

# ULTRASONIC MEASUREMENT OF DEPTH

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Echo sounding consists merely in transmitting a short burst of sound under water and measuring the time required for the echo to return. It is one of the simplest of the products of this electronic age.

Soundings used to be taken by hand with a lead line, but this was cumbersome and inaccurate. A line might shrink or stretch according to its wetness, and it would not hang straight unless the ship was stopped. In deep water the drag on a long line made it difficult or impossible to detect the loss of tension when the sounding weight struck bottom. This difficulty led to the invention of many ingenious devices in which the maximum hydrostatic pressure would register in the lead, but none of these was as accurate as a measurement of the time of travel. An expendable sounding bomb was invented in Germany and used to some extent in the 1920's. To take a sounding a small bomb was tossed overboard. It would arm itself after it was wet and would detonate on contact with the bottom. The sinking time of the bomb could be measured by an ordinary stop watch and the depth calculated from the supposedly known sinking rate.

Echo sounding by measuring the travel time of sound waves is so obvious that it is hard to say when it was first invented. In fact the English language seems to have anticipated the invention. We have "sound" meaning to measure depth and "sound" meaning acoustic energy. These homonyms come from the old French, but from different words. Actual echo sounding required instrumentation and the courage to experiment. It was first tried about 1912 in this country by Fessenden and separately in France by Langevin. As a result of the Titanic disaster in 1912, Fessenden was concerned with detecting icebergs by underwater echoes but he obtained far stronger echoes from the sea bottom. Langevin had developed quartz crystals for ultrasonic generators and, since they radiate far more efficiently in water than in air, he applied them to the problem of depth sounding.

Exploitation of these experiments needed to await development of practical means for indicating the echo time which ranges from a millisecond to several seconds, according to the depth of water.

All the mechanical and optical art of oscilloscopes and oscillographs was reviewed and many ingenious depth indicators were tried. But there is a world of difference between a laboratory instrument and a practical sea going apparatus. The two most successful solutions to the time measurement problem were the red light indicator which came in the middle 1920's and the graphic recorder in the early 1930's.

The red light indicator (Fig. 1) contains a neon lamp which travels at constant speed around a circular depth scale. The sound bursts are transmitted as the neon lamp passes zero on the scale, and the lamp flashes at the instant each echo is received. The retina of the eye retains the image of the flash long enough for



FIG. 1. RED LIGHT DEPTH INDICATOR (RAYTHEON TYPE DE-111)

the observer to read the position on the scale where the flash occurred. The recorder (Fig. 2) is essentially the same in principle, but the neon lamp is replaced by a stylus which travels across a calibrated chart scale. The echo causes the stylus to mark the paper electrically, and the mark is permanent. The memory feature of the recorder has considerable advantage. It draws a permanent record which is easier to interpret than a sequence of momentary flashes. However, from the commercial viewpoint the special paper required for the recorder is an appreciable expense, and many customers still prefer the economy of the red light indicator.

With any indicator or recorder it is possible to expand the scale in order to magnify the region of the echo while suppressing the range closer to the surface. This is particularly convenient with a

cathode-ray oscilloscope, which is useful for detailed study of the echo structure. However, a cathode-ray tube indicator is seldom used because it does not have enough advantage to justify its size and cost. Yet it may prove to be the only practical indicator for scale model soundings in tanks where the time of travel is very short.

Before going further into the details of design and performance

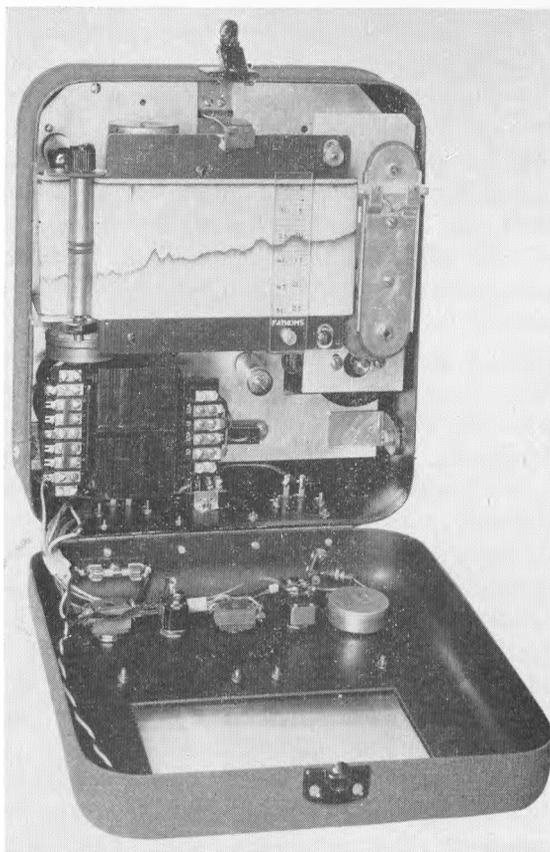


FIG. 2. DEPTH RECORDER (RAYTHEON TYPE DE-112)

let us consider briefly the purposes for which depth sounding has been developed. It is primarily an aid to navigation. It is obviously a protection against running aground, either when a pilot does not know where he is or when he has no chart of the shoals and rocks. It is particularly useful in finding and following a harbor channel in a fog. When out of sight of land, a navigator often fixes his position by comparing his soundings with the chart.

