DEPARTMENT OF COMMERCE

U. S. COAST AND GEODETIC SURVEY

E. LESTER JONES, DIRECTOR

RADIO ACOUSTIC POSITION FINDING

Special Publication No. 146

Compliments of R F Luce. Inspector, Boston Field Station.

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PREFACE

During the World War submarine listening devices and means of locating objects by under-water sound transmission were developed by the military forces of the United States and other countries. In 1923 the United States Coast and Geodetic Survey, in cooperation with the United States Bureau of Standards, began experiments in the use of similar methods for position finding in hydrographic surveys. This work was successful, and the resulting apparatus and methods were first used for the control of hydrographic surveys in 1924, under the operating term "Radio acoustic ranging." The equipment and details of operation as first developed are described in Coast and Geodetic Survey Special Publication No. 107, Radio Acoustic Method of Position Finding in Hydrographic Surveys, prepared by members of the two services mentioned above, who were engaged in the development work, and published in 1924.

Since the date mentioned this method of control has been used extensively by the survey ships *Guide* and *Pioneer*, operating on the Pacific coast of the United States, and, due to the zeal and ability of the officers and other personnel of these ships, a number of improvements have been made, all tending toward standardization, simplification, and increased efficiency.

This publication has been compiled from reports submitted by Hydrographic and Geodetic Engineers T. J. Maher and R. F. Luce, the commanding officers of the ships mentioned above. Its purpose is to describe the apparatus and methods in use at the present time and to assemble the knowledge regarding details of operation that has been acquired to date.

It should not be considered as presenting a completely developed and fully standardized engineering practice, suitable for use under all conditions and in every region. Like all radio and electrical apparatus, the equipment is subject to improvement, and a few defects in operation, such as the failure of sound to carry under certain conditions and interference at shore stations, are not as yet fully understood. Furthermore, many of the details of shore-station installation described herein have been worked out for a certain type of coast and may require modification for use in other regions.

Historical details regarding the early development of this means of control, the personnel engaged therein, and the division of work between the organizations concerned have been omitted. This information, as well as details relative to the changes that have been made, may be obtained by referring to the first publication on the subject.

RADIO ACOUSTIC POSITION FINDING

GENERAL STATEMENT

Nautical charts, upon which mariners must depend for the safe and expeditious navigation of their ships along coasts and into harbors, are based chiefly on hydrographic surveys. In order that each chart may furnish an accurate representation of the area that it covers, such surveys, involve, as one of a number of essential operations, the careful location of the numerous soundings by which the depths throughout the area under survey are determined and of the features, such as rocks, reefs, wreckage, and aids to navigation, that must be charted for the guidance of navigators. This operation is generally termed " position finding." It is also necessary in order that the courses of the various vessels engaged in taking soundings may be directed in such a manner as to secure a complete survey in an economical manner.

For hydrographic surveys within sight of objects on or near the shore, the method almost universally followed for position finding is to locate accurately a sufficient number of suitable objects and then to determine the position of the sounding vessel at short intervals by angles, observed from the vessel, between the fixed objects. (See fig. 1.) Visible features are often located by angles observed from two or more of the fixed objects, and this method is sometimes used to locate the sounding vessel.

When outside the limit of visibility (as imposed by the curvature of the earth) of fixed objects, a number of methods of control have been available in the past—all less accurate and consequently less satisfactory than fixed position work.[1] This, however, is only one of two unfavorable conditions with which the hydrographer must contend in obtaining positions. The second is the fact that observations on fixed objects, even when well within their normal range of visibility, may be prevented by fog, haze, or other thick weather. In many regions atmospheric conditions of this nature interfere seriously with the progress of hydrographic surveys. The desirability of a method of position finding that will obviate these difficulties is apparent, and it is for this purpose that radio acoustic position finding was developed.

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[1] For details relative to the methods used by the Coast and Geodetic Survey for hydrographic surveys, including information concerning the various methods of position finding, see the Hydrographic Manual. Special Publication No. 143, issued by the bureau.

