This is discussed below.) To eliminate this correction it would be desirable to move the transmitter antenna from the mainmast to the foremast and to duplex it with the 1639.8 kc. receiving antenna. Signal strength measurements made aboard ship indicate that it might be feasible to do this, but it was not attempted in 1958 due to the distance from the shore stations at which the ship was working.

In addition to the frequencies of 3280 kc. and 1639.8 kc. which determine the width of the half-wave length lanes portrayed on the phasemeter dials, two other frequencies are needed to transmit the 400-cycle beat signals back to the ship from the shore stations. On the *Hydrographer* frequencies of 2492 kc. and 2496 kc. were used for this purpose, but other frequencies could be used without affecting the length of a half-wave lane. At the beginning of the 1957 season, the 2496 kc. transmitter was at the Green station, Southwest Harbor, Maine. In this location the local fishermen reported that the transmitter caused interference with the receipt of messages from the Boston Marine Operator broadcast on a frequency of 2505 kc. To lessen this interference the 2496 kc. frequency was interchanged with the 2492 kc. transmitter used at the Red station, Wellfleet, Mass. Both frequencies are crystal controlled, but it is possible that the receivers used aboard the fishing boats were not selective enough to filter out a signal only 9 kc. away from desired signal. The 2492 kc. transmitter still caused a minor amount of interference in the vicinity of Southwest Harbor.

Interference on any of the four radio frequencies used in the Raydist system will affect the operation of the lane counters in the phasemeter. In the *Hydrographer*'s system, interference from other radio transmissions appeared to be confined principally to the 2492 kc. and 2496 kc. bands. These frequencies appear to have considerable use by agencies other than the Coast and Geodetic Survey. None of the other users of these bands appeared to be nearby, but at times when the skywaves would permit signal reception from distant points the interference on these bands would often be the deciding factor as to whether the Raydist could continue to be used because of uncertainty in the lane count. With the monitor switched to the shore station using the 2496 kc. carrier frequency it would often be possible to hear the signal from the Boston Marine Operator on the 2505 kc. frequency almost clearly enough to make out the words. Interference of this type did not appear to affect the Raydist as long as the Raydist signal being received aboard ship was strong and steady.

Groundwaves and Skywaves.--Raydist is a phase-measuring system and normally it operates by reception of the groundwave transmitted from the various radio transmitters to the receivers. If the skywave is received, it will be out of phase with the groundwave and the phasemeter will react to this difference in phase. In the area where the *Hydrographer* was working the distance to the Green station was about 150 miles and the skywave would normally begin to be received shortly after sundown and would continue to come-in until sunup. The interference caused by the skywave would depend on the relative strengths of the groundwave and the skywave. With the groundwave still coming in stronger than the skywave the phasemeter dial pointers will oscillate through an arc that increases in size with the strength of the skywave, but usually will not exceed about a half lane. With further increase in the strength of the skywave as compared to the groundwave the size of the oscillations increases. If the skywaves are coming and going, the dial pointers may oscillate through a full lane or more and still return to the correct lane count. When the oscillations reach this size, extra lanes will frequently be added or subtracted from the lane count, and then a few moments later the lane count may be corrected. A continuous skywave signal stronger than the groundwave signal gives such erratic operation that it is impossible to keep track of the lane count. One night in 1957, prior to adding the first set of filters at the shore stations, skywave conditions caused the dial indicating the R-2 distance to add 106 lanes in a space of several minutes. Normally the extra lanes are added or

subtracted one or two at a time, although the total can be considerably more than this.

The working grounds on Georges Bank are about 100 miles from the Red station and 150 miles from the Green station. During daylight hours and normal weather conditions the groundwave strength was sufficient to keep the dials locked to the proper lane count. In 1957 the R-1 dial pointer was very steady, but in 1958 after duplexing the antennas at the Red station the dial pointer was less steady, that is, it had movement other than that related to the movement of the ship. In both years the R-2 dial pointer was less steady than the R-1 dial and it was not unusual for it to oscillate through an arc of several tenths of a lane. There was usually no question of any loss of R-2 lanes due to this movement but it does show the lessening strength of the groundwave with increasing distance.

On normal days the coming of darkness meant the beginning of skywave reception. Their effect would usually begin to be noticed one or two hours after sunset, although on some days the effect seemed to appear with the disappearance of the last rays of the sun. If the lane count could be carried through this initial period of skywave interference, the Raydist would often settle down and operate with normal stability for several hours longer. The nights when the lane count could be carried past midnight were very limited in number. In 1957, there were only four nights when the Raydist continued to operate the entire night, and in 1958 there were an equal number. On only one of the nights in 1957 and on two nights in 1958 there were no gains or losses of lanes during the night. A point of interest in this connection is that one of the nights of continuous operation occurred in September 1957 on a night when the northern lights were very prominent and normal radio reception was very poor. The good Raydist conditions on this night could be due to the fact that the northern lights canceled out the skywaves and the reception of other radio signals from distant points. In 1957, the best conditions for night operation came in September, while in 1958 they occurred earlier in the year.

On the working grounds the phasemeter dials had to be set by visual methods, so if the lane count was lost at night survey operations could not be resumed until daylight. Frequently when the Raydist was left turned on after survey operations had ceased due to loss of the R-2 lane count, it was noted that often after a burst of skywave activity the groundwave would then come in strong and the R-2 dial would be relatively stable, while at other times the skywave effect would be present all night. On most mornings the skywave effect would be noticeable right up to the time the sun came up over the horizon, with frequently an especially bad burst of activity a few minutes before sunrise.

The effect of the skywave interference was noticed principally in the R-2 distance, and it was rare for the R-1 dial to lose or gain lanes even with the R-2 dial inoperative due to the skywave effect. The distance to the Green station was about 150 miles as compared to 100 miles to the Red station and this was probably the principal cause of the disparity in dial action. If the distance to the Green station had been not over 100 miles, it is likely that the Raydist would have kept the R-2 lane count on more nights. To make the R-2 dial comparatively as stable as the R-1 dial the distance between the shore stations would have to be decreased to about 100 miles, in place of the 165 miles used in 1957 and 1958. This is because the 1639.8 kc. signal transmitted at the Red station is received at the Green station. Also, the R-2 distance signals have to travel along all three sides of the triangle as compared to only one side for the R-1 signal, and the path from the Red to the Green station is usually close to land where propagation conditions are poorer than over water. If no distance in the Raydist net exceeded 100 miles it is possible that the survey ship could operate 24 hours a day on most days without having the skywaves interfere with the lane count.

At the end of the 1958 survey season the distance to the Green station had increased to about 175 miles. In the daytime the R-2 signal was very strong. At night the conditions were quite similar to those for shorter distances, except for one week when the radio reception conditions were poor for the Raydist and the hours of operation were restricted almost exactly to the daylight hours.

Interference.--The monitor, located aboard ship, besides giving the frequency of the 400-cycle difference frequency can also be used to listen to the 400-cycle signal as originated at the ship or at either shore station. It is normally kept turned to low volume or turned off, but when action of the phasemeter dials or the pens on the Brush Recorder indicate interference it is turned up to an audible volume. The quality of the tone will then help locate the source of the interference. Skywave interference produces a distinctive beat note that is easily recognizable, precipitation static has a steady crackling noise, and interference from other radio broadcasts is readily apparent. No tone means loss of power or equipment failure.

The passage of a weather front, or thundershower conditions, will cause interference with the Raydist. It is worse to have the center of the disturbance in the vicinity of either the ship or one of the shore stations, but it may also cause trouble if the disturbance is along any one of the radio paths. The monitor will indicate the presence of a disturbance by a crackling static noise when it is turned up in volume. Aboard ship the possibility of interference frequently can be detected on the radar. Some times the rain clouds as seen on the radar will cause interference and some times not, but the chances are that they will, especially if rain is falling on the ship. A steady rain without heavy static does not appear to have any adverse effect, although the beginning of the rain may cause interference. The type of interference produced by precipitation static is similar to that produced by turning the power off, the dials stop turning except for an occasional waver. The condition may last for a few minutes or several hours. The normal condition is a coming and going condition where the Raydist is off and on several times in a period of an hour or so. Usually when precipitation static causes a loss of lane count, it is necessary to run an hour or more to a calibration point. Frequently the Raydist can be recalibrated on arrival at the point, but often it is necessary to anchor and wait for the atmospheric conditions to improve.

