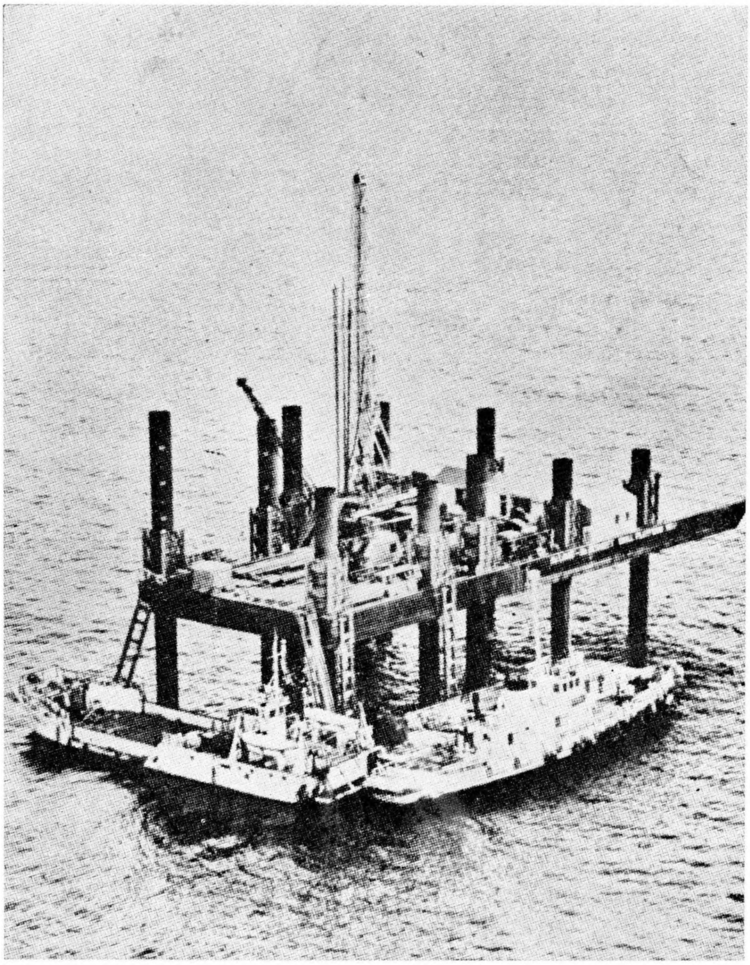
ELECTRONIC SURVEYING IN OFFSHORE AREAS



A movable barge-on-legs drilling platform now being used on an experimental basis by the Humble Oil & Refining Company.

ELECTRONIC SURVEYING IN OFFSHORE AREAS (1)

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Electronic surveying, or radiolocation as it is more generally known, should be differentiated from radionavigation methods with which most of us are more or less familiar. The principal difference between the two methods is the order of accuracy required. In radionavigation a fix within 1/2 to 3 miles will suffice, depending upon the method and the area involved. This order of accuracy, however, would not be sufficient for electronic surveying purposes. Some of the methods used are adaptable for both radionavigation and radiolocation. Other methods, however, are practical for only one or the other of the two uses. In the offshore areas, electronic surveying or radiolocation has found its greatest application in supplying horizontal control in the petroleum deposits. Electronic surveying has also been used to control hydrographic surveys in the United States and various other parts of the world. These surveys are generally conducted by governmental agencies of the country involved. A number of aerial surveys have been controlled by electronic methods in various parts of the world. Some locations for offshore structures have been made, but these constitute a small percentage of the total electronic surveying that has been done. Undoubtedly many more locations will be made in the future as more of the offshore areas are leased for drilling.

It is difficult to say just when electronic surveying as such had its beginning, but certainly the greatest stimulus came immediately following World War II. At this time geophysical operations in offshore areas were increasing rapidly, giving rise to a serious need for electronic surveying methods in those operations. Also, there were released at this same time quantities of wartime electronic equipment which was suited in varying degrees to electronic surveying requirements.

The need for electronic surveying was due principally to the breakdown of visual means of surveying as applied to the offshore surveying problem. Shortly after World War II, geophysical work was being conducted out to about 25 miles from shore. Since that time, this work has been extended as far as 125 to 150 miles offshore. Even for the shorter distances, visual surveying means are seriously limited by poor visibility conditions. In addition, visual control for offshore surveying generally requires an excellent radio communications network so that simultaneous transit readings can be made. These factors resulted in a slowing up of the geophysical operations, which hampered the work and resulted in increased costs. As illustration of the costs involved, a reflection seismograph crew costs between $60,000 and $125,000 per month including surveying, depending on the particular type of survey and the area involved.