This method is based on the fact that sound travels through the water with a definite velocity, sufficiently uniform for the purpose required and capable of accurate measurement by tests. The position of a point is determined by creating a sharp sound under water, measuring the time required for this sound to reach the sound-receiving apparatus of each of two shore stations, and then computing the distance between the known points and the point to be

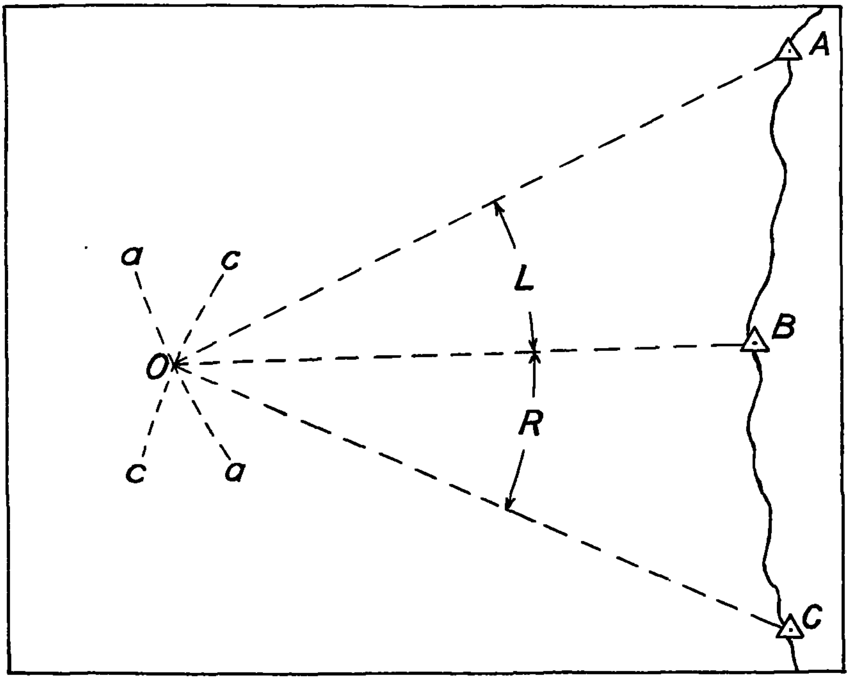

FIG. 1.—Position finding

Points such as *A*, *B*, and *C* are located accurately and are plotted in their proper relative positions on a projection of suitable scale. Any point such as *O* can then be located by observing the angles *R* and *L*, for at no other point from which *C* is the right and *A* the left object (unless *O* is on the circle passing through *A*, *B*, and *C*) will they have the same values. In hydrographic work the position of *O* is plotted with a three-arm protractor. This is the method used for position finding when in sight of known points. It is evident, however, that, if the distances *OA* and *OC* can be measured, an equally satisfactory location of *O* is obtained by the intersection of the arc *aa*, of which the distance *OA* is the radius and *A* the center, and the arc *cc*, of which the distance *OC* is the radius and *C* the center. This is the method used in radio acoustic position finding.

located from the elapsed times and the velocity of sound in water. (See fig. 1.)

The shore stations' sound receivers are accurately located at sites far enough apart so that the distance arcs will give good intersection throughout the area where they are required for control. A third station may be provided as a check, but it is not essential. Important requirements for this method, as well as for visual fixes, are that the survey ship must have direct control of the observations, and that results must be available very soon after observations are completed.

In the past a survey controlled by visual observations on control objects has been referred to as "fixed position" work. As this term must now be extended to include radio acoustic ranging, it is customary to distinguish between the two methods by referring to the older method as "visual position" or "visual fix" work and to designate the radio acoustic method by the abbreviation R. A. R.

Radio acoustic control has been used on the north Pacific coast of the United States for the past four years and, under the conditions encountered in this region, its value has been proved in every respect. Hydrographic parties have been able to carry on their work with little regard for weather conditions and to increase their output many times over that possible with methods previously available. A position 206 miles offshore has been obtained by this method, and little difficulty has been experienced in its regular use out to the limit fixed for hydrographic surveys, 50 to 70 miles offshore.

The apparatus required for radio acoustic position finding falls naturally into two classes—that provided on board ship and that installed at shore stations. These will be taken up in the order named, after which the methods of operation will be described.