One other type of radio interference that should be mentioned is a special condition wherein the ship is operating near one of the shore stations. In 1957 and early 1958, it was noted that after calibrating the Raydist dials northwest of Provincetown on Cape Cod (see fig. 1) the R-2 dial would frequently lose lanes when the ship passed to the eastward of Cape Cod Light and the path from the ship to the Red station was principally over water. The interference was attributed to a large radar station on the northeast end of the cape.

The real reason for the loss of R-2 lanes was discovered one morning in 1958 when the ship was brought to a point about five miles east of the Red station to calibrate the Raydist prior to making a run offshore to determine another position on the Texas Tower. This particular morning no signal could be received from the Green station. The equipment aboard ship and at the Green station was checked for defects and none were found. The 2496 kc. transmitter at the Red station was then turned off and with it off the 400-cycle difference signal as transmitted by the 2492 kc. transmitter at the Green station came in loud and strong on the Monitor. The source of the trouble was the strong signal from the nearby 2496 kc. transmitter feeding through the filter in the R-2 circuit and causing the automatic volume control to operate and to blank out the weaker 2492 kc. signal coming from the Green station. The condition was remedied by having the operator at the Red station drastically decrease the percentage of modulation of the 2496 kc. transmitter, and then to increase it again in steps as the ship proceeded away from the station. If the survey ship is to operate frequently in the vicinity of one of the shore stations, some easy method should be provided for decreasing and again increasing the strength of the carrier frequency signal.

Lane Width and Distance

In the DM-Model Raydist used on the *Hydrographer* the transmitter aboard ship determines the width of an R-1 lane, or half-wave length. For a frequency of 3280.000 kc. the lane width is 149.87307 feet, which is obtained by dividing the velocity of propagation of the radio wave, 983,167,315 feet per second, by 3,280,000 and then dividing the quotient by 2.

The R-2 distance and the width of an R-2 lane are complicated by the fact that an elliptical method is used to measure the sum of the R-1 and R-2 distances, and then the R-1 distance is subtracted in the phasemeter. In 1957, the manufacturer stated that the length of an R-2 lane was 149.836 feet, but in the winter of 1957-58 a recomputation was made and the following formula derived:

$$\text{R-2 distance (in feet)} = 149.87307\,Pg + 0.00012\,(\text{R-1} - \text{R-2}) \quad (1)$$

where

Pg = phasemeter reading of the Green station in lanes
R-1 = distance to Red station in feet
R-2 = distance to Green station in feet

The above formula is difficult to use in the field, but it can be reduced to another form that allows a correction to be computed when the ship moves from the calibration point, where the dials are set, to any other point. The correction formula is

$$X = +0.00012\,[(Pr'' - Pr') - (Pg'' - Pg')] \quad (2)$$

where

X = R-2 correction in lanes
Pr'' = phasemeter dial reading of Red station at the calibration point
Pr' = phasemeter dial reading of Red station at the desired point
Pg'' = phasemeter dial reading of Green station at the calibration point
Pg' = phasemeter dial reading of Green station at the desired point

The correction formula is used with a lane width of 149.87307 feet, the same as for the R-1 distance, and no correction is applied when the dial is set at the calibration point.

The correction formula can be derived by consideration of the elliptical method used to measure the R-2 distance. In the sum of the R-1 and R-2 distances the R-1 distance is measured by the 1639.8 kc. frequency, doubled to 3279.600 kc. and transmitted from the Red station to the ship. This is 400 cycles less than the effective frequency of 3280.000 kc. used to measure the R-1 distance that is subtracted in the phasemeter.

The R-2 distance in the sum of the R-1 and R-2 distances is measured directly, but by an effective frequency of 3280.400 kc., which is 400 cycles larger than the frequency used to compute the lane width. The 3280.400 kc. frequency results when the 3280 kc. signal received at the Green station is transmitted back to the ship as a 400-cycle difference frequency. Computing the correction is a matter of proportion and the factor 0.00012 is the quotient when 400 is divided by 3,280,000.

No attempt was made to determine the maximum distance at which usable signals to operate the Raydist could be obtained. As mentioned previously a usable signal was obtained from the Green station at a distance of about 225 miles, but at the same time the Red station signal was not usable at an R-1 distance of 175 miles due to having duplexed antennas at the Red station. The Decca navigation system charts carry notes to the effect that the position accuracy is doubtful beyond a distance of about 240 miles from the network stations. It is believed that somewhat the same limitation would apply with Raydist. Under good conditions it was determined that the Raydist operations are not seriously curtailed by increasing distance, but when radio wave propagation conditions are below normal, distance has an adverse effect.

Shipboard Origins of Distances

The point aboard ship from which the R-1 distance is measured is midway between the 3280 kc. transmitter on the mainmast and the 1639.8 kc. and 3280 kc. receiving antenna on the foremast. On the *Hydrographer* the distance between the masts is about 100 feet, or 0.7 Raydist lane, so the origin point for the R-1 distance is 0.35 lane aft of the foremast.

The origin of the R-2 distance cannot be defined as a single point, but must be expressed in a formula. This is due to the elliptical method used to measure the R-2 distance and because the R-1 distance is subtracted in the phasemeter. The formula for the R-2 origin point is best expressed as a correction formula to reduce the R-2 distances as indicated by the phasemeter dial to what they would

be if they were measured from the foremast. The formula is

$$Y = 0.35 \cos (SH - Ar) - 0.7 \cos (SH - Ag) \quad (3)$$

where

Y = R-2 correction in lanes
SH = ship's heading by gyrocompass
Ar = azimuth from ship to Red station
Ag = azimuth from ship to Green station

As stated above, the R-1 distance in the sum of the R-1 and R-2 distances is measured to the foremast, while the R-1 distance subtracted in the phasemeter is measured to a point midway between the masts, and R-2 distance is measured to the mainmast. These various origin points are reduced to the foremast by the formula.

RAYDIST-CONTROLLED HYDROGRAPHIC SURVEYS

Of prime concern when using electronic equipment to control hydrographic surveys is instrument reliability. The Raydist appears to be reliable and stable and to give long periods of trouble-free operation. It is necessary though, to pay attention to small details. Any type of interference will affect the stability of the lane count, and even though the interference itself may not be of sufficient magnitude to cause skipped lanes it will hasten the time when other interference will do so. In 1957, the Electronic Position Indicator was also used at the shore stations. At the Red station a relay switch was installed to permit a rapid change of one tower antenna from the Raydist to the EPI circuits. The relay connection was satisfactory, but the arrangement of the leads and the disposal of the surplus end wire was not, and this connection gave trouble until it was removed. Later on it was replaced in a satisfactory manner and gave no further trouble.

The failures of the component parts during the two seasons of use were limited in number and mostly of a minor nature. The potentiometers in the phasemeter that furnish the power to operate the Brush Recorder gave some trouble and had to be replaced. The need for new potentiometers is indicated by a poor record on the Brush Recorder tape and the failure of rapid spinning of the phasemeter dials to correct the trouble. The manufacturer indicated, early in 1959, that it was testing a new potentiometer which seems more serviceable and less expensive. If they prove successful, the *Hydrographer*'s Raydist will be equipped with these units.