Here a single sounding is of little value, but when the course and speed are known and the soundings are tabulated for a brief period, they can usually be matched with some unique position on the chart.

Soundings are equally essential to the surveys which provide the basis for navigation. The Navy Hydrographic Office and the U. S. Coast and Geodetic Survey use echo sounding extensively in preparing navigator's charts. They use essentially the same equipment as the navigator but take particular care to maintain precise control of the speed of the indicator or recording mechanism. They also observe water temperature and salinity since these variables affect the velocity of sound. In harbors and inland waters the survey function is carried out by the Army Corps of Engineers and the U. S. Geological Survey. Here again the equipment is similar except that it is designed for relatively shallow water. Increasing attention must be paid to the elevation of the water surface which varies with the tide and with the flow of streams. Occasionally depth sounding locates submerged wrecks, either for protective charting or as a preliminary to salvage operation.

Depth sounding is invaluable to the fishing industry, both as a navigation instrument and as a means for finding fish. Most fish caught commercially swim a few feet above the bottom in depths of 50 to 100 fathoms, on the sloping sides of submarine ridges or banks. They are caught by trawling parallel to the ridge, maintaining constant depth, with a net rigged to drag or just clear the bottom. Continuous sounding is almost essential because the fish congregate along a contour of constant depth. Unless the fisherman is lucky enough to find a school of fish he may trawl for hours and catch practically nothing. This wastes valuable time on the fishing grounds and risks unnecessary damage to the net. However, by careful attention to the depth sounder it is often possible to detect echoes from the schools of fish or even from individual fish. Various fish finding equipments are available commercially. Some are essentially depth sounders with a beam of sound directed downwards. Others search with a horizontal beam, much as naval vessels search submarines with sonar. It seems fair to say, however, that all fish finders are only marginal in performance, because fish, even in schools, reflect very little sound. Better equipments for finding fish are being developed but economics pose a major obstacle. It is an important endeavor, however, because the world's population is rapidly approaching limitations in the food supply. Oceanographers believe that there are many more fish in the ocean than we have yet learned to catch.

Echo sounding has application also to geology. For different kinds of bottom, the reflection coefficient differs not only in its value but also in the way it varies as a function of the angle of incidence. The reflection of sound is much like that of light. There is specular reflection, as with a mirror in optics, where sound is reflected at an angle equal to the angle of incidence. There is also diffuse reflection in which the sound is scattered in all directions from a rough surface. Both phenomena occur on the bottom of a waterway, partly because the interface is never truly smooth, and partly because the particles which compose the bottom move and interact in a random manner. In addition, an appreciable fraction of the incident sound is transmitted into the bottom and absorbed. In sonar applications, one is generally concerned with specular reflection at normal incidence, or when incidence is oblique, with the component of scattered sound which returns to the source. Regardless of the angle of incidence, the intensity of this returning sound is proportional to the back scattering coefficient.

The back scattering coefficient is a function of the angle of incidence. This has been measured for a variety of harbor bottoms which, except for rocks, are comparatively smooth [1]. The reflection from a rocky bottom tends to produce rather uniformly diffuse scattering, either because the rocks are spherical, or if jagged, because they are oriented at random. Smooth sand or mud bottoms, on the other hand, are characterized by a relatively large proportion of specular reflection. There are no data for the rippled sandy bottom of a river. Here one would expect an intermediate condition, but the reflection coefficient should depend also on the direction of the ripples. While sand and mud are alike in producing relatively large proportion of specular reflection, mud has a smaller coefficient because it absorbs more of the sound. The presently available data are nearly enough to permit a classification of the bottom by echo sounding providing one takes the trouble to measure the reflection for various angles incidences.