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GENERAL CATEGORIES OF RADIOLOCATION METHODS

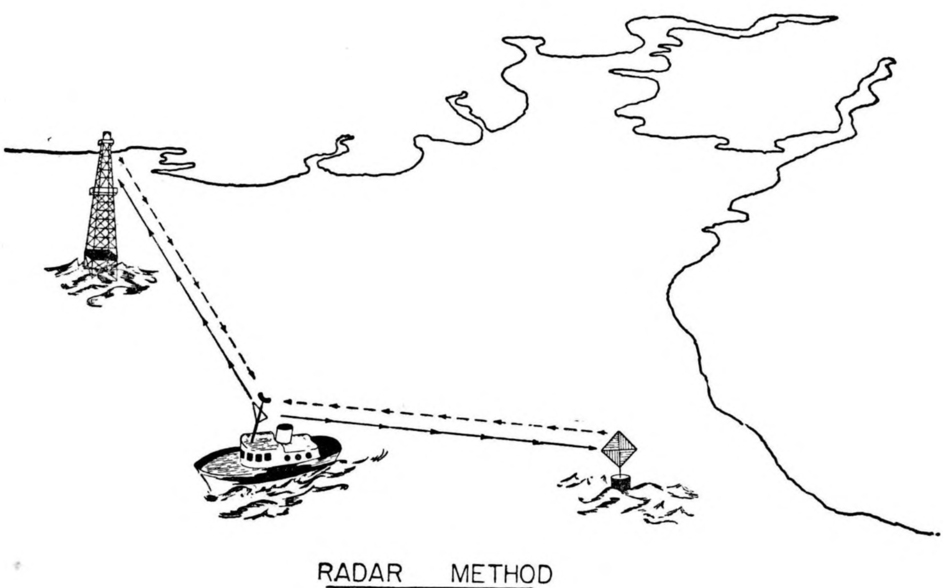
Radiolocation methods can be classified in two general categories. There are the circular methods, in which the position is defined by the intersection of two or more circular arcs centered on known fixed points. The second category comprises the hyperbolic methods, in which the position is fixed by the intersection of hyperbolic lines of positions. These hyperbolic lines of position are determined by a measurement of time difference or phase difference between radio signals received from three or more fixed transmitters at known locations.

CIRCULAR METHODS

In the circular category, the three methods that have found the widest application in offshore work are the radar method, the sonic method, and the Shoran method. Other methods have been developed from time to time but, in general, have had limited application.

Radar Method

The radar method utilizes a conventional search radar unit installed generally on the vessel whose position is to be determined. The method is based upon measuring the time necessary for a pulse of radio energy to travel to some object, be reflected, and return to the radar equipment. This travel time is converted to



RADAR METHOD

FIGURE 1

a range reading and presented to the operator on a dial or counter on the equipment. The simplest use of this method involves taking ranges and bearings on natural targets or man-made structures which exist in the area of operation and whose position can be or has been accurately determined. This is illustrated in figure 1. Unfortunately, natural targets or man-made structures very often do not exist in the area where they are desired for radar control. It is, therefore, necessary in the majority of such surveys to resort to artificial targets to supplement those already existing. These targets may be located on shore or they may be located on a buoy or the mast of a boat which is anchored at a known point in the working area.

The range at which the radar method can be used is from 20 to 30 miles on passive targets such as an oil derrick located on a platform offshore or from 8 to 12 miles on a wire mesh corner reflector located on the mast of a boat. The actual ranges obtained vary with the size of the reflecting object, the transmitting power of the radar equipment, and (because of the high radio frequencies used in radar), the height above the water of the radar antenna and the reflector, and the moisture content of the atmosphere. The range of the radar method can be increased by the substitution of beacons for the artificial corner reflectors. The beacons receive the radar pulses and transmit corresponding pulses in reply. But, as in the case of reflecting objects, the actual range obtained depends upon a number of factors, principally the antenna height involved, the transmitting power of the radar set and the beacon, and the moisture content of the atmosphere. The radar method may use two or more ranges for position fixing or it may use combinations of ranges and bearings. Radar ranges are generally more accurate than radar bearings but the bearings serve to identify targets and as a rough check on the position fixed by the ranges.

Some representative figures as to the accuracies obtainable with the radar method as used in electronic surveying operations along the Gulf Coast are from plus or minus 200 to 300 feet at a range of 2 to 3 miles to plus or minus 500 to 600 feet at a range of 10 to 12 miles. These accuracies are obtainable only by the use of an accurate ranging unit in conjunction with the conventional search radar. In general, radar accuracy decreases as the range increases so that at longer ranges less accuracy may be expected from this method.