In May 1957, the manufacturer assigned two of its technicians to help install the Raydist equipment at the shore stations and aboard ship. When survey operations began one technician sailed to the working grounds with the ship. In addition to giving personal instruction to the Coast and Geodetic Survey electronic technicians aboard ship, he was available for consultation by radio with the technicians at the shore stations. Before he returned to his company in the middle of September, he spent one 10-day trip to sea running an instruction school for the shipboard technicians, then just prior to leaving he visited each shore station while the ship was at sea and serviced the equipment and gave instructions to the electronic technicians at the shore stations. After the departure of the company technician, the electronic technicians attached to the ship had no trouble keeping the equipment in operating condition.

Personnel at Shore Stations

The Raydist at the shore station will operate automatically once it is turned on and providing the source of power is reliable. Since the ship was operating at some distance from the shore stations, it was deemed advisable to have a man on watch at each shore station during the time the Raydist was in operation. On the Georges Bank project the normal hours of operation were from sunup to several hours after sundown. Two men at each station were sufficient to cover this period and not exceed eight hours of duty for each man. The normal procedure was to have one man come on duty about one-half hour before sunrise and then have the men on duty continuously for sixteen hours. If it was desired to have someone on duty later in the night the station would be left unattended during part of the daylight hours. Also if the

Raydist should operate during the night it would be left unattended. When not in use, the transmitters are usually turned to a standby position and the other equipment is turned off.

An electronic technician was assigned to each shore station and the second man at each station was a seaman from the ship. The least experienced technician was assigned to the Red station on Cape Cod because this station could be reached in less time should a condition develop that could not be corrected by the assigned technician. It is believed that this condition outweighs consideration of the fact that the Red station has more equipment than the Green station. When the seaman was on duty the electronic technician was available at his place of residence and could be quickly reached.

The personnel at the shore stations are always instructed to inform the ship, via radio, immediately when anything interrupts the Raydist operation. A power failure of short duration at either station may not be readily noticeable aboard ship if the ship is turning at the time the failure occurs. Also a break in the signal from the R-2, or Green, station may not be easily recognized aboard ship if the ship is proceeding on certain courses. This is due to the elliptical method used to measure the R-2 distance and the hookup between the R-1 and R-2 dials.

Checking Shipboard Origin Points

During the 1957 survey season, there was some question as to the location of the origin points for the R-1 and R-2 distances aboard ship since at that time the formula previously given in this Bulletin for the R-2 origin had not been developed. Early in the 1958 field season, a test was made to determine the shipboard origins by actual observations. To do this the ship was anchored in Provincetown Harbor, at the end of Cape Cod, in a position where there was a strong three-point sextant fix. Anglemen were then placed on top of the pilothouse and near the foremast, and they took angles from this position as the ship was swung around the anchor. Simultaneous angles and Raydist dial readings were taken for each 15° increment of gyrocompass heading for the entire circle.

Each fix was plotted on a 1:20,000 aluminum-mounted sheet having R-1 and R-2 distance circles, in lanes, and signal positions. The R-1 and R-2 distances were scaled off and subtracted from the observed values to determine dial errors on each heading. To take out the initial error in setting the dials the errors for each dial were meaned algebraically, and the mean error subtracted from the individual errors. The azimuth from the ship to each shore station was scaled from the plotting sheet and subtracted from each ship heading, to obtain the relative ship heading with the direction to the shore station as the initial.

A curve for each distance was then plotted as shown in figure 4, where the abscissa is the relative ship heading and the ordinate is the distance error. The R-1 curve is almost a perfect cosine curve with approximately 0.35 lane correction on relative headings of 000° and 180°, and with a negligible correction on headings of 90° and 270°, as would be expected from the previous discussion and with the origin point referred to the foremast.

The R-2 curve is similar to the R-1 curve but in its present form it does not tell too much about the original point. The R-2 curve was replotted using polar coordinates and the new curve is shown in figure 5. In this figure the azimuths are supplements of those used in figure 4, or azimuths to the Green station relative to the ship's head. The radial lines are distance errors.

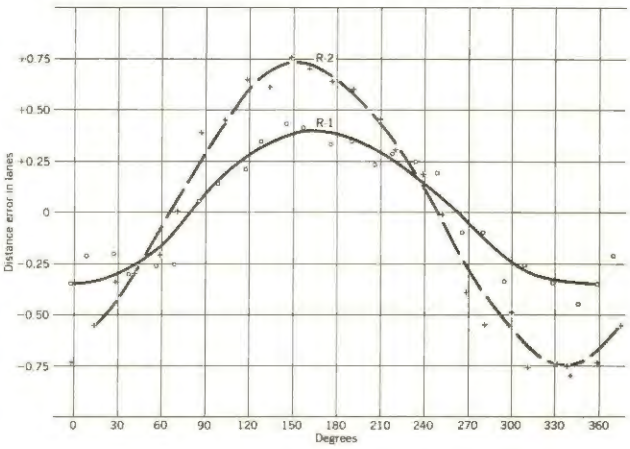

FIG. 4.--Distance corrections as related to ship's heading. Tests made at Provincetown Harbor, June 4, 1958.

In figure 5 a circle with a radius of 0.35 lane can be drawn through the distance error points. This is the result of the 0.35 lane distance between the origin points for the R-1 distance as measured in the sum of the R-1 and R-2 distances and the R-1 distance as subtracted in the phase meter, as discussed earlier in this Bulletin. At the point where this test was made the azimuth to the Red station is almost exactly 90° to the right of the azimuth to the Green station. The circle mentioned above can be drawn when the right angle condition exists, but at other places the figure will be an ellipse. The R-2 curves shown in figures 4 and 5 agree with the formula given in a previous section.

The correctness of the R-1 and R-2 correction formulas was also checked in another manner. When the ship is on the baseline between the Red and Green stations, as determined by sextant fixes, the difference between the sums of the dial readings with the ship headed first towards the Red station and then towards the Green station should be equal to the sum of the corrections for the two ship headings. The sum of the corrections was 1.4 lanes which was exactly the difference between the sums of the dial readings.

Corrections to Raydist Distances

When phase-comparison methods are used to measure distance, the instrument errors found in shoran and the Electronic Position Indicator are not encountered. The velocity of propagation of radio waves traveling over water are known to within a very small percentage of error so once the Raydist dials are accurately set there is no additional error that is a function of the distance. An exception to this would be where the amount of land between the ship and the shore station varies from place to place. There will be no error if the Raydist dials are set under the same conditions as they are used in the survey. Methods used to set the dials at the initial point are discussed below.

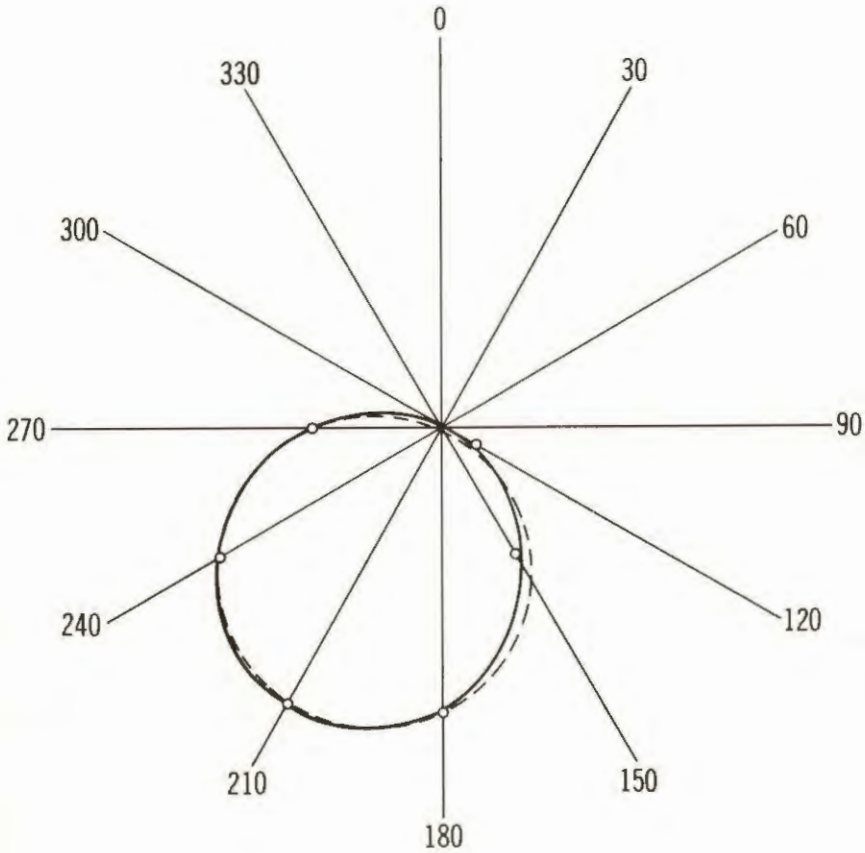

FIG. 5.--R-2 corrections where R-1 station is 90° to right of azimuth to R-2 station. Plotted azimuths to R-2 station minus ship's heading or 360° minus azimuths in fig. 4.

