# AN ACOUSTIC TRANSPONDER SYSTEM

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## ABSTRACT

Acoustic transponders provide a particularly appropriate means for navigating relative to the deep sea floor. Their successful use, however, is dependent on solution of certain engineering problems and on understanding of the sound propagation situation in which the equipment is to be used. During the past year we have developed, built and used a set of appropriate, inexpensive transponders. These allow for selective calling of any one of three units (using pulses at 10.0, 10.5 or 11.0 kc) all of which reply at 12.0 kc. The design lifetime is $10^6$ pulses delivered over a period of up to one year. They have been built primarily to provide tracking information for a deeply towed, unmanned vehicle used for echo sounding and magnetometer observations. With this system useful responses have been obtained to ranges of 8 nautical miles. In normal operation the useful range is limited by the shadow zone formed by upward refraction of the acoustic energy near the sea floor. Use at sea has shown that these elements can provide effective navigational information and has allowed direct observation of the shadowing effects as the principal range limiting factor.

## INTRODUCTION

For a number of years, we have been interested in the fine-scale shape and physical properties of the deep sea floor. In addition to a desire for basic understanding of this aspect of the ocean, we have been stimulated by questions related to bottom reflection of acoustic energy, and, more recently, by the practical problems associated with trying to find objects on the bottom. We have also been concerned with related questions as to the detailed nature of the sea floor and how to examine it. In this latter context, we have received support and encouragement for our work from the Deep Submergence Systems Project to augment the continuing interest of the Office of Naval Research.

One can approach the problem of understanding the fine-scale nature of the sea floor in either of two rather extreme ways. The first is to develop very high resolution equipment for use near the surface; the second is to operate conventional instruments in unconventional fashion near the sea floor.

## THE NAVIGATION PROBLEM

We have adopted the latter approach and it is in this context that our navigation problem arose. The over-all system which we are using is shown in figure 1. We have been towing from a surface ship a fish which is 7 1/2

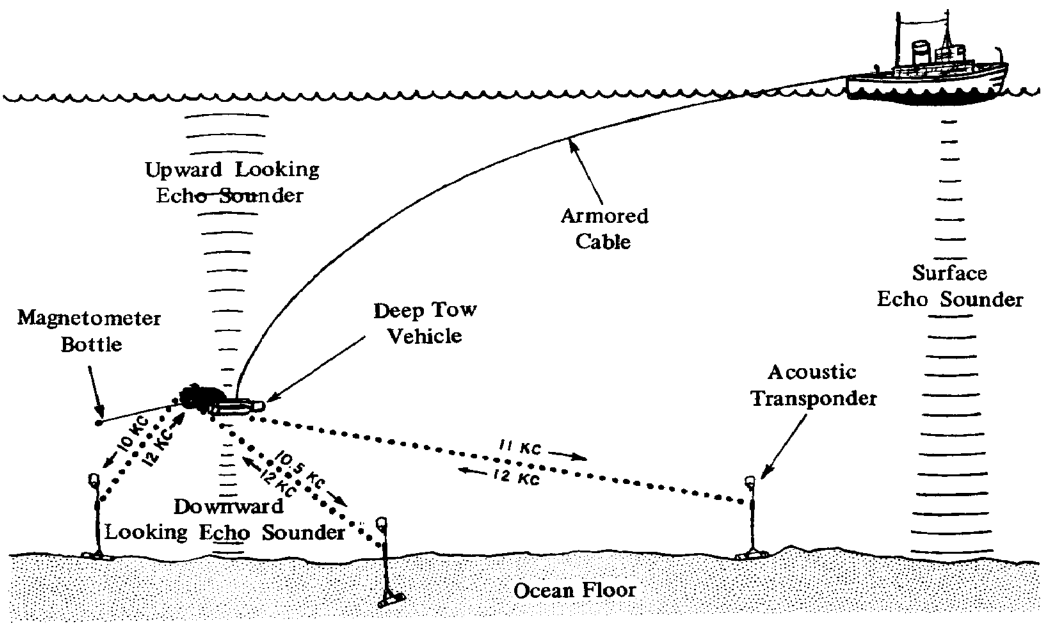


FIG. 1. — Deep towing in an acoustic navigation net.