Sonic Method

The second circular type method which has found considerable application for offshore surveying is the sonic method. This method involves buoys which are generally called « sonobuoys ». Each buoy contains a hydrophone in conjunction with an amplifier and a radio transmitter, together with an antenna located on top of the buoy. The hydrophone picks up sound vibrations from the water which are amplified and used to trigger the transmitter which sends out a radio signal. In the sonic method, the buoys are located in the area of operations as shown in figure 2. A charge of explosives is detonated to set up a shockwave in the water. This shockwave is received by the hydrophone in the sonobuoy which transmits a corresponding radio signal in return which is received at the vessel. Knowing the velocity of sound in water and the velocity of radiowaves in the atmosphere, it is possible to calculate the distance from the explosion to the buoy once the time is measured between the explosion and the return of the radio signal.

The range of the sonic method as generally used in geophysical work is limited to approximately 6 to 12 miles, depending upon the type of sea bottom, water depth, and size of explosive charge. In some cases where the water is shallow or the bottom very soft the range may be even more severely limited. The accuracy of this method is probably less than the radar method since the velocity with which sound travels through the water is much less constant than the velocity of radio waves through the atmosphere. It is affected by the temperature of the water and by the salinity of the water. This latter factor may vary considerably in the vicinity of river mouths. Since the sonic method requires the detonation of explosives and is of such short range, this method is not readily adaptable to any geophysical operation except seismograph operations. It has an advantage for seismograph operations that other methods do not in that the time of detonation of the explosive charge and the time of return of the radio signal from the sonobuoy can be recorded on the seismograph record so that a permanent record can be had of each fix. It is the writer's understanding that the U.S. Coast and Geodetic Survey has used the sonic method with special techniques to measure distances considerably greater than those just quoted. The ranges and accuracies obtained, however, are not known to the writer at present.

Shoran Method

The most extensively used and the most accurate of the circular methods is the Shoran method, illustrated in figure 3. This equipment was developed for the Air Force during World War II for aerial photo reconnaissance and blind bombing. The Shoran equipment consists of the indicating unit located on the vessel and two or more base stations or beacons located at known positions. Although the principles behind the Shoran method are the same as those of a radar set used in conjunction with radar beacons, the Shoran equipment is instrumented quite differently. The indicating equipment can receive signals only from its associated beacons and does not pick up echoes from reflecting structures in the area. Furthermore, there is no provision in the Shoran method to develop

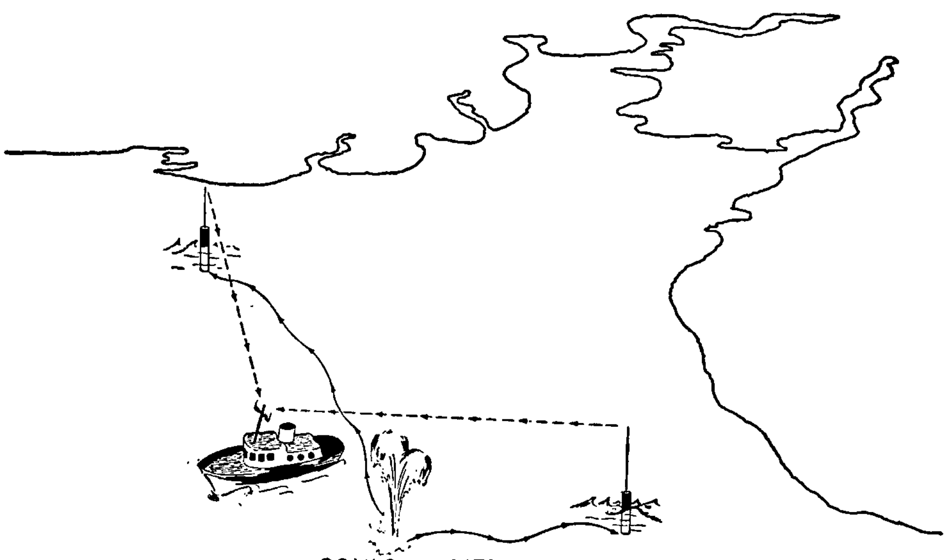


FIGURE 2

information pertaining to the bearing of the beacons. The Shoran indicating equipment differentiates between the beacons by sending out its transmitted pulses on two separate frequencies shown as $F1$ and $F2$ in figure 3. Each base station receives interrogating pulses on its particular frequency and retransmits corresponding pulses back to the indicating station on a third radio frequency, *F3*. Circuits incorporated in the indicating equipment keep the replies returning from the two beacons separated to eliminate confusion. The two return pulses from the beacons are presented to the operator on a cathode ray oscilloscope along with a