Aboard ship it is desirable, when engaged on large-scale surveys, that the distances be measured to the point where the transducers for the echo sounders are installed. On the *Hydrographer*, the transducers are several ship frames aft of the foremast so it was decided that all distances should be corrected to what they would be if measured from this mast.

The correction formulas for distance in lanes are

$$W = -0.35 \cos (SH - Ar) \quad (4)$$

$$Y = 0.35 \cos (SH - Ar) - 0.7 \cos (SH - Ag) \quad (3)$$

where

W = R-1 correction in lanes
Y = R-2 correction in lanes
SH = ship's heading by gyrocompass
Ar = azimuth from ship to Red station
Ag = azimuth from ship to Green station

To apply the above corrections would be laborious if all course changes necessary to maintain the ship on the sounding line were considered, and if minor changes in azimuth to the Red and Green stations were taken into account. On the Georges Bank project the change in azimuth to the shore stations was slow, as evidenced by the flatness of the distance arcs, so a mean azimuth for each hydrographic sheet could be used without introducing appreciable error. The ship's head was taken as the azimuth of the guideline for the sounding line being run. Figure 6 shows a table of corrections for one of the survey sheets.

Two additional corrections may be necessary for the R-2 distance. One of these is due to the way the antennas are arranged at the Red station. With the duplexed antenna as used in 1958, no correction is necessary. With the three antenna arrangement used in 1957, a correction is necessary and it will be

$$Z = d \cos (As - At) \quad (5)$$

where

Z = correction to R-2 distance in lanes
d = distance in lanes between 1639.8 kc. broadcasting antenna and Red station mark
At = azimuth from station mark to antenna
As = azimuth from station mark to ship

Figure 7 shows the correction figure for these corrections. It should be noted that the curve has been drawn so that the abscissa is the azimuth from the ship to the shore station rather than the reverse.

In 1957 when the Raydist was received, the manufacturer indicated that the position of the 1639.8 and 3280 kc. receiving antenna at the Red station determined the size and sign of the R-2 distance correction, in place of the transmitting antenna. The change in antennas has no effect on the size of the correction but it does change the sign. All surveys made in the 1957 survey season were affected by this change in the sign of the correction.

The other R-2 correction results from the elliptical manner in which the R-2

Correction Table for Ships Head
(Vicinity of Texas Tower #2)

Ships Head	ΔR_1	Ships Head	ΔR_2
000 - 005	0.0	344 - 002	-0.6
006 - 020	+0.1	003 - 038	-0.7
021 - 036	+0.2	039 - 054	-0.6
037 - 063	+0.3	055 - 068	-0.5
064 - 107	+0.4	069 - 079	-0.4
108 - 138	+0.3	080 - 088	-0.3
139 - 156	+0.2	089 - 097	-0.2
157 - 173	+0.1	098 - 105	-0.1
174 - 188	0.0	106 - 113	0.0
189 - 204	-0.1	114 - 123	+0.1
205 - 222	-0.2	124 - 131	+0.2
223 - 249	-0.3	132 - 141	+0.3
250 - 291	-0.4	142 - 152	+0.4
292 - 318	-0.3	153 - 165	+0.5
319 - 336	-0.2	166 - 183	+0.6
337 - 351	-0.1	184 - 216	+0.7
352 - 005	0.0	217 - 233	+0.6
		234 - 249	+0.5
		250 - 260	+0.4
		261 - 269	+0.3
		270 - 277	+0.2
		278 - 286	+0.1
		287 - 294	0.0
		295 - 303	-0.1
		304 - 311	-0.2
		312 - 321	-0.3
		322 - 331	-0.4
		332 - 344	-0.5

Ships head in degrees true.
$\Delta R_1 + \Delta R_2$ in Raydist Lanes.

FIGURE 6

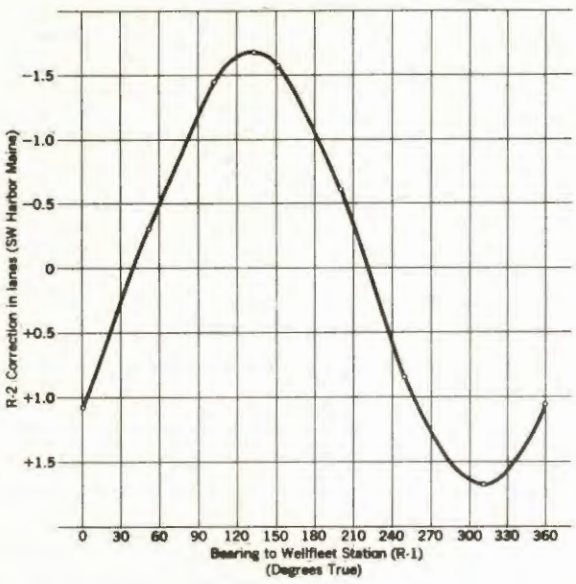

FIG. 7.--Corrections for eccentricity of 1639.8 kc. transmitting antenna at Red station, as applied to R-2 distance.

distance is measured and the correction is

$$X = +0.00012 \; [(P_r'' - P_r') - (P_g'' - P_g')] \quad (2)$$

This formula is described under Lane Width and Distance, above. This correction will need to be applied only as the ship moves away from the point at which the dials were set. In general, these corrections can be neglected while the survey is in progress and only used in computing the final Raydist distances for the smooth sheet.

Determining Dial Setting Errors

The Raydist phasemeter is so constructed that the distance counters can be changed manually in two ways. Each dial has a rapid-motion switch that permits the pointer to be moved in either direction at high speed. A slow-motion switch on the R-1 dial permits one lane to be added or subtracted as the knob is turned one revolution in the appropriate direction. The slow-motion switch on the R-2 dial will add or subtract two lanes for one full turn of the knob. The slow-motion knobs are graduated in tenths of lanes, but it was found advisable to always leave them set at 0.0.

The rapid-motion switch on the R-1 dial will not affect the R-2 dial at the beginning and during the rapid movement, but when the switch is turned off very frequently the R-2 pointer will add or subtract a turn or two because of the momentum of the R-1 pointer and the elliptical connection in the phasemeter. The rapid-motion switch in the R-2 circuit has no effect on the R-1 dial. The slow-motion switch for the R-1 dial will affect the R-2 pointer in the same amount as the R-1 pointer is moved, but in the opposite direction. The slow-motion switch for the R-2 dial does not affect the R-1 dial.

Because of the possibility of moving the R-2 dial during the setting of the R-1 dial, it is good practice to always set and calibrate the R-1 dial first. On the approach to the calibration area both dials are moved to approximate values by means of the high-speed switches. This can take several minutes or more if the ship has travelled a considerable distance since the Raydist was last used. One or more lanes can be put in with the rapid-motion switch by using considerable care, but it is often better to use the slow-motion switch for this purpose.