In the sections relating to ship and shore apparatus, a radio acoustic set recently constructed in the instrument division of the bureau is used as a basis for the descriptions and illustrations. As standard radio parts obtained from different manufacturers may not be identical in construction, and as the arrangement of such parts and their assembly in cabinets is often a matter of individual preference, the descriptions and illustrations may not conform in all respects to sets in previous use.

SHIP APPARATUS

The apparatus provided on shipboard consists of equipment for producing a sound under water; for detecting the sound impulse when it reaches the ship; for receiving radio signals that announce the arrival of the sound impulse at each shore station; and for recording the receipt of sound and radio signals in such a manner that the time intervals between them can be determined. The principal items of equipment are as follows:

(*a*) *Bombs.*—The under-water sound is obtained by exploding a bomb. Various sizes are used, depending on the distance from shore stations and other considerations.

(*b*) *Sound receiver.*—The sound of the bomb explosion is picked up by a suitably designed and located receiver which is connected electrically with an amplifier.

(*c*) *Amplifier.*—This apparatus is also connected with a radio receiver. Its purpose is to amplify both sound and radio signals sufficiently to operate a relay.

(*d*) *Radio equipment.*—A short-wave receiver is used to pick up radio signals from the shore stations and for general communication with the stations. For the latter purpose a transmitter, of course, is also necessary.

(*e*) *Chronograph.*—This instrument has two pens. One of these, actuated by a split-second chronometer, draws on the tape a seconds-of-time scale. The other pen is connected with the relay mentioned above, so that it records on the tape the receipt of the sound and radio signals.

BOMBS

The bombs used in radio acoustic work are made up by the survey parties. Each bomb consists of a container, explosive, detonator, and fuze.

Containers.—The container is usually an ordinary commercial tin can with friction top. Three sizes—one-half pint, 1 pint, and 1 quart (holding one-half, 1, and 2 pounds of explosive, respectively)—are used. For unusually great distances or with special conditions such as intervening shoals, banks, or ridges, a larger cast-iron spherical container may be necessary. Such a container usually has an outside diameter of 7½ inches, is one-half-inch thick, has one flat surface about 2½ inches in diameter to prevent rolling in a seaway, and holds about 4 pounds of explosive.

The size of bomb required depends on the distance from control stations and other conditions and can be determined only by actual experience on the working ground. Under the most favorable conditions (deep water and uniform bottom) a small bomb will often carry a long distance. Under other conditions the effective distance of any bomb may be very uncertain.

Explosive.—Trinitrotoluol, commonly called T. N. T., is the explosive. Loose T. N. T., grade A, as furnished by the United States Navy Department, is generally used. Cast blocks of this explosive, known as Triton blocks, each weighing one-half pound, covered with a thin copper plating and having a hole for the detonator, are obtainable from the United States Engineers. These explode with a sharper sound than the loose material, but are more difficult to detonate.

T. N. T. is a light yellow, crystalline substance, relatively insensible to shocks, friction, or pressure. It has high chemical stability, even when subjected to temperatures as high as 150° F. for a considerable period. At 180° C. there is a slow evolution of gas and at 300° C. it ignites. When a small, unconfined quantity is ignited, it burns slowly, giving forth a dense black smoke. Its density ranges from

0.75 to 1.0 (hand packed). Grade B of this explosive, darker in color and containing more impurities, may be used if grade A is not obtainable.

Detonators.—The detonators generally used are commercial blasting caps, nonelectric, No. 8. Army blasting caps, No. 8, are slightly more powerful and are especially desirable if it is necessary to use cast blocks of explosive.

Blasting caps are small copper tubes containing fulminate of mercury. The ignition point of this substance is above 150° C. It is not affected by variation in ordinary storage temperatures but should be kept dry. The explosive action is very sudden, violent, and destructive. Fulminate of mercury is readily detonated by friction, shock, sparks, and sulphuric or nitric acid.

Fuze.—Standard commercial, slow burning, waterproof time fuze is used. It has a powder core in a center of jute or similar material with a triple taped covering which is coated with a bitumastic or asphalt compound. In cool weather the fuze should be warmed slightly before using to prevent cracking of the waterproof compound. This fuze burns in air at an average rate of 1 inch in 4½ seconds, but the burning rate in water of the fuze in use should be determined experimentally, as the different brands vary somewhat and usually burn at a different rate in air and water.