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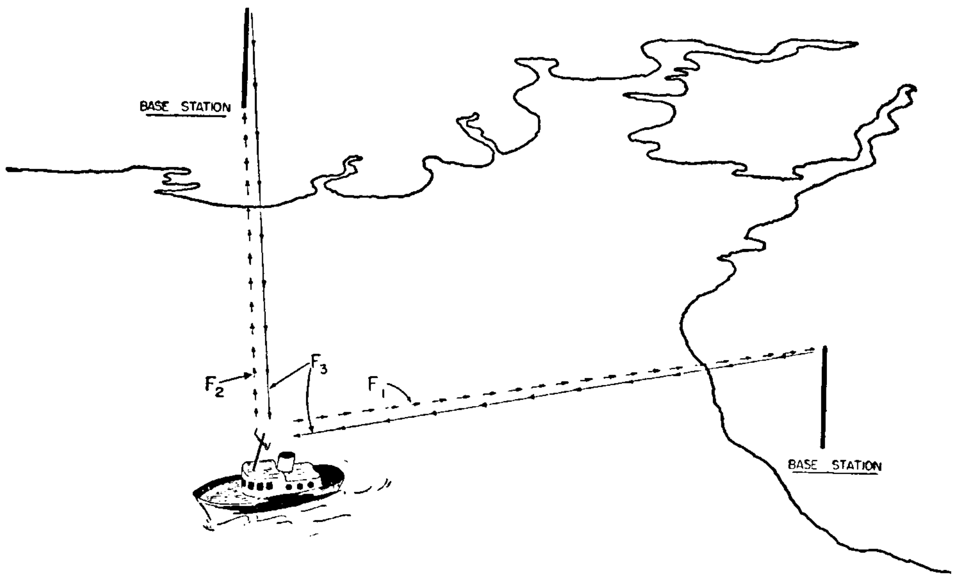

SHORAN METHOD

FIGURE 3

marker pulse. When the return pulses are properly aligned with the marker pulse, the ranges to the two base stations are read on dials on the front of the equipment.

Having been so designed, the Shoran method is readily adaptable for controlling surveys conducted with aircraft. These have been principally aerial photographic and aerial magnetometer surveys.

Because the Shoran equipment operates on frequencies of from 200 to 325 megacycles, the range obtainable depends principally upon height of the antennas involved. With 100-foot towers on the base stations and 40- to 60-foot towers on the vessel, ranges from 25 to 35 miles can be obtained. The range offshore can be increased by placing the base station equipment on vessels and anchoring them at points offshore which have been surveyed in by the Shoran indicating vessel. Accuracy is sacrified, however, each time this is done since the base station vessels cannot hold a precise position when anchored. When used with aircraft, the range of the Shoran method may be considerably increased depending upon the height at which the aircraft will fly. The accuracy of the Shoran equipment as generally used on the Gulf Coast is plus or minus 50 to 75 feet on any one range. A big factor in this connection is the fact that the Shoran accuracy is almost completely independent of the range being measured. This is not the case with most other electronic surveying methods. With very accurate calibration methods and rigid operating procedures, the accuracy of the Shoran equipment can be increased to approximately plus or minus 30 feet plus 2 1/2 feet per 100 miles of range being measured. These modifications and operating procedures have not been found to be practical for geophysical operations or for the surveying of platform locations in the Gulf of Mexico. These methods have, however, been used by governmental agencies in this and other countries for long-range triangulation using aircraft. With high flying aircraft and by utilizing these rigid operating and calibrating techniques, it was possible to measure lines of 200 to 400 miles in length with accuracies comparable to those of first-order triangulation.

E. P. I. Method

By combining some of the techniques of Shoran with some of those from Loran, the U.S. Coast and Geodetic Survey developed a longer range survey method for hydrographic surveys. This they call E. P. I., Electronic Position Indicator. By operating at approximately 1,800 kilocycles, they have measured lines up to 500 miles in length. Unfortunately, the techniques necessary to operate this equipment at the lower frequencies have resulted in a lower order of accuracy than Shoran and more rigid operating requirements. With E. P. I., the USC&GS has measured lines from 100 to over 400 miles in length with accuracies from 1 : 1,300 to 1 : 7,000. It is believed that the equipment is capable of even greater ranges.

HYPERBOLIC METHODS

As geophysical work in petroleum development progressed farther offshore throughout the past few years, a need arose for a surveying method which would have a greater range offshore than the previously discussed methods. This need led to the adaptation of the hyperbolic methods for the longer range radiolocation work. The hyperbolic methods generally available for electronic surveying are Raydist, Lorac, and Decca, all trade names. All three of these methods are based upon the principle of measuring the phase difference between radio signals received from two transmitters located at known positions.