Mud reflects less sound than sand because more of the sound penetrates the softer material. As long as the mud is homogeneous, the sound will propagate through it, but will be rapidly attenuated by the viscosity of the mud. If a harder stratum underlies the mud some of the sound will be reflected upward. When the mud is not too thick this reflected sound gets back into the water with an intensity sufficient to cause a discernable second echo. Often the underlying stratum is not distinct and the density changes gradually from clear water through soft ooze to hard soil. In such cases the echo is stretched out in time. Occasionally the upper ooze is

so soft that it is difficult to define where the bottom really begins, and then it is equally difficult to determine with a lead line. The softness of the bottom can often be judged by the quality of the echo, without resource to quantitative measurements, but this requires experience. In a few instances these phenomena have been used to study sedimentation with a view to determining the geological age of a body of water. Observations in Lake Michigan show acoustic penetration through at least 7 fathoms of clay overlying till [2]. In the Gulf of Maine sediment ranging up to 50 fathoms of thickness has been found [3]. Both of these studies were made with essentially standard commercial equipment. If the geologists are interested in pursuing this sort of investigation, more basic research is needed, directed particularly toward the choice of an optimum frequency of sound for penetrating various types of mud and silt.

The application of depth sounding to hydraulic research is the one to which this paper is primarily directed. This new application poses certain problems which have not occurred before. One is to measure the shape of the bottom in detail in order to study scour patterns and ripples. Another is to integrate depth over a cross-section of a stream in order to facilitate computation of volumetric flow. Both of these measurements may require greater accuracy than has been needed in navigation and even survey applications. Finally the hydraulic engineer wants soundings, not only in real streams, but also in small scale laboratory flumes.

In the matter of accuracy, the variations of the velocity of sound come immediately to mind. The velocity is a function of temperature, salinity, and hydrostatic pressure [4]. Hydrostatic pressure increases the velocity slightly more than one part per million for each meter increase in the depth, so this variation may be neglected completely in shallow water. Figure 3 shows how the velocity increases with temperature and salinity. The two salinities shown are not extreme, but represent the range which is usually encountered in ocean waters. The hydraulic engineer works mostly with fresh water, where salinity may be neglected. His major concern is temperature, which causes a total variation of some 7 percent in the working range of natural water.

When there is a vertical temperature gradient in the water, it is quite a complicated thing to correct exactly for its effect on the depth sounding echo time. The reciprocal of the velocity of sound must be calculated as function of depth, and this reciprocal integrated along the sounding path to find the total time of travel. In oceans and lakes appreciable thermal gradients occur because the

surface water is warmed by the sun or cooled by winter air. The warmer water is less dense and remains at the surface, and any surface-cooled water sinks to the bottom. In rivers and streams, however, there is probably enough turbulence to stir the water and produce a reasonably uniform temperature from surface to bottom. When this is true it is sufficient to determine the average temperature from a few measurements, and to assume that the average velocity exists along the entire path.

One way of overcoming the uncertainty in the velocity of sound

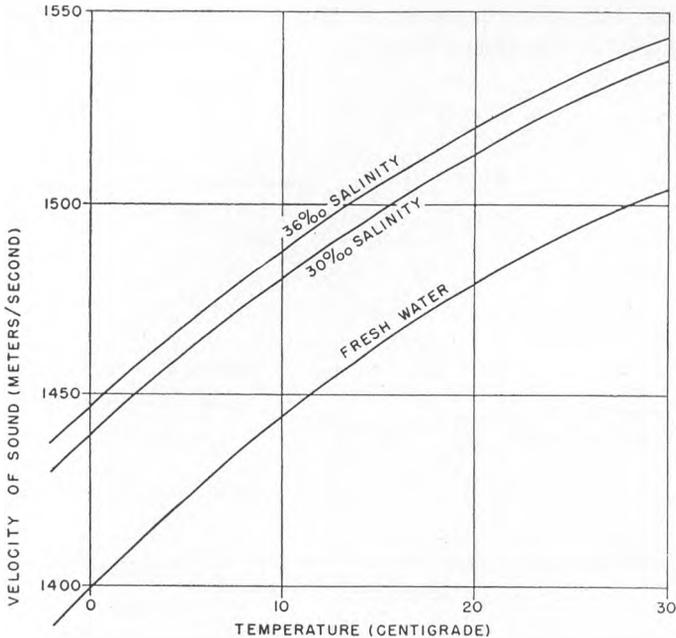


FIG. 3. VELOCITY OF SOUND IN WATER AS A FUNCTION OF SALINITY AND TEMPERATURE

is to calibrate the echo sounder with echoes from a horizontal bar lowered on chains to a known depth. This method is used extensively in the survey work of the Army Corps of Engineers. It corrects the errors in the time of travel, but does not eliminate inaccuracies due to the gradual onset of the echoes.