Three methods were used to set and calibrate the Raydist dials: three-point sextant fixes plotted on a 1:20,000 aluminum mounted calibration sheet; running the ship along a distance arc as determined by gyrocompass bearings to a buoy, lighthouse, or other fixed object; and circling a buoy, or passing by a fixed object. Regardless of the method used, several trial positions were generally taken in order to set the dials to approximate values before taking the observations to determine the dial setting error. It was standard practice never to move the dials to a new setting by manual methods once the dial error had been determined. If the dial error as determined was considered too large, the dial was reset and then recalibrated at the new setting, the previous calibration being rejected. All data for setting and calibrating the dials were kept in a bound book.

To set the dials by use of sextant angles, it is best to place the anglemen on the flying bridge, relatively near the foremast. The ship is stopped in the water and several trial fixes are taken to set the

dials to approximate values. Then a series of three angle sets and simultaneous phasemeter dial readings are taken, the ship's heading is recorded for each fix. The observed dial readings are corrected for the error due to the ship's head and for the azimuth correction due to the antenna placement at the Red station, if applicable. The resulting value is subtracted from scaled distance for the three-point fix as plotted on a large-scale aluminum plotting sheet. This gives the correction to be applied to the dial reading to arrive at true distance. If the three values for each dial do not agree within a few tenths of a lane of each other, the calibration should be repeated. The three values are meaned for the final correction.

To set the dials at a buoy or fixed object, it is necessary to know the R-1 and R-2 distances of the object, either by scaling from a large scale plotting sheet, from an inverse computation for a fixed object such as a lighthouse, or for a buoy by a previous determination by Raydist methods. The azimuth, and its complement, of the distance arc for each station at the object location is then scaled from the plotting sheet or obtained from the inverse computation. To set the dials by running along the distance arcs, the ship is headed towards the buoy along a line that has the same gyrocompass bearing as the azimuth of the distance arc, taking into account gyro errors. As the ship approaches the object or buoy the dial is set to the correct reading. When the ship is near the object or buoy, and on the bearing line, the R-1 dial is read three times and the ship's head is also noted for it may be considerably different from the gyro bearing. With this method it is advisable to set the R-1 dial first. The safety of the ship being considered, it is advisable to be as close to the object or buoy as is practicable. On Georges Bank when calibrating on the Texas Tower, the ship was always within 0.5 mile of the tower before the dials were calibrated. The method of computing the dial correction is the same as for the three-point fix method, if the object sighted on is a fixed object. For a buoy it is necessary to apply a correction for the scope of the anchor chain. This method of calibrating the dials should only be used when the distances from the shore stations are large and the curvature of the distance arcs is small. If the curvature in the arcs is large, a correction will need to be applied. The use of calibration buoys are discussed below.

The method of circling a buoy is probably the easiest and fastest method of all to use. The method passing by a fixed object is usually confined to periods of limited visibility since normally it is best to run a bearing to these objects. To set the dials by the circling method, it is necessary to have the same knowledge of the distances and the azimuths of the distance circles as for the method outlined above. Since events move rapidly in this method, preparation must be made by writing down on a sheet of scratch paper, for use by the hydrographer who will con the ship while observing the buoy bearings by pelorus, the azimuth and its supplement for each distance arc. With this information at hand and as the ship circles the buoy at slow speed, the hydrographer mans the alidade at the gyrorepeater calling out, "R-1 bearing 100° coming up," as the R-1 bearing is approached and, "Mark," when the bearing is reached. He then repeats for the R-2, and again for the R-1 and the R-2, using the supplementary bearings and completing the circle around the buoy. The swing of the ship should be checked before each bearing, and if necessary the propeller speed should be increased momentarily after a bearing to hasten the swing of the ship. The dial reading applicable to the bearing is noted at each mark and is recorded along with the ship's heading. The dial correction is computed as given above.

The method is the same when using a fixed object except that instead of circling the object it is passed twice, once with bearings to the right and again with bearings to the left of the ship. The two values obtained for each distance should check within a few tenths of a lane or they should be repeated.

In the dense and prevalent fog encountered on Georges Bank, it was frequently necessary to use a variation of these methods. For a buoy that could be picked up on the radar, the ship would be conned to approach the buoy the same as though the buoy were to be picked up, that is against the current. With the ship stopped and the bow very near the buoy

the Raydist dials would be set and read, the ship's head noted, and an azimuth to the buoy taken. A correction was then applied to correct the position of the foremast to that of the buoy.

On Georges Bank the dials were also set at the Texas Tower in the fog. To do this the ship would be headed towards the tower by radar on a course normal to the R-1 distance arc. As the tower was approached the course would be changed sufficiently to keep the ship clear of the tower but to keep the tower leg in sight. Once in sight of the tower it was usually not difficult to complete the calibration due to the large bulk of the tower. The only difficulty was with the strong currents in this area.

When using buoys to set the dials much work can be saved, if a procedure is followed that permits the buoys to be found with a minimum loss of time. The buoys could often be picked up on the radar, but this was not true when the sea was choppy or the buoy had lost its radar reflector. The procedure followed was always to keep the best lane count possible on the phasemeter even though the dial count might be lost for a period of time. On Georges Bank, the ship was anchored after the loss of lane count due to sky-waves or other reasons. Since usually only the R-2 lane count was lost, the Raydist would be left on until the ship anchored; during the run to the anchorage, usually near a calibration buoy, an effort would be made to maintain an approximate count of the R-2 lanes. In the morning, the Raydist would be turned on before heaving in the anchor and the dials reset, if necessary to allow for the change in position of the ship with reference to the anchor during the night. With this information available it was usually an easy matter to run down the R-1 distance arc and find the buoy. If it was foggy it might be necessary to run several distance arcs, with a spacing depending on the visibility. Often the bottom configuration in the vicinity of the buoy would be of help.

If it was necessary to locate a buoy in the fog, that could not be picked up by radar and the raydist dials were not set to approximate values, loran would be used to obtain an initial position. To do this, the ship would be stopped and a loran position taken and plotted on the largest-scale navigation chart available. The position would then be transferred to the survey sheet and the Raydist distances scaled. These values would then be set on the dials and used in the search for the

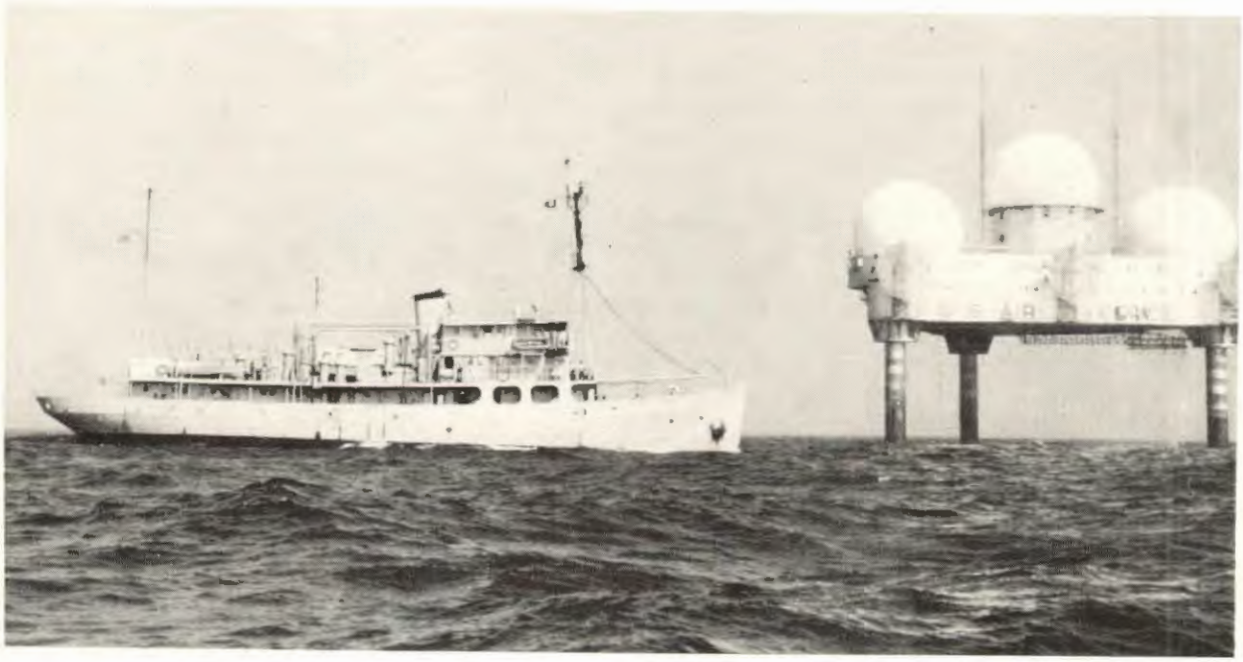

FIG. 8.--Texas Tower No. 2 on Georges Bank and ship *Hydrographer*.

buoy as described above. Good results were obtained by this method.

