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The Development and Use of the Hydrophone

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[*Editor's Note: The following is the second of a series of articles on the Development and Use of the Hydrophone. Other articles on this subject will appear in future issues of the Experimenter.*]

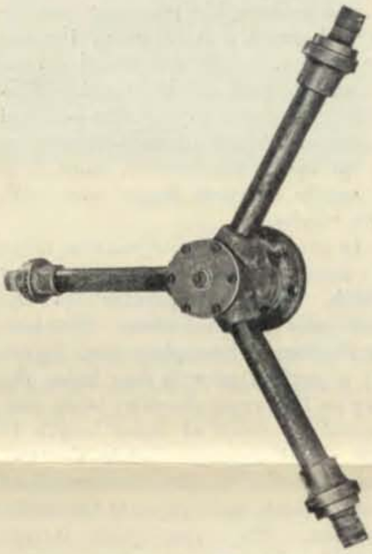
PART II

In the January issue of the "Experimenter" we discussed the binaural sense and saw how it was utilized in the operation of the C-tube device for locating under-water sounds. It was apparent, however, that the C-tube had two serious limitations. In the first place it was slow and cumbersome to operate and required the listening vessel to be practically lying to while making observations, and in the second place it was equi-sensitive in all directions which limited its range if a multiplicity of sound sources were present.

We shall explain in the present article how the first of these difficulties was overcome by employing the principle of compensation.

Suppose that the two hollow rubber spheres which were used for sound receivers in the C-tube are mounted permanently in a rigid position along a horizontal line parallel with the keel of the vessel and, say, four feet apart. They might in practice be so placed on the outside of the ship's skin or located within a water tank in the bottom of the vessel.

These two receivers, indicated at L and R in Figure 1, are joined together by a pipe. This pipe is not, however, continuous from L to R, for at some point along its length it is interrupted by a plug, P, which effectively blocks the passage of sound from L to R. On both sides of this plug are take-off pipes of equal length terminating in the stethoscope leads L′ and R.′ We have, therefore, the sound picked up by the underwater receiver L transmitted to the left ear L′ of the operator, while that picked up by the receiver R is independently transmitted to his right ear R.′



Mounting for Three Microphones

Imagine now that the plug P is located at the exact center of the pipe joining L and R so that the sound paths L-L′ and R-R′ are equal in length. If sound waves come from a direction (1) perpendicular to the base line L-R, they will energize the two receivers simultaneously and the operator will, of course, observe the sound to be binaurally centered. If, on the other hand, the sound waves travel in a direction, such as (2), oblique to the base line L-R, each wave front will strike receiver L prior to receiver R and the corresponding response will be observed to be binaurally off center in a direction to the operator's left.

Let us now assume that, by some mechanical contrivance, the plug P can be slid along the pipe joining L and R and, at the same time, carry with it the two take-off pipes, one on each side of P, leading to the stethoscopes. In this manner, by moving the plug, say, to the right, the length of the sound path from L to L′ is increased while the path from R to R′ is simultaneously shortened by an identical amount; and vice versa.

Referring to Figure 2, let the sound waves be traveling in the direction (2) oblique to the base line of receivers. After each wave strikes the receiver L it has to travel a further distance, MR, through the water before striking the receiver R.

Fig. 3. Assembled Two Spot Compensator

The time, T, required for the sound to traverse this distance MR is known as the *water-lag* between the two receivers for the particular direction (2). This time is, of course, determined by dividing MR by the velocity of sound in water, V

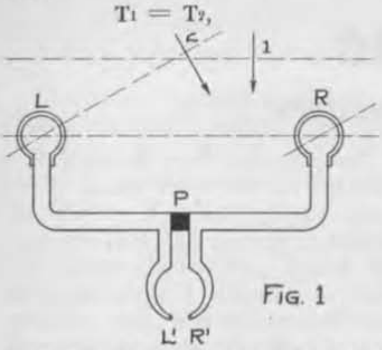
$$\text{that is } T_1 = \frac{MR}{V_1}$$

Figure 2 shows the plug P displaced to the right, in which case the length of the sound path through the pipe, L-P, minus the sound path, R-P, divided by the velocity of sound in air, V_2, gives a certain time, T_2, known as the *net compensation* between the two receivers.