It is difficult to measure echo time precisely because the echo cannot start and stop suddenly. No one has succeeded in building an efficient sound projector that is free of resonance. Furthermore, the receiving system usually requires electrical tuning, or narrowbanding, to exclude much of the noise that is generated by the wash

of water against the hull of a moving vessel. In any resonant system, mechanical or electrical, the response is not instantaneous, but gradual, as an exponential function of time (Fig. 4). Whatever the indicating device, it requires a certain threshold to distinguish an echo from the background noise. The indication of the echo must be delayed until this threshold level is reached. If the delay were constant, it would cause little trouble, but obviously the delay varies with the intensity of the echo. A strong echo, arriving at time  $t_0$  is indicated at  $t_1$ , but a weaker echo (10 db weaker in Fig. 4) is not indicated until  $t_2$ . Since the echo intensity may vary as much as 20 db with the character of the bottom, there is always some uncertainty in the delay time.

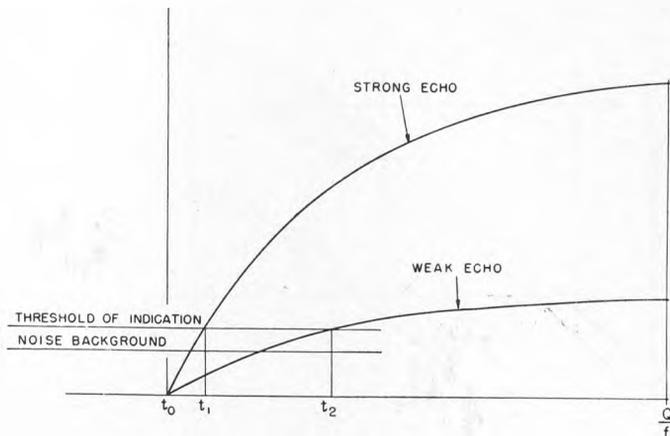


FIG. 4. RESPONSE AS AN EXPONENTIAL FUNCTION OF TIME, AND DELAY INTRODUCED BY A FINITE THRESHOLD

The amount of delay, and its variability, can be reduced to some extent by lowering the threshold, but background noise always imposes a limitation to this approach. The rise time of a response depends on the frequency and on the effective  $Q$  value of the system. Since a signal attains 95 percent of its final value in  $Q$  periods of the oscillation the delay increases inversely as the frequency. Errors in depth measurement from this cause often amount to 1 percent in ordinary echo sounders. In hydraulic research, particularly in the laboratory, the problems seem quite different. In shallow water the frequency of the sound may be increased, perhaps by an order of magnitude, before excessive attenuation limits the performance. If operating conditions are relatively quiet, the receiver may be designed to accept a much wider band of noise, and consequently con-

tribute little to the  $Q$  of the system. These design changes should make the uncertainty in depth quite negligible.

Another cause of a gradually rising echo intensity involves the geometry illustrated in Fig. 5. The sound is transmitted downward in some sort of a beam with an intensity proportional to the directivity function  $\delta(\theta)$ . This is a function of the angle  $\theta$  from the axis. It is assumed for simplicity that the bottom is level, and that the ship is on an even keel, so that the normal incidence occurs. Traveling with a velocity  $c$ , the sound goes down a distance  $d$  and returns as an echo. At a time

$$t_0 = 2d/c \tag{1}$$

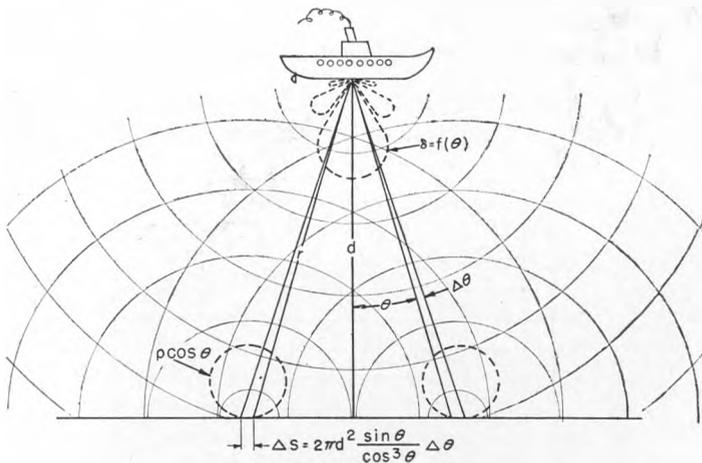


FIG. 5. GEOMETRY OF ECHO SOUNDING OVER A HORIZONTAL BOTTOM

after the transmission began, the echo starts to appear from the nearest point directly beneath the ship. The first sound returns from only an infinitesimal area of the bottom and contains only an infinitesimal amount of energy. As time continues, a progressively larger area of the bottom contributes reflected sound, and the echo increases accordingly. At any time  $t$ , the instantaneous echo power is the resultant of contributions from all of the bottom within a cone of angle  $\theta$ , where

$$\sec \theta = t/t_0 \tag{2}$$

To treat this problem mathematically requires some assumption about how the back scattering coefficient of the bottom varies with the angle of incidence. One might naturally assume Lambert's cosine law. Actually the reflection from a smooth bottom is more

specular than that, and from a rocky bottom it is more uniformly diffuse. Thus, if one wants to generalize by assuming an average bottom, Lambert's law appears to be a very fair compromise. With this assumption it can be shown [5] that the echo power arriving at any instant  $t$  is

$$w = 2\pi w_0 \rho \frac{A_c^2}{\lambda^2 d^2} \frac{1}{t_0} \int_{t_0}^t \delta^2(\theta) \cos^5 \theta \times 10^{-2ad \sec \theta} dt \quad (3)$$