Raydist

For the purpose of briefly discussing the hyperbolic method, let us consider figure 4, which diagrams a Raydist network and will serve to illustrate its operation. Points *A*, *B*, and *C* represent radio transmitter locations on shore. If we plot the lines of equal phase difference between stations A and B we will generate a family of hyperbolas, *A* through *E* in figure 4, with transmitters *A* and *B* as the foci of the family. Similarly, the lines of zero phase difference between transmitters *B* and *C* will give a second family of hyperbolas 1 through 5 with *B* and *C* as the foci. The distance between adjacent lines of zero phase difference is known as a « lane ». On the base line the lane width is equal to 1/2 of the wavelength being used or approximately 275 feet for the wavelengths used in the Gulf Coast area. The indicating equipment on the vessel receives the signals from the three transmitters and by comparing the phase between the signals from transmitters *A* and *B* and between the signals from transmitters *B* and *C* is able to determine which of the hyperbolic lanes in each family is being occupied by the vessel. The intersection of these two hyperbolas gives the point of position for the vessel. This is illustrated in figure 4 by the location of the vessel at the intersection of hyperbola *B* in one family and hyperbola 2 in the second family. The relay station as shown in the diagram is added to the network to eliminate the necessity for synchronizing transmitters *A*, *B*, and *C*. This relay station receives the signals from transmitters *A*, *B*, and *C*, determines the phase between *A* and *B* and between *B* and *C*, and sends these relative phases to the vessel on a separate radio frequency. The equipment on the vessel uses this relay signal as a base for measuring the phase differences between transmitters *A* and *B* and transmitters *B* and *C*. In effect, then, the equipment on the vessel compares the phase of the signals as received directly from the transmitters with the phase received at a fixed point on shore, the relay station. The equipment on the boat has two indicating devices to indicate the lane count in both hyperbolic families simultaneously.

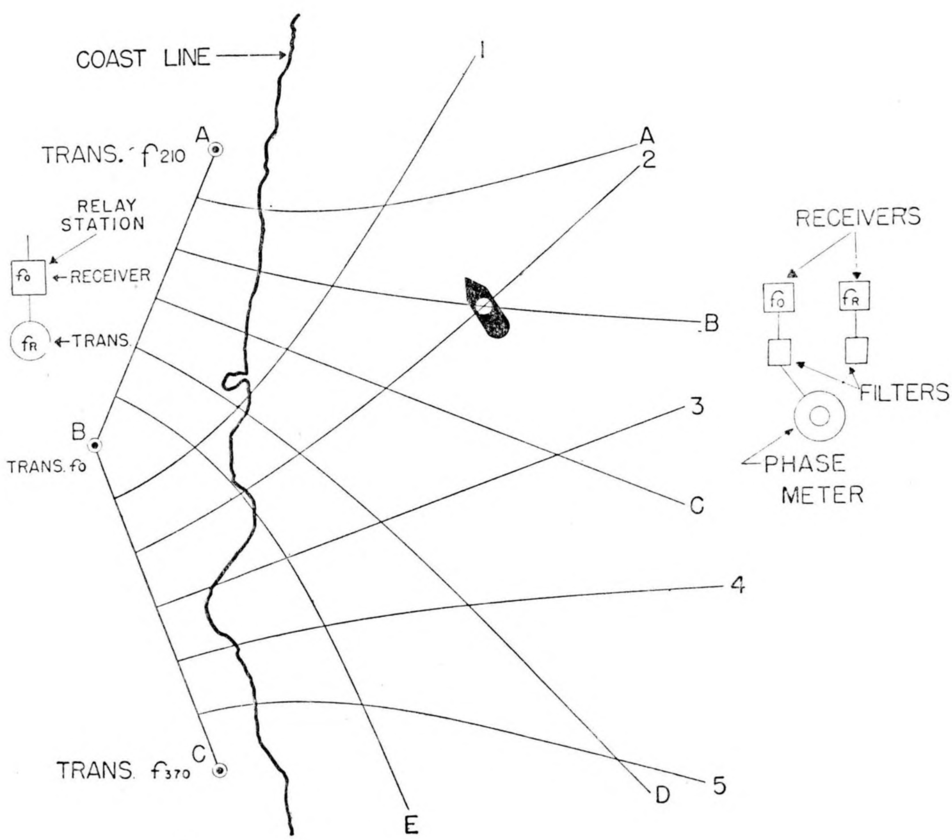

Fig. 4

Lorac

The Lorac system is based upon the same principles as the Raydist system but it does not employ a separate relay station. Instead, in the Lorac system, the end station transmitters *A* and *C* are switched at about 10 cycles per second to act alternately as base transmitters and as relay transmitters.

Decca

In the Decca system, transmitters *A*, *B*, and *C* are synchronized by using harmonically related radio frequencies and eliminating the need for the relay station.