feet long, weighing 1350 lbs. It is connected mechanically and electrically to our ship by means of 25 000 feet of 3/8 inch diameter well-logging cable with a coaxial core. Gradually this instrument package has grown. Our first work with the fish was concerned with upward- and downward-looking echo sounders. These tell us the depth and altitude of the fish, and thus inform us as to the fine-scale topography of the sea floor. We have also used a magnetometer and are now adding a temperature probe, sound velocity meter and a side-looking sonar. The control, as well as the data recording are done at the surface on board R/V *Oconostota*, a converted tug about 100 feet in length and displacing 322 tons. Results of the use of this equipment have been reported in part at Military Oceanography Symposia of the Navy [1, 2].

As a part of using this instrument we have been concerned as to its position while we were making measurements. For this reason we needed a bottom-referenced navigation system. Although our concern was with a towed instrument, it is clear that the navigation problem is similar whether one has an unmanned vehicle on the end of a wire or a manned vehicle down near the bottom. This reinforces Mr. BUFFINGTON's comments [3] but in rather a different context; namely, the navigation problem does not go away just because you take the man out of the craft down on the sea floor. We examined the problem and set gross specifications for the transponders which would be the key element in this navigation system. About 50 watts of acoustic power is appropriate. A lifetime of one year of listening and about $10^6$ reply pulses was also assumed to be reasonable. We decided that we could build transponders inexpensively enough to make them expendable. Since we would very likely return to the same area several times, we could trade off their cost against the cost of ship time needed to find them each time they come back up to the surface. We decided to differentiate among the several transponders by using call-up diversity rather than reply diversity and we picked 10, 10.5, and 11 kc as the call-up frequencies which we would use. All of the three types of transponders answer at 12 kc. It seemed that recognition delay times in the circuitry should be less than 2 milliseconds and a 3-millisecond pulse length would be appropriate.

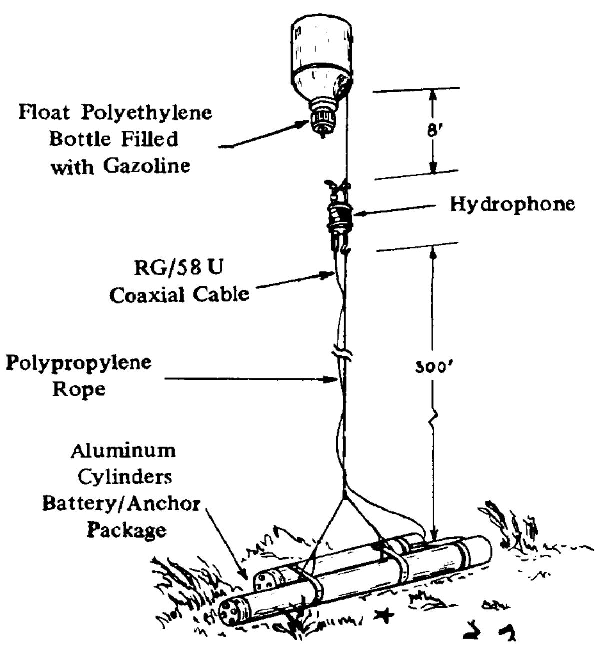


FIG. 2. — MPL acoustic transponder.

The resulting configuration is shown in figure 2. The five-gallon polyethylene bottle, filled with gasoline, and tethered by a polypropylene line, provides buoyancy to hold the small transducer about 300 feet above the sea floor. The transducer is a cylinder of PZT ceramic of 3-inch diameter and 3-inch length. Its beam pattern is cylindrically symmetric with vertical response 10 dB less than that in the horizontal plane. The battery pack and electronics are in separate pressure cases which lie on the sea floor with adequate negative buoyancy to anchor the assembly. These aluminium cases have a diameter of 5 inches. The electronics case is 24 inches long, and the battery case 48 inches long. We have used dry cells (Eveready Alkaline No. E 97 S) to form a 24-volt and a 48-volt battery. Each of these has a capacity of about 16 ampere hours, compatible with our philosophy of building very low-drain circuitry rather than providing a very large battery. The current drawn when passively listening on the sea floor is about 0.9 milliampere, thus we need only eight ampere hours from the 24-volt supply for a year's operation. The 48-volt supply is disconnected all the time except when a ping is actually transmitted, and it has adequate capability to provide the million pulses which we wanted.