Where  $w_0$  = total power transmitted

$\rho$  = reflection factor of the bottom for normal incidence

$A_c$  = capture area of the transducer

$\lambda$  = wavelength of sound

$d$  = depth

$a$  = coefficient of attenuation of sound in water

The definite integral is the only factor in equation (3) which varies with time. Figure 6 shows how it behaves for a few arbitrarily

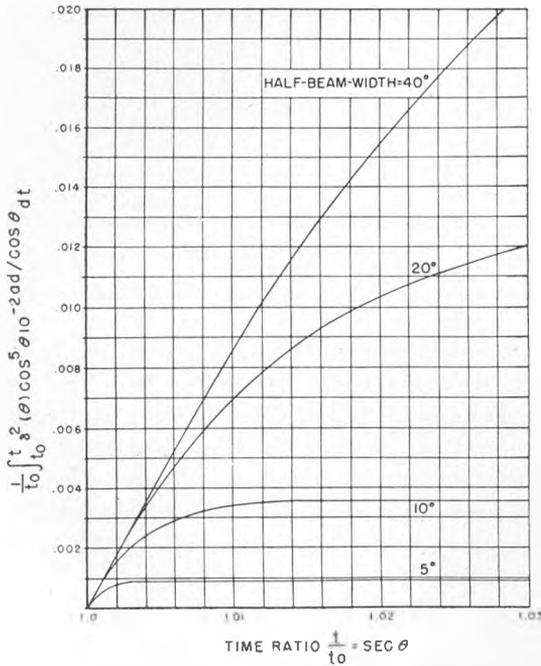


FIG. 6. VALUE OF THE DEFINITE INTEGRAL IN EQUATION (3) AS A FUNCTION OF NORMALIZED TIME, FOR THE CASE  $ad=0.01$  BEL. THE DIRECTIVITY IS THAT OF A CIRCULAR PISTON, WITH THE BEAM WIDTHS AS NOTED AT THE  $-10$  db LEVEL

chosen widths of the sound beam  $\delta(\theta)$ , and for one moderate value of attenuation. The origin represents the time  $t_0$  when the echo begins to arrive, and the abscissa is the normalized time ratio  $t/t_0$ . The time required for the echo to reach any arbitrary value is thus proportional to the echo time  $t_0$ , and the resulting error in depth measurement is proportional to the depth itself. Regardless of the beam width, all these curves have the same initial slope, which is equal to the attenuation factor  $10^{-2ad}$ . In a sounding equipment designed for good accuracy the indicator threshold would presumably occur at a level so low that this initial slope still persists. Figure 6 shows only the time dependent portion of expression (3). For the best accuracy we want the fastest rise of the echo. Therefore, we should maximize

$$t_0 \left[ \frac{dw}{dt} \right]_{t=0} = 2\pi\rho W_0 \frac{A_c^2}{\lambda^2 d^2} 10^{-2ad} \quad (4)$$

The reflection factor  $\rho$  is a property of the sea bottom over which we have no control. We can always gain by increasing the transmitted power  $W_0$ , but this is expensive. Also if the size of the projector is fixed,  $W_0$  is limited by cavitation to the order of 1 watt per square centimeter. Regardless of the transmitting power, the other parameters in equation (4) should be chosen wisely. The wavelength  $\lambda$  is inversely proportional to the frequency while the attenuation factor  $a$  per unit distance increases roughly in proportion to the square of the frequency. Obviously, there is an optimum frequency for which  $10^{-2ad}/\lambda^2$  is maximum. The optimum frequency increases as the depth diminishes. Also, it is considerably higher for fresh water than for salt because sea water has more than 50 times as much attenuation over most of the useful range of frequencies [6].