RANGE AND ACCURACY OF HYPERBOLIC METHODS

The Raydist phase indicators will accurately measure to 1/100th of a lane width On the base line this quantity would be equal to less than 3 feet but, since the hyperbolas spread out as they progress from the base line, the accuracy of this method decreases as the distance from the base line increases. Further, because of the geometry of the networks and the angles at which the hyperbolas intersect, the accuracy of a hyperbola network is better in the center of the network than it is along the edges. In the Gulf Coast Raydist networks, accuracies of plus or minus 150 to 200 feet are obtainable at ranges up to 125 miles offshore. At ranges closer inshore the accuracy improves. The range of a hyperbolic network will depend upon the radio frequencies used and the power of the base transmitters. On the Gulf Coast, using frequencies between 1,750 and 1,800 kilocycles and transmitting powers of 500 watts, the Raydist networks have been used as far as 150 miles offshore. The range and the accuracy of the Lorac network is comparable to that of Raydist since the two use almost identical frequencies and geometrical configurations of the base stations. The Decca method utilizes wavelengths considerably longer than either Raydist or Lorac and consequently should have less accuracy. The range obtainable with Decca, however, should be somewhat greater. In general, it can be said that the hyperbolic methods are considerably more adaptable to geophysical surveys than they are to geodetic control procedure over long distances.

The Raydist equipment has an advantage over the other two hyperbolic methods in that it can be instrumented in various ways to give more than 30 variations of hyperbolic, elliptical, and pure range configurations. For specialized applications, one of these variations may give better control and simpler operation than a purely hyperbolic configuration as just described. One of these configurations is quite adaptable to the measurement of a single line, which makes that particular configuration adaptable to long range geodetic control.

The hyperbolic methods have an operational disadvantage in that the equipment on the vessel is capable of indicating accurately the fraction of a lane corresponding to the vessel's position but it cannot differentiate between lanes. In normal practice, this is overcome by starting at a known point and adding or subtracting lanes, as the case may be, as the vessel moves through the network. If, however, the lane count is lost for any reason, then the vessel must return to a known point to reestablish the proper count. Precautions are taken to guard against this lane loss and in actual practice it does not occur too frequently. No practical lane identification feature has been developed yet for either Raydist or Lorac. Decca is said to have lane identification at this time.

ELECTRONIC NETWORKS OF THE GULF COAST

Figure 5 shows the area of Raydist coverage on the Gulf Coast. It comprises the coastal area of Texas, Louisiana, and Mississipi. Five of the six networks are in operation. The sixth, the Brownsville network, is proposed for construction when the requirements in that area make it economically practical.

The Gulf Coast coverage for Lorac is quite similar to the Raydist coverage. In addition to the Gulf Goast, Raydist and Lorac have been used in other areas in the United States for temporary jobs. The Gulf Coast networks are the only permanent installations at this time. Raydist and Lorac have also been used in offshore areas in other parts of the world. As a matter of general interest, Raydist is being used as a means of tracking jet aircraft and guided missiles. It is also used to determine the speed of ships during builders' and acceptance trials. In the latter application one instance of note was the trials of the liner, *United States.* Decca has not been used in the United States up to the present time. This is due principally to the unavailability of the harmonically related frequencies needed for the Decca method. Decca has, however, been used extensively in other parts of the world, principally for radionavigation, although some hydrographic work and geophysical survey work has also been so controlled. Decca is one of the methods suitable for both radionavigation and radiolocation.