## THE CIRCUITRY

The electronic circuitry is shown in functional block form in figure 3. The tuned amplifier has a band width of about 1 kc and feeds its signal to the key element of any transponder — the signal recognition circuit. This element decides whether it has heard an interrogation and, if so, commands the transmitting part of the equipment to ping back. The signal-recognition circuit compares the signal in a 200-cycle band (centered in a 1 kc band) with the total signal in the broad 1 kc band. At the correct interrogation frequency, the energy is concentrated in the middle of the band and the ratio of the outputs of these two circuits (200 and 1000 cps bands) is quite different than it is when the energy is spread across the whole band. When the transponder hears a ping at the wrong frequency, outside the 200-cycle wide filter, the ratio is again wrong. By using a combination of amplitude and phase comparison and by utilizing the fact that we are making a relative rather than an absolute measurement we can set the threshold low enough to keep the pre-recognition delay less than a millisecond at 3 dB signal-to-noise ratio without spurious triggering. Everything following is essentially cut off until the recognition block says GO. When the recognition circuit has been in the GO position for 1.5 milliseconds, the gate generator initiates the 3-millisecond output pulse. This pulse is subsequently amplified and transmitted into the water. Following the triggering of the transmitter, the recognition circuit is disabled for about 0.6 sec.

The call-up signal is initiated by the keying circuit of a Precision Graphic Recorder. It is telemetered down the wire and transmitted from a PZT transducer of 3-inch diameter and 9-inch length, mounted at the trailing edge of the tail fin of the fish with its axis vertical. The beam

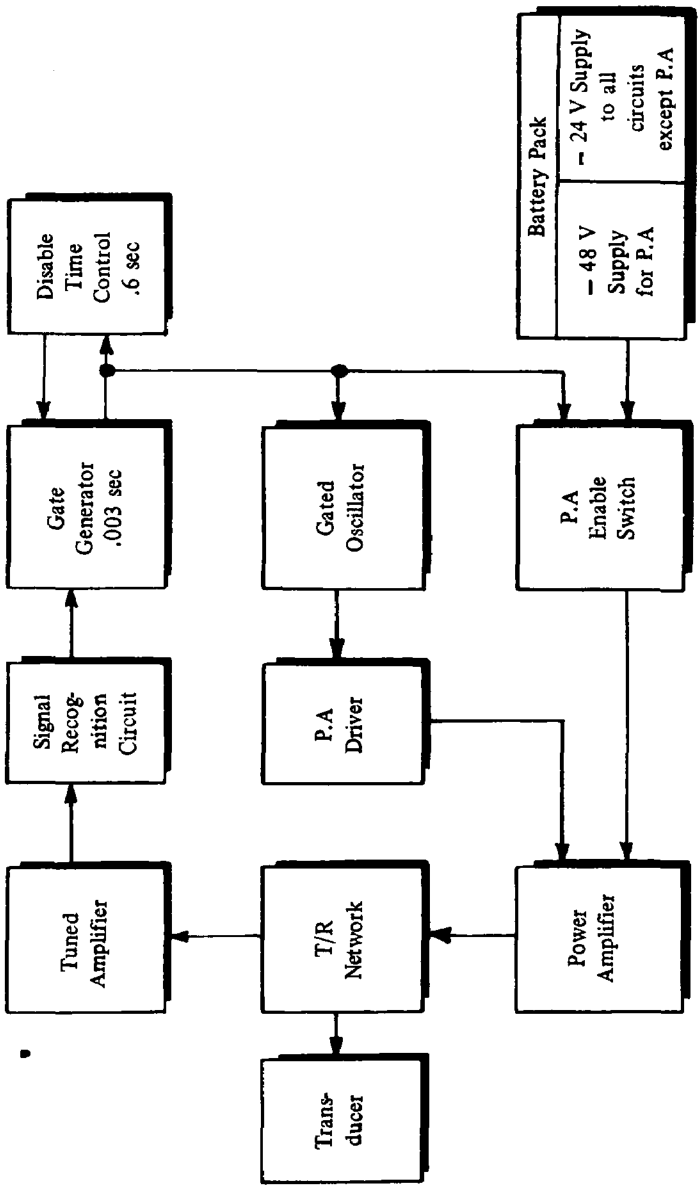


FIG. 3. — MPL transponder block diagram.