Construction of bombs.—The first operation in making up a can bomb is to weight the container—by filling it about one-third full of cement, which is allowed to harden, or by placing iron disks in the bottom to give a weight of about one-half pound per pint of capacity. In the cover of the can a hole slightly larger than the diameter of detonator is punched. The can is then filled with explosive and covered. If it is desired to use less explosive than the capacity of the container, the T. N. T. should be placed in the can first and the remaining space filled with clean, dry sand.

One end of a suitable length of fuze is inserted straight into the detonator as far as it will go without any twisting motion. If rotated when in contact with the detonating material, the friction might cause the cap to explode. A pair of special blasting-cap crimpers are next used to crimp the detonator onto the fuze. The crimp should be about one-eighth inch from the open end of the cap, care being taken not to squeeze the detonating material itself.

Through the hole in the cover a cavity is made in the explosive, using a pointed hardwood stick to make a hole slightly larger than the cap; the detonator is inserted well within the explosive and the joint made water-tight between the fuze and cap. This may be done with yellow soap or, better, with modeling wax, although the latter is more expensive. It is not necessary to make the can itself water-tight, but quite essential that no water get in between the cap and fuze.

Another and more effective method is to use a quick-drying compound, such as supplied by some fuze manufacturers. A product known as "celakap" has been used with good results. The cap with about one-quarter inch of fuse is dipped into the compound and held so that the material will flow down around the joint between cap and fuze. In about a minute this compound will be sufficiently dry to produce a waterproof joint but will still be soft enough, so that the material adhering to the cap and enlarging its diameter will not interfere with the insertion of the cap into the hole in the T. N. T. Further drying of the compound effectively cements the cap and fuze into the explosive, so that tying will probably be unnecessary.

The method used for cast-iron bombs is similar to the above. This type of container has a ¾-inch filling hole and may have a second hole at the opposite end of a diameter. In this case one hole should be tapped and plugged with an eye-bolt, which will add to the convenience of handling the bomb. A funnel is used to pour in the explosive, no additional weight being required. An alternate method of sealing the filling hole is to provide a hole for the fuze in a ¾-inch cork which is drawn over the fuze until it is just above the detonator. This cork is jammed into the filling hole, and a quantity of modeling wax is tamped around it.

For pressing explosives into the cans a wooden implement, similar to a potato masher, flat on the bottom and slightly smaller in diameter than the smallest can, may be used. A similar implement of smaller cross section may be used for the cast-iron containers.

In making up Triton block bombs a detonator and fuze are inserted in the hole in the block and covered with yellow laundry soap.

Precautions.—A number of containers may be filled with explosive before the bombs are needed, but under no circumstances should a detonator and fuze be inserted until just before a bomb is to be fired. Only one bomb should be thus completed at a time, and this must be kept well away from all other explosive. Smoking or a flame of any kind must not be permitted near the place where the bombs are assembled.

Grade B of the explosive leaves a stain on the hands and is poisonous. When it is handled, either rubber gloves should be worn or the hands washed with the following lotion, which, when allowed to dry on the hands, closes and protects the pores:

Take 6½ grams borax and 282½ cubic centimeters of distilled water. Heat to boiling point and then add 56½ grams casein. After casein is dissolved add 250 cubic centimeters of distilled water.

Additional precautions with regard to storage are given below.

Storage.—T. N. T. should be stored in a magazine that is kept thoroughly clean and is used for the storage of no other material except the containers. It should be handled as little as possible and kept free from dust, oil, acid, and alkali; the latter increases the sensitivity of the explosive. It should be kept dry and not exposed to direct sunlight or subjected to high storage temperature. In case of a serious fire by or near T.N.T., a violent explosion is probable. The flooding system of the magazine should always be in proper working order, and magazine temperatures should be taken with sufficient frequency to detect any important change.

When grade B of the explosive is kept in boxes, the lower portion may appear moist as if impregnated with a brown liquid. This does not affect its qualities. T. N. T. exudate mixed with a combustible material or cellulose absorbent is highly inflammable, ignites easily, and can be exploded in a manner similar to low-grade dynamite. Boards or boxes impregnated with this substance should, therefore, be disposed of promptly.