Reference Points for Use in Setting the Phasemeter Dials

When making a hydrographic survey in an offshore area, it is necessary to have reference points for setting the Raydist dials in the immediate area of the survey. The Texas Tower on Georges Bank, U.S. Air Force radar station, made an excellent permanent reference point. The depth of the water in the immediate vicinity of the tower is about 8 to 9 fathoms so the *Hydrographer* could come close to the tower. The southwest leg, the legs are 10 feet in diameter, was selected as the reference point and several runs were made between Cape Cod and the tower to determine the position of this leg. Good agreement was obtained between the runs made in 1957 and 1958. Figure 8 shows the tower and the Ship *Hydrographer*.

The tower leg was used as the reference point when setting the Raydist dials for the 1:10,000 scale survey in that vicinity. A fixed reference point should be used for surveys at this scale so as not to introduce errors due to movement of the reference point. For surveys at some distance from the tower, and at scales of 1:20,000 and 1:40,000, buoys were used as reference points for setting the dials. For 1:20,000 scale surveys it was considered sufficiently accurate to plant buoys in depths as deep as 12 to 15 fathoms, and for scales of 1:40,000 the depth was increased to 25 fathoms. For scales smaller than 1:40,000 the depth can be increased further.

The buoys used were mine marker buoys 30 inches in diameter. Three automobile engine blocks were used as an anchor, and the anchor line consisted of 1/2-inch steel cable from the buoy to about 1 fathom above the bottom and the remainder was 3/8-inch chain. The scope was usually 1.4 to 1.5:1. The buoys would usually be under the water when a swell passed over, but in two years of use no buoy dragged anchor and only one was lost. This loss was ascribed to the use of too long a piece of cable below the buoy and it probably chafed on the bottom.

If buoys are used to set the dials, it is necessary to take into account the scope

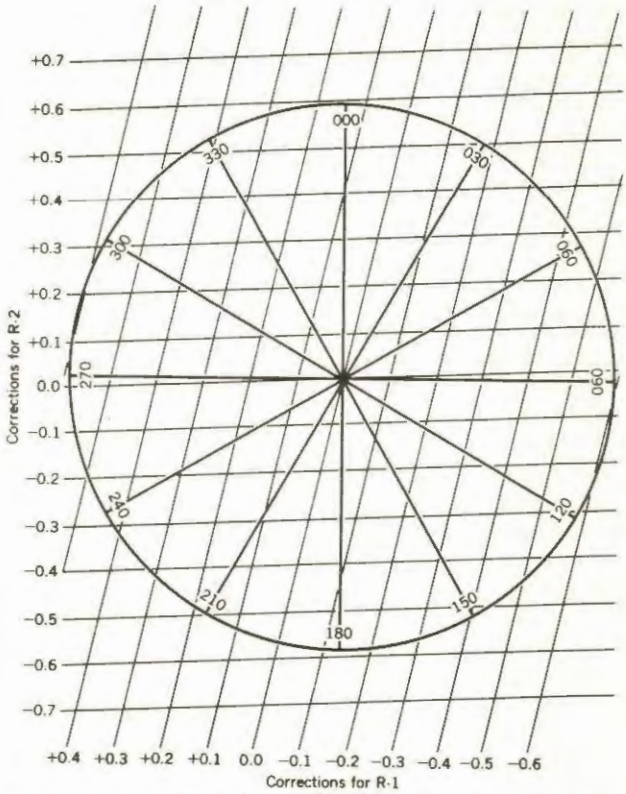

FIG. 9.--Anchor line slope corrections when dials are set at buoys. All directions are in degrees true. Scope of buoy is 0.6 lane. All corrections are in Raydist lanes.

of the anchor line at the time the position of the buoy is determined and when setting the dials at the buoy. To do this the direction of the current is observed each time the buoy is used. With this information as an argument a curve similar to that shown in Figure 9 is used to compute the correction. The curve is constructed by using the depth of the water at the buoy and 0.9 of the length of the anchor line. No allowance is made for tide.

Considerable planning should enter into the selection of the sites for the buoys. In many cases the presence of water depths of sufficient shallowness will be a determining factor in the location of the buoy. Where suitable locations are available, it is good policy to place the buoys so that the ship will always be within about an hour's run of a calibration point should the dials require resetting. The optimum running time, of course, will vary with the scale of the survey and other conditions.

When buoys were to be located, the Raydist dials were always calibrated at

the Texas Tower and then a run made to the site, usually along a line of hydrography. If a fixed point is not available, it is desirable to use one buoy as the principal reference point and refer all other buoy positions to this buoy rather than to expand the survey from buoy to buoy. At the site where the buoy is to be planted, several trial sounding lines are run across the shoaler areas to determine the depth of the water. With the depth of water accurately known, the correct length of anchor line is determined and attached between the buoy and the anchor. In strong currents the ship is headed down current at the time the buoy is dropped. This permits the ship to be held in one location, as shown by the Raydist dials and by soundings, while the current carries the buoy away from the ship. This method worked very well on the narrow sand ridges found on Georges Bank.

The buoy is located immediately after it is planted. To do this the ship circles the buoy and uses the same method as for calibrating the dials, except that the calibration made at the fixed point is used and the buoy position computed. To check this first position a second run is always made between the fixed point and the buoy, in either direction, within a relatively short period. The two runs are meaned for the final buoy position. It was found that the R-1 and R-2 distances obtained on the various runs agreed with each other within 0.5 lane or less.

In order that the buoys can be found more easily in clear weather, a 2- by 2-inch pole about 6 feet long with a yellow flag near the top is attached to the top of the buoy. To make a radar target to assist in finding the buoy in foggy weather, 1-pound coffee tins are nailed to the four sides of the top of the pole, the bottoms of the cans against the pole. This makes a very acceptable radar target and in a calm sea it shows on the radar at a distance of over 3 miles.

HYDROGRAPHIC OPERATIONS

The survey sheet for Raydist-controlled hydrography is prepared with circular distance arcs which are spaced in lanes rather than in linear distance. The *Hydrographer's* Raydist had a lane width of about 45 meters, or 150 feet, and the distance-arc spacing was 200 lanes for a 1:40,000 scale survey sheet. An Odessey protractor graduated in lanes is used to plot positions.

A hydrographic bridge-watch with Raydist control consists of a hydrographer, combination echo-sounder reader and recorder, and Raydist reader, plus the helmsman, quartermaster, and lookout--when necessary due to fog or darkness, needed to run the ship. In clear weather during daylight hours and with no traffic in the vicinity the hydrographer would be the only officer on watch, but at night and in foggy weather a second officer would be on watch in the pilothouse which is immediately forward of the plotting room housing the Raydist equipment.