pattern of the radiation is cylindrically symmetric except for some screening by the pressure case of the fish in the forward and downward direction. Response in the vertical direction is about 18 dB below that in the horizontal. Its beam width is about $\pm 20°$ at 3 dB down.

## TRANSPONDER ASSEMBLY

Figure 4 shows a transponder assembly being launched at sea. There are many problems in putting transponders over the side, indicated by Mr. CLINE [4]. We are operating a scaled-down version, our ship is smaller and the handling gear is more personal. We first lower the hydrophone with

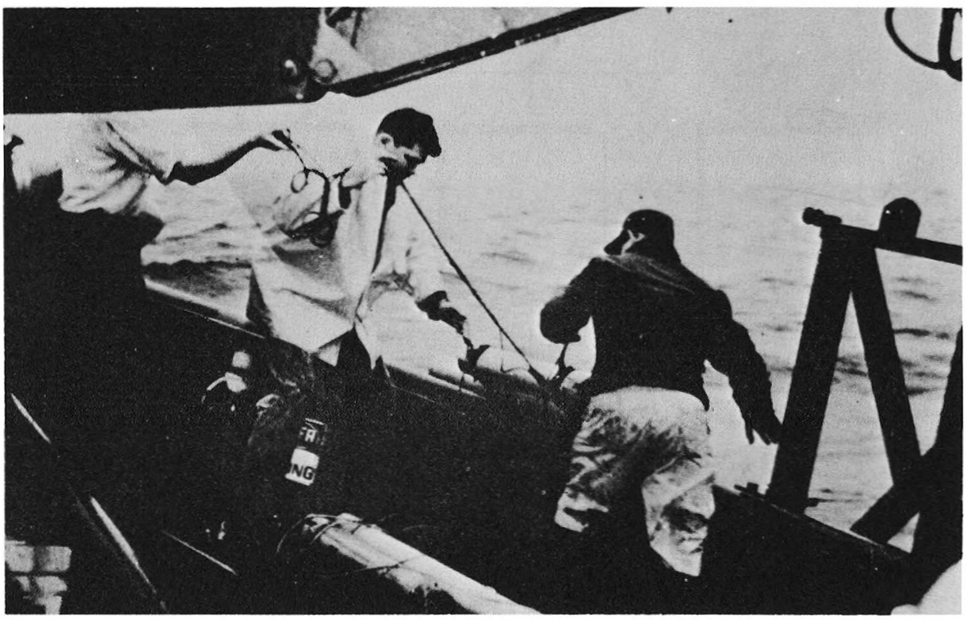

FIG. 4. — Putting the transponder overside.

its float bottle and let that stream out astern and then release the battery and electronics package over the side. We put a small parachute on the package so that it takes about an hour to go down 2000 fathoms. Operationally, what we have done is to make a pass through the area of interest with our shipmounted echo sounder. When we find an appropriate rise in the sea floor, we drop the first transponder. Everything then proceeds relative to that, moving out to a selected range for the second one, and then placing the third in a proper place relative to the existing baseline. We have used these sets of transponders in two situations to date. The first was a survey in 2300 fathoms of water in an abyssal hill region about 10 miles square. Because of what we suspect was a problem of leakage in the battery cases we had navigational information for only one week. We picked the San Nicolas Basin as our next operating area (Figure 5, after EMERY [5]).