The characteristic rise due to the geometrical effect, shown in Fig. 6, was calculated without regard to the transient response of resonant systems. Both effects are present, and operate additively on the echo. Since resonance causes a truly exponential rise, and the geometric effect causes a rise of very similar shape, the echo will build up in almost exponential fashion providing the signal continues indefinitely as shown at (a) in Fig. 7. Of course, the signal does not continue, but has a limited duration, as in Fig. 7(b). The same causes which contribute to a gradual rise at the beginning of the echo also produce a gradual decay, or tail, at the end. This may be demonstrated by considering the limited signal of Fig. 7(b) to be composed of positive and negative unit functions,

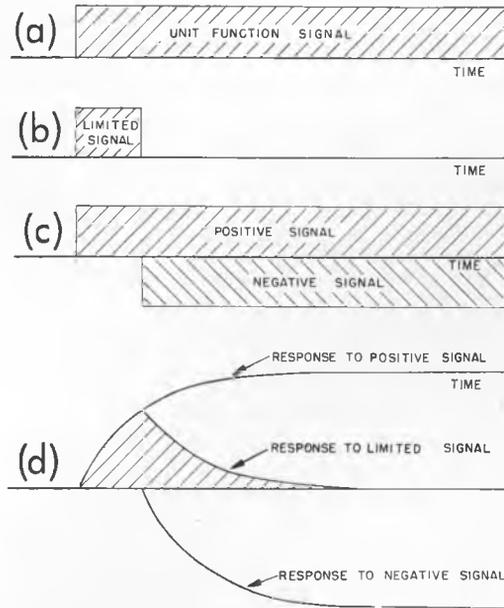


FIG. 7. COMPOSITION OF THE TRANSMITTED SIGNAL AND THE CORRESPONDING ECHO RESPONSE

displaced in time, as in Fig. 7(c). The responses to these two signals are alike, but opposite in sign and displaced in time as in Fig. 7(d). The algebraic sum of the two responses is the response to the limited signal. While the tail of the echo does not affect the accuracy of depth measurement, it may obscure some of the information about the character of the bottom.

The problem of maximizing the rate of rise of the echo is not quite as simple as this discussion would imply. The capture area  $A_c$  is related to the wavelength and to the physical area of the transducer face. The relationship is rather complicated, and involves the directivity of the sound beam which we must consider also from other viewpoints. To some extent one can increase  $A_c$  merely by paying the dollar cost of a large transducer. However, cost is not the only limitation. The directivity is proportional to the ratio  $A_c/\lambda^2$ . If this ratio were too large, the sound beam would be too narrow for the roll and pitch of a ship at sea. If a stable platform were available, the narrower the beam the better for most research applications. In this case there would be some limit to the sharpness of a sound beam which could be obtained in practice. Since this problem has not arisen in the past there is no experience to indicate what that limit is.

A typical transducer beam pattern is shown in Figure 8. Here the relative response in decibels is plotted as a function of the angle from the transducer axis. The pattern consists of one main beam surrounded by several minor lobes. The designer can easily control the width of the main beam, but in general, he cannot eliminate the minor lobes. The pattern shown in Figure 8 applies either in transmitting or receiving. The relative intensity of an echo would be indicated by doubling the decibel scale of this plot. Thus an echo from the direction of the first minor lobe would be some 40 db weaker than the echo on the axis. If the bottom is smooth and hard, delayed echoes from the minor lobes can occasionally be distinguished, but usually they are masked by the tail of the earlier echo from the central beam.

Soundings which show the bottom contour in accurate detail require a high degree of angular resolution. A depth sounder tends always to display the nearest point of the bottom. Suppose the bottom has a step, as in Fig. 9, and consider what would happen when cruising over it. For a considerable distance, the step is nearest to the surface. With a broad sound beam the depth sounder would pick up the echo from the step, and would indicate the apparent bottom as the hyperbolic curve. The region of true bottom beneath this curve would be obscured. If the water were shallower, the depth sounder would be closer to the step, and the obscured region would be shorter. But in the extreme case the hyperbola would degenerate only to a line of 45 degree slope. Of course the situation is not as hopeless as Fig. 9 implies. The echo from the

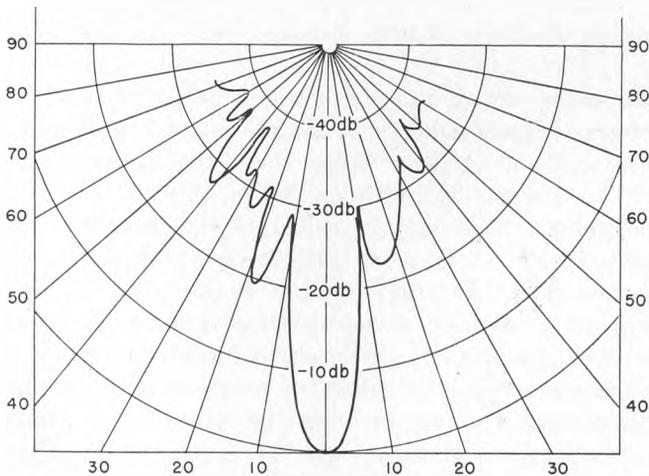


FIG. 8. DIRECTIVITY PATTERN OF RAYTHEON TYPE 2155 TRANSDUCER AT 210 KCS

true bottom would also be present, this would be indicated at its proper time, and might be discernible below the hyperbolic trace. However, we must remember that every echo has a tail, and that the tail of the step echo would probably overlap the true bottom echo. A narrow sound beam would help to suppress the undesired echo from the step, but complete suppression is never possible because of the minor lobes.