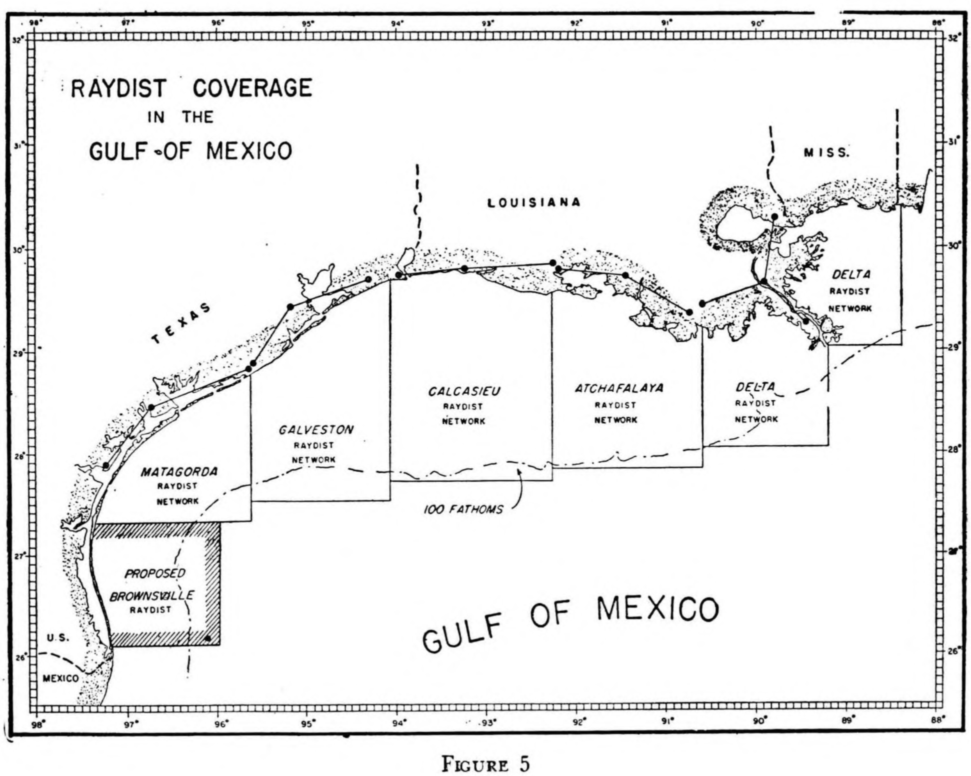

FIGURE 5

ELECTRONIC METHODS IN GEOPHYSICS AND HYDROGRAPHY

It was mentioned earlier that most of the electronic surveying done is in connection with overwater geophysical surveys. These surveys consist of a location grid covering the area of interest. Generally the lines of the grid are oriented north-south and/or east-west, but diagonal lines of various orientations may also be included. The distance between adjacent locations may vary from 1,000 feet to 4 miles depending upon the type of survey being run. The geophysical work controlled by electronic methods has chiefly been either seismic or gravity in nature. In the seismic methods a charge of explosives is detonated and the time necessary for the resulting vibrations to be reflected from geologic features at various depths is measured. In the gravity method, small changes in the earth's gravitation field are measured and contoured. By studying the data obtained, geologists are able to determine the areas of possible petroleum deposits. Other geophysical methods, such as the magnetic method and the electrical induction method, have found only very limited use in the areas wherein electronic surveying has been used for control.

In general, the coordinates of the desired locations are determined prior to the time that the crew leaves for the working area. Depending upon the electronic surveying method to be used, these coordinates are converted to radar or Shoran ranges or hyperbolic lane readings either by manual plotting or by calculation. These ranges or lane readings are given to the radiolocation operator who then, by use of his electronic equipment, directs the boat to each location in turn, in some predetermined order. Because of wind and tide conditions and operational difficulties, the vessel may not always be able to precisely occupy the desired position. After completion of the work, the locations actually occupied by the vessel are replotted on the final map. The scale most generally used for these maps is 1 inch to 4,000 feet. Other scales used are 1 inch to 2,000 feet, 1 inch to 3,000 feet, 1 inch to 5,000 feet, 1 inch to a mile, and 2 inches to a mile.

In hydrographic work the occupation of predetermined positions is generally not as important as in geophysical surveys. For this reason, the hydrographic survey vessel is generally navigated by methods other than by use of the electronic surveying equipment, with the electronic surveying device giving periodic fixes as the depth data is recorded. In this application the electronic surveying equipment serves more as a means of tracking the vessel than as a means for directing it.

LOCATION OF OFFSHORE DRILLING PLATFORMS

For making locations for a drilling platform or other offshore structure, more care is generally taken than is the case with a particular geophysical survey position. The desired position is converted by calculation into ranges or lane readings. If radar is to be used, ranges to all known structures in the area will be calculated. In the Shoran method, quite often more than two base stations will be used for more rigid control. These base stations will be located so that the angles of intersection of the Shoran ranges will be the best practical configuration for the particular location. Generally, with Shoran, there is some latitude possible in the choice of base station locations. If a hyperbolic network were to be set up solely to survey a particular location or localized area, there would be some choice possible in the selection of the base station sites so as to give the best possible hyperbolic configuration in that particular area. However, where the networks are already permanently located, the hyperbolic lanes would be used in their existing configuration.

The operator of the surveying equipment would then use the predetermined ranges or lane readings to guide the vessel to the desired location, taking particular care to occupy the desired coordinates as closely as possible. As the vessel passes the location a small buoy is dropped overboard. In many instances the operator will make several passes dropping a buoy each time so that eventually a cluster of buoys is set. If the structure to be built is not to be started immediately, then a larger, more permanent buoy is set in the center of the cluster. Readings are then made on the permanent buoy and these readings are taken as the final position. When construction is to begin immediately this larger buoy is generally omitted. Care must be taken in making up the buoys, particularly the larger buoy, to insure that the proper amount of anchor chain or line is attached. An anchor line that is too short may cause the buoy to drag the anchor off of position while one that is too long will allow the buoy to drift off of the position where it was originally placed.

In the circular methods, such as Shoran or radar, if more than 2 ranges are used for control, the position is generally set using that pair of ranges that gives the best angle of control. The other ranges are then read and the final position is adjusted either mathematically or graphically. The various ranges may be given different weights in this adjustment process if there is reason to believe that some ranges are less reliable than others.