When bombing operations are going on, several containers filled with explosive but not provided with detonators may be kept on deck in a special cabinet. Containers stored in the magazine should be secured in racks.

Detonators should never be placed in the magazine but should be stored on deck in a metal box, secured to the rail in such a manner that it can be thrown overboard readily.

Bomb lighter.—The heating element of an electric stove affords a convenient means of lighting the fuze. It should be secured in position near the rail.

Bomb failure.—Among the causes of misfires that occur occasionally may be mentioned the following: Breaking of the fuze in handling, which permits water to enter; use of too light a detonator; fuze and detonator washing out of the bomb; throwing the bomb overboard before the fuze is burning properly; and failure to crimp detonator tightly to the fuze.

SOUND RECEIVER

The sound of the bomb is received on the ship by a hydrophone, the nature of which is not very important, as the bomb is always near the ship when fired. It is best to have a hydrophone especially for this purpose, and a hydrophone unit, described later, may be installed in one of the ship's water tanks, or one of the fathometer hydrophones may be used. In the latter case the hydrophone should be connected to a double-pole, double-throw switch, so that it may be connected either to the fathometer or to the R. A. R. apparatus with no chance of being connected to both at the same time. The wires from the hydrophone or from the two-pole, double-throw switch will be connected in series with a number of dry cells and the two binding posts marked "hydrophone" on the amplifier. If the hydrophone used is one of the Navy units, four dry cells in series are used, and if it is one of the fathomer hydrophones, two dry cells are used.

If a hydrophone is mounted in one of the ship's tanks, it should be suspended from a bar of iron bolted across two frames, so that it hangs in a horizontal position about 3 or 4 inches above the hull of the ship. The tank selected should be one which is seldom pumped dry, for if there is not sufficient water to cover the hydrophone it will not pick up the sound of the bomb.

The dry cells should be wired permanently and clamped or otherwise held in some out-of-the-way position. They will need renewal only once or twice per year. When not in use, the hydro-radio switch should be on the radio side, which will open the hydrophone circuit.

AMPLIFIER

The amplifier used on shipboard is illustrated in Figures 2, 3, and 4. It has three stages of amplification and is transformer coupled. The switch marked "hydroradio" at the left of Figures 2 and 4 is used to connect the primary of the first transformer to either the ship's radio receiver or the ship hydrophone. The secondary of this transformer has one end connected to the grid of the first tube and the other end to the binding post *C*, whereby negative grid potential may be applied.

Starting at the left lower binding post $+A$, the positive side of the *A* battery goes first to the filament switch, which will be closed upward when the set is in operation, thence to the left hand of each of the three tube filaments. There is also a wire going to the positive side of the test voltmeter for the filaments and another wire going to one side of a potentiometer, the other side of which is connected to the negative side of the *A* battery at the third binding post marked $-A$. This also is connected by a wire to one side of the three filament rheostats, so that when the filament switch is closed the filaments of the tubes will be heated and may be independently regulated by the filament rheostats numbered 1, 2, and 3.

The voltage across each of the filaments may be measured with the filament voltmeter by turning the filament test switch to the points 1, 2, or 3. The fourth binding post, marked $+C$, is connected to the arm of the 400-ohm potentiometer, and the positive common wire of the *C* batteries is connected to this post, so that the grid potential of the tubes may be shifted from the plus to minus side of the *A* battery.

This gives a very convenient method of changing the sensitivity of the amplifier to any value necessary.

After being amplified by the first tube the signal passes from the plate through a closed circuit jack (into which may be plugged a head set for listening) to the primary of the second transformer and thence to the fifth binding post, marked $+B$. In a similar manner the signal is amplified by the second and third tubes, except that the latter acts as a rectifier, so that its change in plate current may operate a relay. Generally the same negative grid potential should be used on the first two tubes, the second and sixth binding posts being connected in multiple to the same *C* battery of about 6 to 16½ volts.

These two tubes should generally have the same *B* battery voltage of about 90. The amplification by the first two tubes should be about as good in volume and quality as can be obtained. This may be tested by connecting the amplifier to the radio receiving set and listening to radio voice signals, or a microphone may be connected in place of the hydrophone and some one talk into it. One trouble, however, with the latter method is that the amplification is so great that regeneration will take place from the head phones back to the microphone, so that it may be necessary to have the microphone some distance from the amplifier itself.