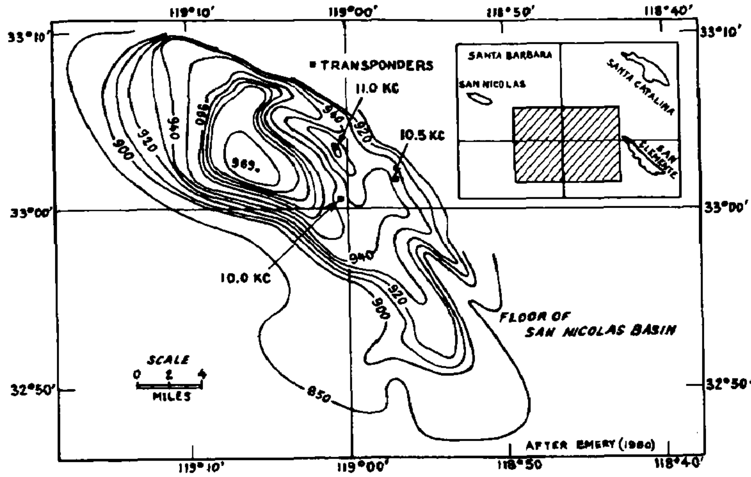


Fig. 5. — Transponder location.

It is not quite as flat as some of the other basins in the Southern California borderland, thus we felt it would be somewhat of a challenge to us. In addition, there is not too much surface traffic in the area. The Pacific Missile Range was able to supply us with Lorac for precise surface navigation. The area in which we are working ranges from 910 to 960 fathoms. (The contour interval is 10 fathoms down to 960 and two fathoms at greater depths). The sea floor in the area near the transponders has been observed using a

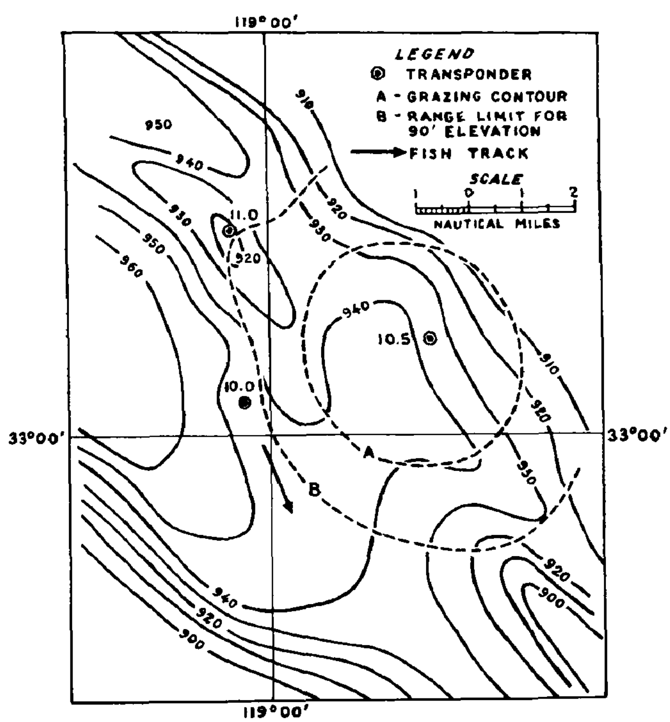


Fig. 6. — Topography and range contours near the San Nicolas Basin.

side-looking sonar (about 240 kc) and is quite smooth. A sonoprobe record [6] a few miles away gives a sharp bottom return as do both 12 kc and 40 kc echo sounders. Bottom material is in general made up of layers of fine-grained sand and silt. The basin is nearly isothermal below 650 fathoms. If one measures temperature and salinity and uses Wilson's computational methods [7 *a*, *b*] one comes to the conclusion that near bottom there will be a positive sound velocity gradient of about $1.7 \times 10^{-2}$/second with a velocity of 4890 feet per second at 900 fathoms depth.