$$T_2 = \frac{LP\text{-}RP}{V_2}$$

It will at once be apparent that, if the position of the plug P is such that:

$$T_1 = T_2,$$



the image of the sound coming from the direction (2) will appear binaurally centered to the operator,—since the time required for sound to traverse the longer air path from L to the stethoscope L′ will equal the total time required for sound to travel the distance MR in water plus the shorter air path from R to R.′ By thus making the *net compensation equal to the water lag* we can binaurally center a sound received from any direction when *fixed* receivers are used. This equality gives us at once the relation:

$$D = \frac{LP\text{-}RP}{2} = \frac{V_2}{V_1} \times \frac{MR}{2},$$

where D is the distance that the plug P is displaced from the center of the pipe.

Referring to the Figure 2 we see that the distance

$$MR = LR \cos \Theta,$$

where LR is the base line separation of the receivers and Θ is the angle between the line of receivers and the direction of the sound source. We can, therefore, write:

$$D = \left(\frac{V_2}{V_1} \times \frac{LR}{2}\right) \cos \Theta,$$

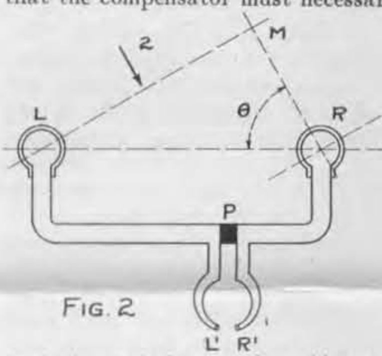
where the quantity within the parenthesis is a constant. Thus we see that the displacement D required to give a binaural centering of the sound is determined directly by the angular bearing of the sound source from the base line of the receivers.

Obviously, then, for a given separation of receivers the position of the plug along the pipe may be calibrated directly in terms of the angular bearing of the sound source from the keel of the vessel. This sliding-plug-in-a-pipe device is called a compensator, or, more particularly, a two-spot compensator, since it is a simple binaural device used with two receivers.

In practice this compensator takes a more convenient circular form which, however, operates on the principles discussed above. The lower stationary base-plate (see Figure 4) is perforated with four holes, the two on the larger diameter being connected by pipes of equal length to the sound receivers, while the two holes on the smaller diameter lead out through equal pipes to the stethoscopes. The upper plate is machined with two annular grooves which are accurately fitted to slide over the two stationary plugs separating the incoming and outgoing holes in the base-plate, whenever the upper plate is rotated. The sound energy in traveling between each receiver and the corresponding stethoscope passes through a distorted U-shaped channel. The relative lengths of these channels are alternately increased and decreased as the upper plate is rotated, that is, the net compensation is varied from zero to a maximum on either side.

The assembled compensator is illustrated in Figure 3, which shows the graduated scales. Care must be taken that the cross sectional area of the sound path remains constant throughout, or, if not, that it is altered gradually, in order to prevent reflections and standing waves within the system. A film of castor oil lubricates and affords an acoustical seal between the moving and stationary parts.

The equipment which we have just described is known as an acoustical hydrophone because the received energy remains in the form of sound waves throughout the system. This arrangement has a disadvantage in that the compensator must necessar-



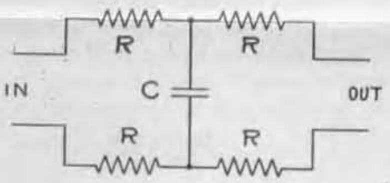
ily be located close to the rubber receivers in order that the sound energy shall not be unduly attenuated in passing through long pipes. Such a location on shipboard is frequently inconvenient as well as uncomfortable for the operator.

The next advance in the art was to overcome this difficulty by the use of a combination electrical and acoustical system. The rubber sphere receivers were replaced by granular carbon microphones mounted in suitable housings to be used underwater. The sound waves picked up in the sea were thus converted to corresponding electrical impulses which, obviously, could be brought by cable to any convenient station on the ship, such

(*Continued on page 4*)

An Artificial Cable Box

When studying the transmission characteristics of various types of cables it is not always convenient to have an actual cable upon which to experiment. This difficulty may be overcome by employing artificial cable built up of series resistance elements and shunt capacitance elements forming a symmetrical "H-type" section as indicated in the figure.