Figures 6 and 7 are illustrations of the accuracies obtainable with the Shoran method for offshore locations without resorting to other than normal cali-

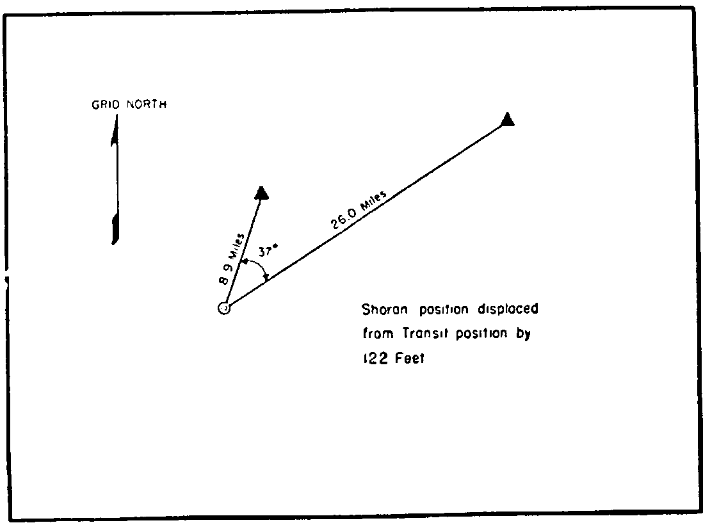

FIGURE 6

bration and operational procedures. These two figures show diagrammatically two well locations that were actually made with Shoran in 1948 and which were checked with a visual survey. In figure 6 we have only two Shoran ranges of 8.9

and 26.0 miles intersecting at an angle of 37 degrees. In this instance, the Shoran position was displaced from the transit position by 122 feet. The location shown in figure 7 was made using ranges from 4 beacon position. These 4 ranges, from 13.1 to 22.1 miles in length, were adjusted by the method of least squares to give the final Shoran position which differed from the transit position by 43 feet.

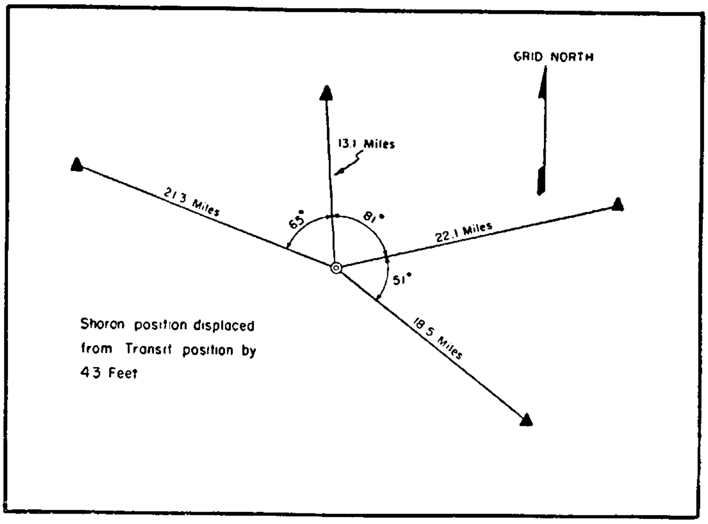

FIGURE 7

TYING ELECTRONIC SURVEYS TO TRIANGULATION NETWORK

In the electronic surveying or radiolocation operations we have been considering, the electronic methods serve as a means to tie the offshore work to the existing control networks along the shore. It is a means of extending this shore control to those offshore areas where it has not been practical to date to locate permanent triangulation stations. Along the Gulf Coast and elsewhere in the United States, the electronic methods are tied to the U.S. Coast and Geodetic Survey triangulation network. All base station positions are surveyed by one means or another in the USC&GS network. The electronic survey is generally based and mapped on the plane coordinate grid system applicable to the particular area of operations. It is of interest to note that, in Louisiana, operations are being conducted as far south as a *Y* coordinate of minus 350,000 on the Lambert grid system. Perhaps the future may bring the establishment of a new Lambert projection zone in Louisiana to encompass the coastal and offshore areas of the continental shelf wherein such a vast amount of petroleum operations are being conducted, and will undoubtedly be extended in the coming years.

FUTURE PROSPECTS

This paper has attempted to give only a very general picture as to the methods and applications of electronic surveying methods. There are many details of operation, and refinements have not been included in this limited discussion. The figures as to range and accuracy given herein have been compiled from various sources and are meant only to serve as a means of comparing the various electronic surveying methods in general, and should not be taken as the absolute limits in any case.

Electronic surveying is undoubtedly still in the development stages. The future should bring refinements of existing methods and perhaps new methods that should make electronic surveying an even more useful tool. The future should also see much more extensive use of electronic methods as a means of establishing long range control networks in inaccessible areas where such control does not presently exist, to tie islands to continental areas over hundreds of miles of intervening water, and to connect datums not heretofore thought possible to connect.