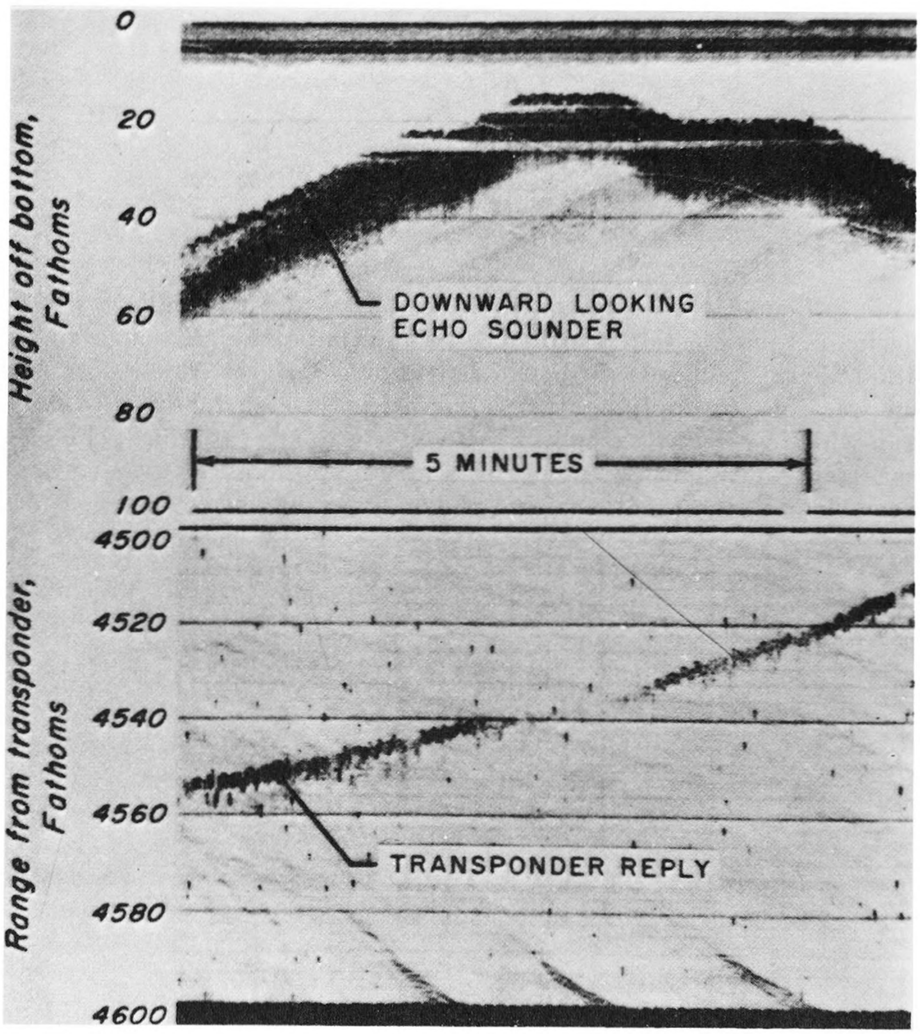


FIG. 7. — PGR record demonstrating shadow effect.

The transponders were placed using the technique described above. The upper left one was placed first on a hill, the second to the south and then off to the east for the third. The three positions for the transponders are shown in figure 6 in an expanded chart. These positions are internally consistent with the data we have gathered so far and also agree with the topography. The transponders were planted in early November 1965 and have been used in late November, December, and in March 1966.

## RANGE LIMITATION

The principal range limitation for near-bottom work is due to refraction. The theoretical situation is shown in figure 6 by the two dashed lines, contours A and B, which relate to transponder 10.5. Curve A is the one at which the shadow zone created by upward refraction will begin, considering that the transponder transducer is 300 feet off the bottom. The grazing ray will touch bottom along curve A which, because of the irregular topography, is not a simple circle. This is the limit of useful coverage if the transducer on the vehicle is right down on the sea floor. If one flies the transducer 90 feet above the sea floor at whatever place he may be then he should have reception for the 10.5 kc transponder out of contour B. This increase in available area with increase of elevation of the calling element should influence hardware as well as operations because, in principle, there is no reason why one cannot have a mast that projects above the small submarine (if that is what one is navigating) and thus be out of the shadow zone and into useful direct path propagation. Using a towed system, one can always tow close to the sea floor and mount his interrogation and listening hydrophone part way up the towing wire.

In order to investigate this shadow effect we went along the course shown in figure 6. Part of the result is shown in figure 7 which reproduces a portion of one of our echo sounder records. The upper trace is the record from the downward looking echo sounder. The lower channel shows the arriving pulse from the 10.5 kc transponder; the direct and bottom-reflected pulses overlap for the geometry which existed throughout this record. It is clear that as the fish went toward the bottom the transponder reply was reasonably clear until the final excursion somewhat below 30 fathoms off the bottom at which point no return was received. When we moved the fish back up, the return pulse came back in view. Similar indications of the shadow zone were obtained at several different ranges.