A step such as drawn in Fig. 9 seldom occurs on a natural bottom, but it illustrates the difficulty in echo sounding whenever the bottom is not level. The fact that the depth sounder measures the distance to the nearest point introduces an error in true depth of a smooth but sloping bottom [7]. The only sure way to sound

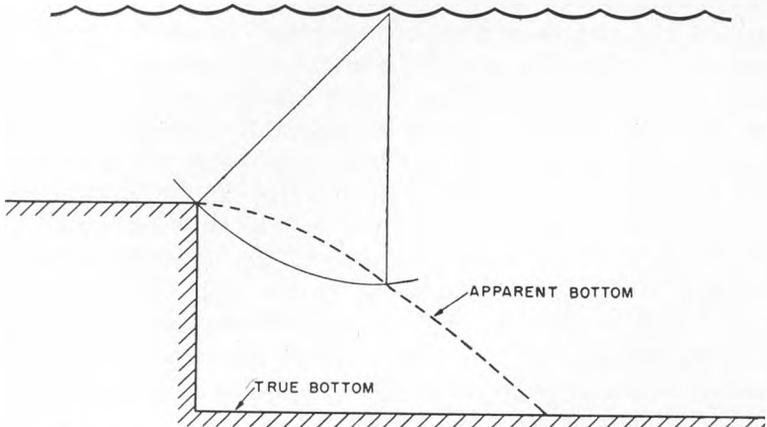


FIG. 9. GEOMETRY OF ECHO SOUNDING OVER A STEP IN THE BOTTOM

the deepest point of any hollow, such as a scour pattern, is to lower the transducer deep enough to be always below the center of curvature of the bottom surface. Even then, the sloping sides of the hollow will be distorted slightly in the display. If the true bottom contour is known, it is easy to calculate the distortion introduced in the echo trace. It is very difficult to interpret a given echo trace and determine the exact contour of the bottom.

The ripples caused by water flowing on a sandy bottom seem much too fine for this sort of geometrical analysis. From this point of view, the ripples might be called the microstructure of the bottom. If their wavelength is shorter than the width of the sound beam, the indicated echo would show only the depth to the crests. While an equal amount of sound would return from the intervening valleys, this would be obscured in the tail of the earlier echo from the crests.

The ripples stretch the echo out in time, but in view of the other factors which also stretch it out, it does not seem practical to measure the average depth of water over a rippled bottom. It is possible, however, that useful information about the amplitude and wavelength of the ripples might be obtained from a study of the back scattering as a function of the angle of incidence.

It is quite another problem to integrate depth on a gross scale and calculate the cross section of a stream. Here the recorded trace can be integrated with a planimeter, providing the depth of water is great enough to make a mechanical recorder practical. A recorder mechanism can drive a stylus reliably with a straight-line motion at speeds up to 24 inches/second. At this speed the scale factor is 1 inch of paper chart for 10 feet of water depth. For a more expanded scale, faster recorders have been made in which the stylus is mounted on the end of a rigid arm and travels across the paper in the arc of a circle. Such instruments produce a valid record but the chart is distorted and the depth graduations are not uniformly spaced. With a chart of this type the trace would be difficult to integrate with a planimeter.

For depths less than 10 feet, as in laboratory flumes, the echo time is so short that a cathode-ray tube seems far more suitable than any mechanical indicator recorder. A cathode-ray tube does not supply a permanent record to be integrated, but this function could be accomplished photographically. It is also possible to integrate a series of soundings electronically in a variety of different circuits. As a matter of fact there are various circuits which measure time electronically. Many of these have been used in cheaper depth sounding equipments to indicate depth by a simple electric meter. They have not been discussed in this paper because, in general, they are quite unsuited to research applications. The chief difficulty is that an electronic circuit gives a false indication whenever it receives a burst of noise which is comparable in intensity to an echo. In laboratory flumes, however, there is every reason to expect that the background noise would be much quieter than on a moving vessel. If so, electronic depth sounders should be completely reliable. The accuracy of their time measuring circuits is controlled primarily by economics. Some electronic counter circuits are available which, although relatively expensive, are capable of greater accuracy than even mechanical instruments. These electronic counting circuits are readily adapted to the integration of a sequence of soundings to yield a direct measure of the area of a cross section.