The loop resistance 4 R and the shunt capacitance C of the section are made the same ratio as the loop resistance and shunt capacitance of any given length, say a mile, of the type of cable in question.

Such a single section may, of course, be made to represent any desired length of cable. An artificial cable will, however, more perfectly reproduce a real cable in its electrical behaviour as it is subdivided into a greater number of uniform sections. This fact will be obvious if we consider that the actual cable is composed, electrically, of an infinite number of sections, each having its minute loop resistance and shunt capacitance. That is to say, the electrical constants are distributed uniformly along its length. In practice, however, a limit to this subdivision, as indicated below, is reached whereat the artificial cable represents, with a sufficient approximation, the genuine cable.

The amount of inductance present in a cable is so small in comparison with the capacitance that its effect at voice frequencies becomes entirely negligible in ordinary methods of testing.

The General Radio Company has developed a series of artificial cable boxes, designated as Type 321-C, each containing the electrical equivalent of thirty-two miles of standard paper cable of a gauge frequently used in practice.

This cable is divided into seven units of 16-8-4-2-1-½-½ mile lengths respectively. By means of seven telephone key switches any combination of these units may be thrown in or out of the circuit at will. Thus, any desired length of cable up to thirty-two miles may be obtained, in half-mile steps.

Type 321 C
CABLE BOX

In order to represent more accurately an actual cable, the 16-, 8- and 4-mile units are built up of the proper number of 2-mile sections; the 2-mile unit is built up of two 1-mile sections and the 1-mile unit of two ½-mile sections. The resistance elements of the cable are wound non-inductively and calibrated to ¼%, while the capacitance elements, which are high-grade rolled wax paper condensers, have a precision of ½%. The cable will withstand D. C. or peak potentials up to 300 volts.

The terminals of the cable are brought to two pairs of input and output binding posts, and the whole assembly is mounted on an aluminum panel and enclosed in a shielded walnut cabinet measuring approximately 15″ long, 8″ wide and 5½″ deep.

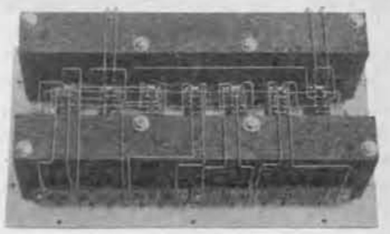
Three different cable boxes have been designed representing side-circuit types of 16, 19 and 22 gauge non-loaded paper cable. The electrical constants at 796 cycles are as follows:

Gauge	Resistance Per Loop Mile	Cap. Per Mile
16 B & S	42.2 ohms	.062 MF
19 B & S	83.2 ohms	.062 MF
22 B & S	171 ohms	.073 MF

The net price of the Type 321-C artificial cable box containing any one of these standard gauge is $180.00. The illustrations show the exterior panel view and the interior assembly of the instrument.

For the convenience of those desiring to experiment with longer lengths of cable, the Type 321-D box has been designed. This contains thirty-two miles of any one of the standard gauges listed above built as a single unit with a switch for throwing it in or out of circuit. This unit, which is built up of sixteen 2-mile sections, carries a net price of $150.00. By joining a Type 321-C box in series with one or more Type 321-D boxes any desired length of artificial cable may be obtained in half-mile steps.

The General Radio Company would be pleased to design and quote prices for special equipment of this sort built to any desired specifications. Besides the non-loaded cables described above, it is readily possible to build a loaded artificial cable with any desired inductance per loop mile or to construct any desired artificial open wire line having, of course, a much higher ratio of inductance to capacitance.



Internal View Cable Box

(Continued from page 2, column 3)

as the chart room, etc. The two electrical impulses on entering the compensator were made to pass through two individual telephone receivers, where they were transferred back into sound energy. These sounds were then fed into the two input pipes of the compensator, which functioned identically as described above.

Fig. 4

DISSECTED TWO SPOT COMPENSATOR

The proper operation of such a system obviously requires that the two microphones, as well as the two telephone receivers, be binaurally matched.