The results are shown in figure 8 in which signal reception is plotted as a function of range from the 10.5 kc transponder, and the depth of the towed fish. The nature of the received signal is given as either clear, absent, or poor. There are gaps in the line because we were not in fact interrogating this particular transponder all the time. Poor reception is essentially of two kinds. Sometimes we had a very weak reply — very fuzzy and irregular. In other instances, as we moved into the transition region a second acoustic path would carry the energy. From a knowledge of travel times, we deduced that this path consisted of one horizontal leg grazing the bottom and one leg via surface bounce. The shadow zone clearly exists, and is about in accord with theory. The three solid lines in figure 8 represent three rays from the 10.5 kc source at a depth of 885 fathoms. The shallowest of these has its deepest point 50 fathoms below the source (935 fathoms), the next goes to 55 fathoms and the third to 60 fathoms below the source (945 fathoms). Examination of the contour chart shows that the water depth near the midpoint of the acoustic path from transponder to fish was a little deeper

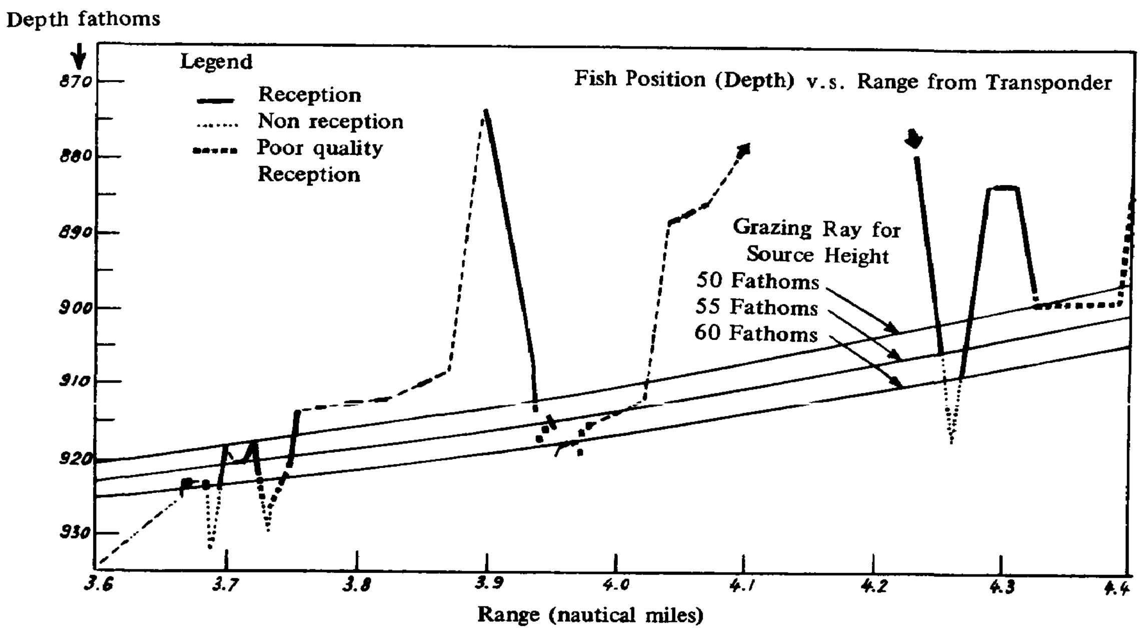


FIG. 8. — Signal reception near the bottom.

than 940 fathoms, corresponding to a cutoff bracketed by rays labeled 55 and 60, in good agreement with the data. Toward the end of the track (at 4.3 + miles) it appears that the intervening depth is somewhat less.