In connection with echo sounding in a small scale flume, it is worth noting the existence of another kind of equipment which has been developed for quite a different purpose. The performance of a radar on a bombing plane can be simulated by ultrasonic echo ranging in a tank of water [8]. Radio waves travel roughly 200,000 times as fast as sound waves in water, so simulation results when all distances are scaled down by this factor. The ultrasonic transducer is transported through the water according to the simulated motion of the airplane. A relief map of a target area, such as a city, is placed on the bottom of the tank. Ultrasonic echoes are presented on a cathode-ray tube plan position indicator, just as the real radar echoes would appear on a bombing mission. This system provides a realistic picture of the target, but it suffers from the same limitations as radar when sounding into a concave region. The ultrasonic radar simulator is cited here, not to imply that the problem of depth sounding in small tanks has been solved, but merely to point out that there may be techniques in that area which could be useful in the hydraulic laboratory.

#### CONCLUSION

This review of the current art of ultrasonic depth sounding has been written in a critical vein in order to emphasize the limitations which might concern the hydraulic engineer. Conventional equipment designed for general navigation purposes does not appear to meet all the requirements of hydraulic research. However, these needs could probably be satisfied with appropriate equipment especially designed for the purpose. The most significant departure from conventional design would be to increase the ultrasonic frequency by an order of magnitude in order to improve the resolution of the echo sounding system. Such a change is made possible by the limited depth of the rivers and flumes where the special equipment would be used. Cathode-ray tube indicators and electronic counters are worthy of consideration for shoal soundings with quiet operating conditions.

#### DISCUSSION

Mr. Bradley was interested in the accuracy obtainable in the range 10 to 40 feet of water, and the cost; the speaker estimated 2 percent for standard commercial equipment and  $\frac{1}{2}$  percent with special equipment. Cost figures should be obtained from a manufacturer, but elements cost approximately \$250.

Mr. Kolupaila wanted to know if soundings could be made from an airplane or if both transmitter and receiver had to be immersed in water. The speaker answered that practically all of the energy from a transducer in air would be reflected at the water surface because of the tremendous difference in acoustic impedances.

Referring to the speaker's mention of two cases in which a firm bottom was detected below alluvial material, Mr. Schneible asked if equipment was commercially available for detecting rock formations 10 to 50 feet below alluvial stream beds. After ascertaining that the question referred to wet beds, Mr. Batchelder emphasized his earlier statement concerning better transmission in wet soils. He thought that it should be possible to make such measurements with commercial equipment, but felt that the question was one to be answered by a geologist. Mr. Schneible had found, in his experience at sites where the depth of rock had already been determined by other methods, that the fathometer gave such indications, but not consistently. He now wanted to know if special equipment was in existence and if the type used in Lake Michigan was a secret type developed for the navy. The speaker assured him that it was a standard fathometer and was used by the University of Illinois. He also referred to a paper by Firstak at the University of Chicago.

Mr. Bengal spoke of his experience in using the equipment for soundings in San Francisco Bay and along the lower channels of the Sacramento and several other rivers. They found that they could measure the depth of the very light and porous mud (75 to 80 lb/ft<sup>3</sup>) found in San Francisco Bay, with the hard blue clay or sand bottom showing up as a very sharp line.

In response to a question by Mr. Liu concerning application of the fathometer to detect the movement of dunes, the speaker stated that continuous observations at one point would yield the desired information.

Referring to slide No. 9, Mr. Shoumatoff recalled a similar instance in which a form asserted to be that of a huge lizard was observed during soundings in Lock Ness. Mr. Batchelder had been assured by a sound expert of the British Admiralty that it could be nothing but "the monster."

#### REFERENCES

1. Urick, R. J., "The backscattering of sound from a harbor bottom," *J. Acoust. Soc. Am.* 26, 231 (1954).
2. Hough, J. L., "Fathogram indications of bottom materials in Lake Michigan," *J. Sedimentary Petrology*, 22, 162 (1952).

3. Murray, H. W., "Topography of the Gulf of Maine," *Bull. Geol. Soc. Am.* 58, 153 (1947).
4. Del Grosso, V. A., "The velocity of sound in sea water at zero depth," *Naval Research Laboratory Report* 4002 (June 11, 1952).
5. Batchelder, L., "Optimum signal characteristics for distance measurement by echoes," *Proc. National Electronics Conference*, 7, 29 (1951).
6. Beranek, L. L., *Acoustic Measurements* (John Wiley and Sons, Inc., New York, 1949), p. 76.
7. Schärfe, J., "Besonderheiten bei Echolotungen über unebenem Grund," *Fischereiwelt*, 7, 99, (1952).
8. Rosenberg, P., "Supersonic Training Device" U. S. Patent 2,518,938 (August 15, 1950).