It was found convenient for the hydrographer to keep a plotting abstract, similar to the one the Coast and Geodetic Survey uses on shoran-controlled hydrography. This abstract is used to keep track of the positions and course changes, to record the Raydist dial readings, and to compute and apply the applicable corrections to these readings. The dial corrections as determined at the calibration point should be recorded on the abstract, and then these corrections changed by the addition of the heading corrections and azimuth correction to the R-2 distance, where applicable, as the hydrography proceeds. Lanes gained or lost in the phasemeter should also be used in computing the correction to be applied. The Raydist dial readings are also recorded in the sounding volume which constitutes the original record. At a later date the sounding record readings are corrected and used to plot the smooth sheet.

The principal duty of the Raydist reader is to keep track of the lane count as shown by the Brush Recorder tape, and independently of the figures shown on the dials of the phasemeter. At the calibration point the lane count is picked up on the Brush tape and from this point it is carried forward by the Raydist reader, with frequent checks to ascertain that his count agrees with the figures shown on the dials. He should inform the hydrographer of any discrepancy that he cannot resolve by a recount. The reading and marking of the Brush tape are discussed in greater detail below. In addition to monitoring the tape, the reader marks the position numbers on

the Brush tape and on the printer tape at each position, and from the latter tape he reads off the distance as shown by each dial reading so that it can be recorded by the recorder and the hydrographer. On the *Hydrographer* it was not necessary for the Raydist reader to push a button at the fix since the Raydist was connected to the electric sounding clock and a fix mark was made automatically at the position.

Usually the configuration of the bottom will permit one system of arcs to be selected and still give good development of the bottom. Georges Bank has a strong rotary current and it was found that the ship could be conned along the desired sounding line more easily if it followed a distance arc than if the line cut across both sets of arcs. It was also necessary that the sounding lines cross the sand ridges, for with lines parallel to the narrow ridges they would often be missed.

To facilitate the running of the lines parallel with a set of distance arcs the distance, in lanes, at which it is proposed to run the lines should be noted in colored ink along the edge of the survey sheet. On Georges Bank the general spacing of sounding lines in depths of 10 to 20 fathoms was 400 meters. In these depths a spacing of 8.0 Raydist lanes which is about 365 meters, was selected and distance readings at 8.0-lane intervals were indicated along the edge of the sheet. By use of this method lines can be run in disconnected areas and still join with no loss of spacing, also it is easy to compute the arcs on which to run splits. Before running the line the hydrographer applies the corrections with reverse sign to the indicated figure so that after the dial reading is corrected it will be the same as the indicated figure.

With Raydist it is easy to put the ship on a sounding line that runs along a certain distance arc for one revolution of the dial pointer is equal to a side displacement of about 45 meters (with a frequency of 3280 kc.). After getting the ship on line the hydrographer would turn the con over to the Raydist reader, first telling him how course changes would increase or decrease the dial reading. After a little experience most readers could follow the selected arc within 10 to 20 meters of the desired distance from the shore station. If the reader has trouble the hydrographer should take the con until the ship is again on a stable course.

A voltmeter connected to the phasemeter was installed in the pilothouse where it would be visible to the helmsman and the method of having the helmsman con the ship along the distance arc was tried. The more experienced helmsmen could do the task in an efficient manner but with less experienced helmsmen it was found that having the Raydist reader take the con was much better.

In laying out systems of sounding lines in the vicinity of a calibration buoy, it is advisable at first to concentrate on the lines more removed from the buoy and to leave the lines adjacent to the buoy until last. This permits sounding lines to be started in the vicinity of the buoy immediately after the dials are calibrated. Also on some days the atmospheric conditions may make Raydist operation uncertain and it is well to have lines near a calibration point that can be run at these times.

Interpretation of Brush Tapes.—The Brush tape constitutes a visual record of the lane changes in the phasemeter. It is used to ascertain whether these changes are the result of the movement of the mobile station or to other causes. If due to other causes, it means that the dial correction obtained at the calibration point is no longer correct and must either be changed to a new value by using information scanned from the Brush tape, or the dial must be recalibrated. Due to the manner in which the Raydist measures distance, lanes are skipped in whole lanes only and the fractional lane count does not change. In fact if the calibration methods are sufficiently accurate and the partial-lane knob on the dial is kept set at 0.0, each calibration should have the same fractional lane as part of the value.

Figure 10 shows a Brush tape under average conditions. At the time of each fix a tick mark is made on the top of the tape, and it is numbered by the Raydist reader. To read the lane count corresponding to this fix it is necessary to follow the curved lines across the tape, as shown in the figure. In counting the lanes, the reader usually numbers every fifth or tenth lane, unless the lane marks are widely spaced or the ship makes a turn. Only on the hundred lane marks

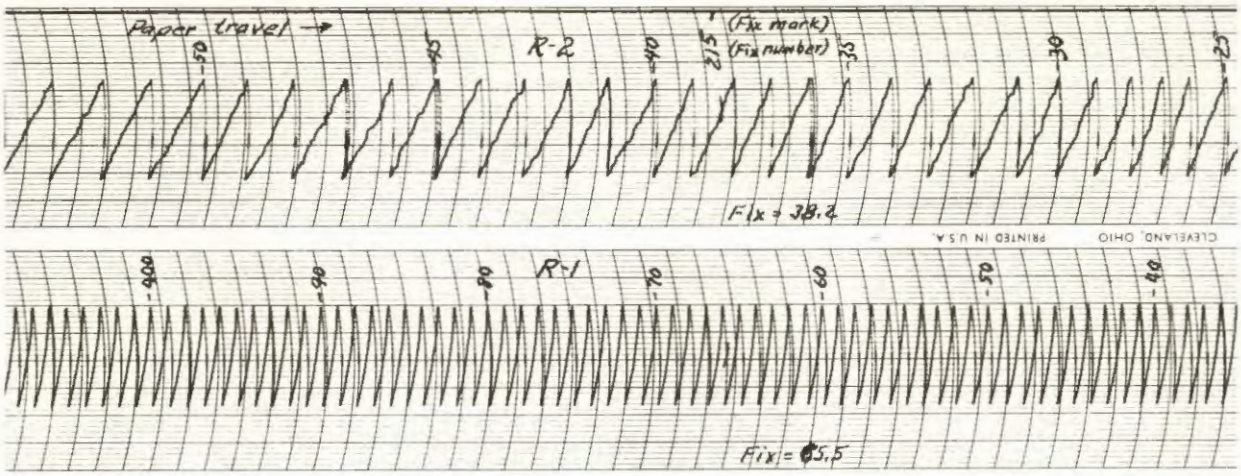

FIG. 10.--Brush Recorder tape under average conditions.

are the hundreds and thousands of lanes shown. One thing the reader has to learn is which direction of pen movement will increase or decrease the lane count. If the pen returns to the same end of the lane mark, the lane count remains the same.

Course changes should be shown on the tape, as well as being recorded in the sounding volume, for it helps in scanning the tape for gain or loss of lanes. No set rule can be given as to whether at times when skywave interference is present it is better to run towards and away from the poorest station, or to follow the distance arc of this station. Both methods were tried; sometimes one was more successful than the other.

When the lane marks have been appearing with a regular spacing, such as is shown in the R-1 trace in figure 10, and interference, or a power failure, causes a loss of lanes for a short period the number of lanes lost can be determined by use of spacing dividers. The correct setting of the dividers should be obtained from adjacent marks and then this same spacing used to fill the gap. If more than a few lanes are lost, it is better to set the dividers so that each point represents 5 lanes in place of a closer setting where each point represents 1 lane.

If, for example, in figure 10 the R-1 dial had failed to record the passage of the ship over a space of 5 lanes, the R-1 dial would read high by 5 lanes and a negative correction of this amount would have to be added to the correction already in use. Also it would be necessary to scan the R-2 trace for skipped lanes since stoppage of the R-1 dial affects the R-2 dial.