## UTILIZING TRANSPONDERS

We are gradually learning how to utilize these transponders. Beyond simple reconstruction of the actual track of the towed body we are able with simple hand-plotting techniques to provide ourselves with information as to how to alter course to place the fish closer to a desired track. We intend to expand the number of beacons in this particular area to provide for navigation over a somewhat larger region for use with our side-looking sonar and in conjunction with operations the *Trieste* may conduct in the same area. We hope this summer to instrument a deep-ocean abyssal hill region for the same kind of work. We hope not only to track our towed vehicle but also to be able to have precise knowledge of where bottom samples or sea-floor heat flow observations are made relative to local topographic details. In short, we feel that we are moving from a development stage into one of actual application of this navigational technique in sea-floor search and survey and in various aspects of submarine geology and geophysics.

## ACKNOWLEDGMENTS

It is a privilege for the authors to be able to acknowledge the very essential and effective close cooperation provided by Captain Cleveland Davis and the crew of R/V *Oconostota*. Drs. John Mudie and Carl Lowenstein have assisted us at sea and with computational techniques which are being published in this volume [8, 9]. Frederick Stone and Glen Forbes played essential roles in construction and testing of transponders. Support for this work has been provided by the Office of Naval Research (Undersea Programs Branch) and the Deep Submergence Systems Project (Sensors Group) both through contract Nonr 2216 (05).


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## APPENDIX

**Excerpts from :**

### UNDERWATER ACOUSTIC POSITIONING (*)

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...Over a flat sea floor, with the transponder-transducer 100 metres above the bottom, this dictates a region as in figure 8, starting at a range of about 4 km and becoming gradually higher.

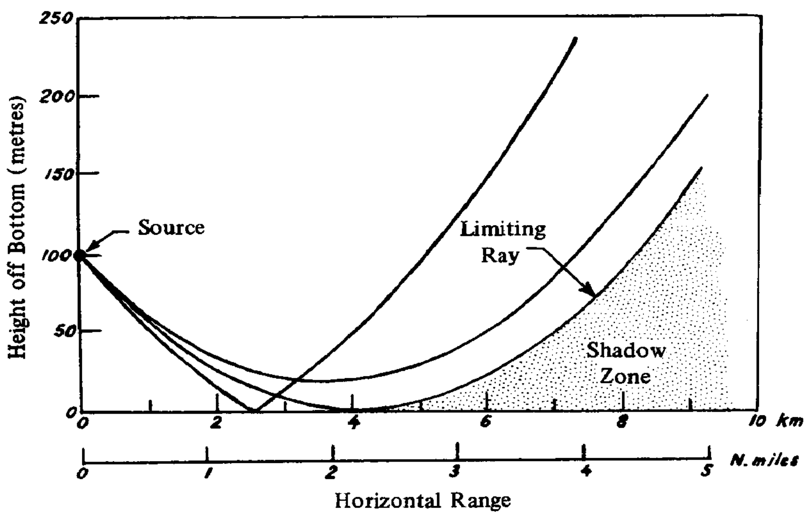


Fig. 8. — Upward-refracted rays from a near-bottom source

...In a more recently placed transponder field, sufficient data have been gathered to allow an accurate analysis of the positional errors. Using 460 instances in which ranges from the instrument to all three transponders were simultaneously read from the records, and the fish was deeper than 2 km, it was possible to carry out the transponder location calculation, and from this to determine the root mean square difference between the observed ranges and the best fitting calculated position in each instance. A personal communication from J.D. Mudie stated that the resulting number was 3

(*) This article was presented at the First Marine Geodesy Symposium, held in Columbus, Ohio, in September 1966.

metres, which is the same magnitude as several sources of error neglected in our computations (such as, transponder answering delay, and motion of the fish between transmission and reception of signal).

A translation of these range accuracy numbers into position accuracy (LOWENSTEIN and MUDIE, 1966) shows a mean position error of 5 metres radius. The individual position errors are 2 to 20 metres, varying with location in the transponder field.

...In addition to the random errors associated with the timing data there are systematic errors associated with the value of the sound speed used, and possible motion of the transponder hydrophones in near-bottom currents. The former, at the depths in which we are working, can be considered as a simple scale assignment which can be based to a few parts in $10^4$ on sound speeds computed from available hydrographic data. If the tracking of a near-surface craft is to be done, the measurements of sound velocity (or temperature and salinity) must be made as a function of depth in the near-surface water throughout the survey. Travel times must be corrected accordingly.