It has doubtless been apparent to the reader that, as in the case of the C-tube, a single position of the compensator gives a binaural centering for sounds arriving at either of two ambiguous angles symmetrical with respect to the base line. This ambiguity is eliminated in practice by employing three microphones mounted on the vertices of an equilateral, horizontal triangle. By means of a switching device the compensator may be connected across any of three possible pairs of receivers. If, now, the compensator scales for each of these base lines are referred to the center line of the vessel, two consecutive observations on any two of the base lines suffice to remove the ambiguity. One type of mounting for these three microphones when suspended in a water tank in the bottom of the vessel is illustrated on Page 1.

We have seen that the displacement of the compensator is a cosine function of the angular bearing of the sound source. Hence, the most accurate bearing is to be obtained by choosing that base line which is most nearly perpendicular to the direction of the target.

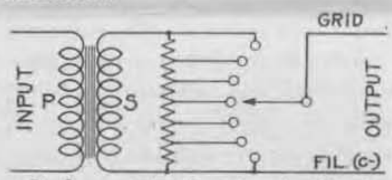
An auxiliary piece of apparatus deserves mention. This is a device known as the pilot valve which is inserted in the stethoscope leads. When turned in one direction this valve affords a direct by-pass connection between the two stethoscope leads and by so doing excites both ears simultaneously at all times and produces, therefore, an artificially centered "pilot" sound. Occasional reference to this pilot sound gives the operator a means of checking his true binaural center, which, during protracted periods of listening, tends to become vague due to mental fatigue.

Two-spot hydrophone equipment of this sort was manufactured in a variety of forms during the latter months of the World War. It proved to be more convenient and rapid in operation than the C-tube and permitted bearings on a sound target to be taken with considerable success while the listening vessel was underway, obviously a distinct advantage in U-boat hunting.

In a subsequent issue we shall continue our resume of the development of the hydrophone art.

A 600,000 Ohm Potentiometer

Probably the most satisfactory method of controlling the gain in an amplifier consists of using a high resistance potentiometer in the input or grid circuit of one of the amplifier tubes after the manner indicated in the figure. This potentiometer must necessarily have a very high resistance in order that it shall draw no appreciable current from the secondary of the preceding coupling device and thereby disturb its characteristics.

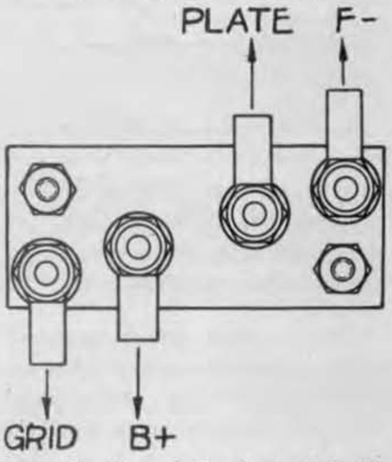


Such a potentiometer is likewise useful as a voltage divider to increase the range of a vacuum tube voltmeter and in numerous other lines of research.

The General Radio Company is developing a 600,000 ohm potentiometer to be known as the Type 452, which will be calibrated in 15 steps of two TU each, giving a total attenuation of 30 transmission units. This instrument will be mounted in a walnut cabinet approximately 5″ square and 3″ deep. The resistance units between successive steps on the potentiometer are colloid metal resistors and are calibrated with a precision of the order of 5%, which is quite satisfactory for this type of work. The correct calibration of such an instrument in terms of transmission units stipulates, of course, that it be used merely as a voltage divider, that is, that no energy be drawn from the output. Price on application.

Plug in System for Audio Frequency Couplers

Experimenters who are interested in the subject of audio frequency amplification and more particularly in the various methods of audio frequency coupling often feel the need of an arrangement whereby different couplers may be quickly inserted in the amplifier system for comparison.



A combination of the General Radio Type 274-B Base and the Type 274 Four plug plate offers an excellent solution to this problem. The couplers which may be either transformer, impedance, or resistance are mounted permanently on the type 274 Four plug plates while the type 274-B Base are properly connected in the amplifier circuit. This feature makes possible a quick determination of the relative merits of different types of amplifying systems. By making the connections to the type 274-B bases as indicated in the diagram an additional feature is secured since the type 274 Multi-connector plugs fits the two middle jacks thus permitting the experimenter to make easy connection to the output of the different stages of the amplifier. The prices of the various items mentioned are as follows:

Type 274-F Transformer mounting plate	.75
Type 274-B Base	1.00
Type 274-M Insulated multi-connector plug	.50