A power failure at the R-2 station does not mean that the R-2 dial stops moving. With a power failure at the Green station the R-1 component in the R-2 distance takes over and the dial continues to turn and lane marks on the Brush tape continue. The new marks are now similar to the R-1 marks and unless the dissimilarity between the new and the previous marks is considerable, it is difficult to tell that a power failure has occurred. This is the reason that the operator at the shore station should notify the ship immediately of any interruption to the Raydist at his station.

When lanes are added or subtracted that are not the result of ship movement the Raydist reader should note the fact on the tape and inform the hydrographer. The reader then picks up a new count that is in agreement with the dial reading.

Distance Comparisons

In proceeding to and from the working grounds on Georges Bank the baseline between the Red and Green stations was crossed in the area northeast of Cape Cod. Also some hydrography was done in this area and some of the sounding lines crossed the baseline. On many of these crossings the Raydist was in operation and minimum sum distances were obtained, corrected for dial setting and other errors,

and compared to the computed length of the baseline. The results of the several crossings are as follows:

Date	Computed *Lanes*	Observed Minimum *Lanes*	Error *Lanes*
June 3, 1957	6365.9	6365.4	-0.5
June 4, 1957	6365.9	6365.9	0.0
June 5, 1957	6365.9	6366.8	+0.9
June 27, 1957	6365.9	6365.6	-0.3
July 6, 1957	6365.9	6366.4	+0.5
July 7, 1957	6365.9	6366.1	+0.2
July 20, 1957	6365.9	6363.9	-2.0
July 21, 1957	6365.9	6366.1	-0.2
June 4, 1958	6365.9	6365.9	0.0
July 13, 1958	6365.9	6365.3	-0.6
Oct. 7, 1958	6365.9	6365.2	-0.7

Several times the Raydist was calibrated northwest of the Red station and then again off the coast east of the Red station. The results of these tests are as follows:

Date	NW. of Red Station Dial Correction		E. of Red Station Dial Correction	
	R-1	*R-2*	*R-1*	*R-2*
June 4, 1958	+1.2	-0.5	+1.3	*
July 13, 1958	-1.8	-1.5	-1.8	*
October 7, 1958	+0.8	-5.8	+0.2	-5.6

On June 4 and July 13 the R-2 failed before arriving off the coast east of the Red station and the asterisk denotes the absence of an R-2 reading. The reason for the failure was the strong carrier frequency signal from the nearby Red station, as discussed above. It is possible that the variation in the R-1 calibration value on October 7, 1958, when northwest and east of the Red station is the result of the weak signal being emitted by the 2496 kc. transmitter at the Red station. On this day the signal strength was decreased so that the 2492 kc. signal from the Green station could be received.

On one of the runs made to determine the position of the Texas Tower No. 2 on Georges Bank the Raydist was calibrated on the Texas Tower No. 3 on Nantucket Shoal, which is approximately 70 miles southeast of the Red station (See fig. 1), in place of being calibrated off Cape Cod as was the normal procedure. The position of the Georges Bank tower as determined by this run agreed very closely with the other runs indicating that the Raydist measures distance without appreciable error. The results of the several runs are:

Date	Place of Calibration	Distances in lanes to Texas Tower No. 2	
		R-1	*R-2*
July 21, 1957	NW. of Cape Cod	4068.6	6268.9
Sept. 24, 1958	Texas Tower No. 3 Nantucket Shoals	4068.3	6269.2
Oct. 2, 1958	E. of Cape Cod	4068.2	6268.9

SUGGESTIONS FOR USE OF RAYDIST

The following rules have been formulated for the use of Raydist on hydrographic surveys:

1. Begin the lane count on the Brush Recorder tape for each station as soon as the dial is calibrated.
2. When regular fixes are not being taken, take trial fixes at intervals not exceeding 10 minutes. Write the time of the fix on the Brush tape and on the tape from the printer.
3. When interference causes considerable movement of the Brush Recorder pens, keep a watch on the phasemeter dials as well as on the tape since it is easier under these conditions to discern added or skipped lanes by action of the dial pointer.
4. When interference is threatening loss of lane count and the ship is approaching a turn in the sounding line, keep the ship on the same course and maintain speed until the situation improves. On turns keep a close watch on the phasemeter dials.
5. Do not attempt hydrography on 1:20,000 and larger-scale surveys if the lane count is in doubt. On 1:40,000 scale surveys continue hydrography as long as it is believed the error in determining the dial correction does not exceed one lane. On 1:100,000 scale surveys this can be increased

to 3 lanes. Where hydrography is run with a doubtful lane count check into a calibration point as soon as possible; preferably before the lane count is totally lost.

6. If hydrography is continued all night plan to check into a control point the first thing in the morning, even though it may be believed that the lane count is correct.

7. When lanes are added or subtracted, due to interference or other causes, begin a new corrected count on the Brush tape that is in agreement with the phasemeter dials. On the Brush tape and in the plotting abstract make notes that indicate which distance is affected, the number of lanes involved (jumps always come in whole lanes) and whether added or subtracted, i.e., R-1 lost 1 lane, R-2 added 2 lanes, etc.; the added or subtracted notations refer to the effect of the change on the dial readings and not to the number of lane marks made on the tape.

8. Change the distance correction shown on the plotting abstract to reflect the gained or lost lanes. If lanes are lost add them to the existing correction, and if gained subtract them.

9. When determining the position of calibration buoys or when setting the dials at these buoys make an allowance for the scope of the anchor line.

10. Keep a running abstract of the dial corrections as determined from day to day. In this abstract include the name of the object used and its position. This information will make it easy to compute a new correction if the position of the object is changed for any reason.

11. Keep an abstract of the runs made to determine the buoy positions. This makes it easy to compute the final buoy positions at the earliest possible time.

SHORAN CONTROLLED LAUNCH HYDROGRAPHY

On Georges Bank are several areas where the depths were too shoal to be surveyed by the ship *Hydrographer*. These were done with launches carried aboard ship and using shoran for control. One area was around the Texas Tower and for this area one shoran station was placed on the tower and the ship was used as the second station. The other area was at a distance from the tower and it was necessary to use two floating shoran stations, the ship and one of the launches.

To survey the more distant area, two buoys were planted near the edges of the area to be surveyed and a third buoy off to one side where it would serve as a mooring buoy for the launch which would serve as a shoran station. The three buoys were located by Raydist, referred to the Texas Tower, and with checks on the positions. The positions of the two buoys in the survey area were plotted on the survey sheet, scale 1:20,000, and distance arcs were drawn using the position of the mooring buoy as a center. For the second set of arcs a center was selected in a location that would give a good angle of intersection, and in depths where the ship could anchor with a relatively short scope of anchor chain.

To accomplish the hydrography the ship was anchored as near as possible to the preselected point, and during the course of the hydrography Raydist readings were taken at 15-minute intervals and plotted on a large-scale diagram. On this diagram corrections to the shoran distances, as referred to the preselected point, were computed, and once each 1/2 hour they were relayed to the launch by voice radio. At the launch station the personnel recorded the launch heading each 1/2 hour so that a correction could be applied for the scope of the anchor line.

The buoys in the survey area were used to calibrate the shoran. By taking readings alongside the buoys calibration values were obtained that permitted the launch hydrography to be accurately fitted to the adjacent ship hydrography. The sounding lines were run along the distance arcs from the ship station.

CONCLUSION

Raydist control for hydrographic surveys is a supplement to that furnished by shoran and the Electronic Position

Indicator. Due to the fact that the Raydist phasemeter dials have to be set at a known point will preclude the use of Raydist in many instances where shoran and the EPI can still be used.

For surveys in shoal water areas far offshore Raydist furnishes excellent control for it permits strong control for the close spacing of sounding lines that is required to adequately develop the bottom configuration. In these depths buoys can be planted and used as calibration points for the phasemeter dials.

The Raydist equipment is reliable and will give long periods of trouble-free service. When working at a long distance from the shore stations, atmospheric conditions and the length of the daylight hours will affect the length of the working day.

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