The first two tubes should be U X 201 A or their equivalent, while the third should be a U X 171 for ship work. The grid bias of this tube should be such that when a *B* battery of 180 volts is used the plate current through the relay should be almost zero for no signal. This should be adjusted with the first two tubes removed. About 67½ volts *C* battery will be necessary for this, being connected to $-C\ 3$, the second binding post from the right side.

The *C* battery should be such that when the potentiometer is turned toward the negative side the plate current will drop clear to zero when the potentiometer is about halfway over, or, in general, the combination must be such that when the amplifier is switched onto either the hydrophone or radio set the relay will not be operated except when a signal is received.

In order that the operation of switching from the hydrophone to the radio set may not operate the relay, four switch springs are so arranged that the relay is short circuited during the change.

The relay (fig. 5) is a regular telegraph relay with magnet coils wound with fine wire to about 800 ohms resistance, so that the relay will operate on small changes of current. The magnets may be made to approach or recede from the armature by means of the thumb nut shown at the left of Figure 5. The amount of movement of the armature is governed by two thumbscrews with lock nuts, the one that is touched by the armature when current flows through the magnet having a silver contact, the other having an insulating pin. The armature is connected to terminal *A2;* the contact just described is connected to *A1*, and *A3* is connected to a third contact spring held on an arm whereby it may be adjusted. The third contact operates the radio transmitting relay.

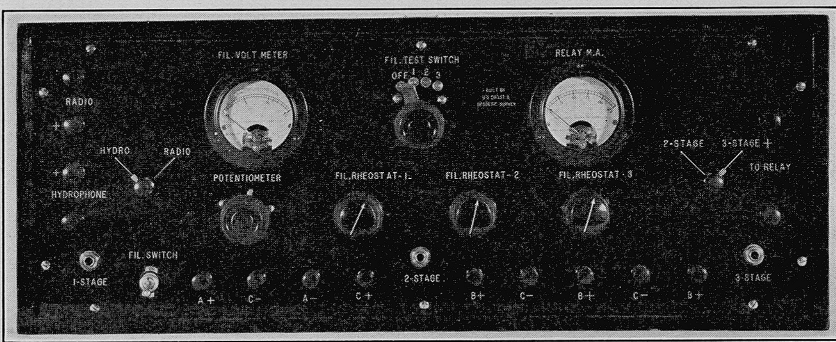

FIG. 2.—Ship amplifier

One end of a coiled spring is attached to the armature, the other end being fastened to a thread wound around an adjusting post, seen at the right of the figure. The magnet terminals at the left-hand end of the relay base are to be connected directly to the right-hand terminals of the ship amplifier. The actual adjustment of the relay

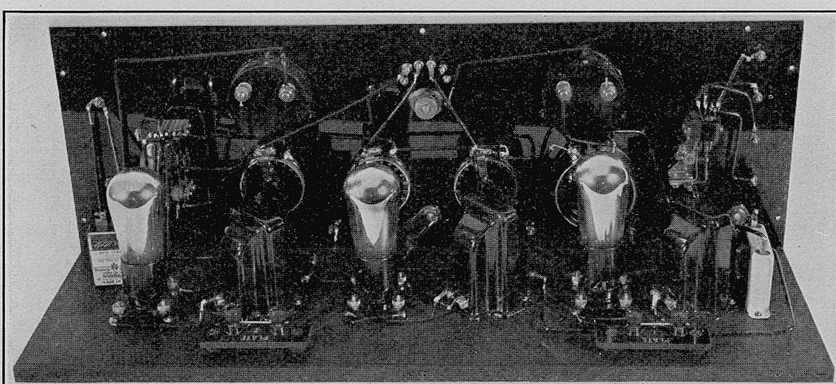

FIG. 3.—Ship amplifier, interior view

depends largely upon that of the amplifier, amount of static, and other conditions. However, the aim should be to reach such adjustment of both the relay and amplifier that nothing will need to be changed to meet varying daily conditions except the potentiometer on the amplifier.

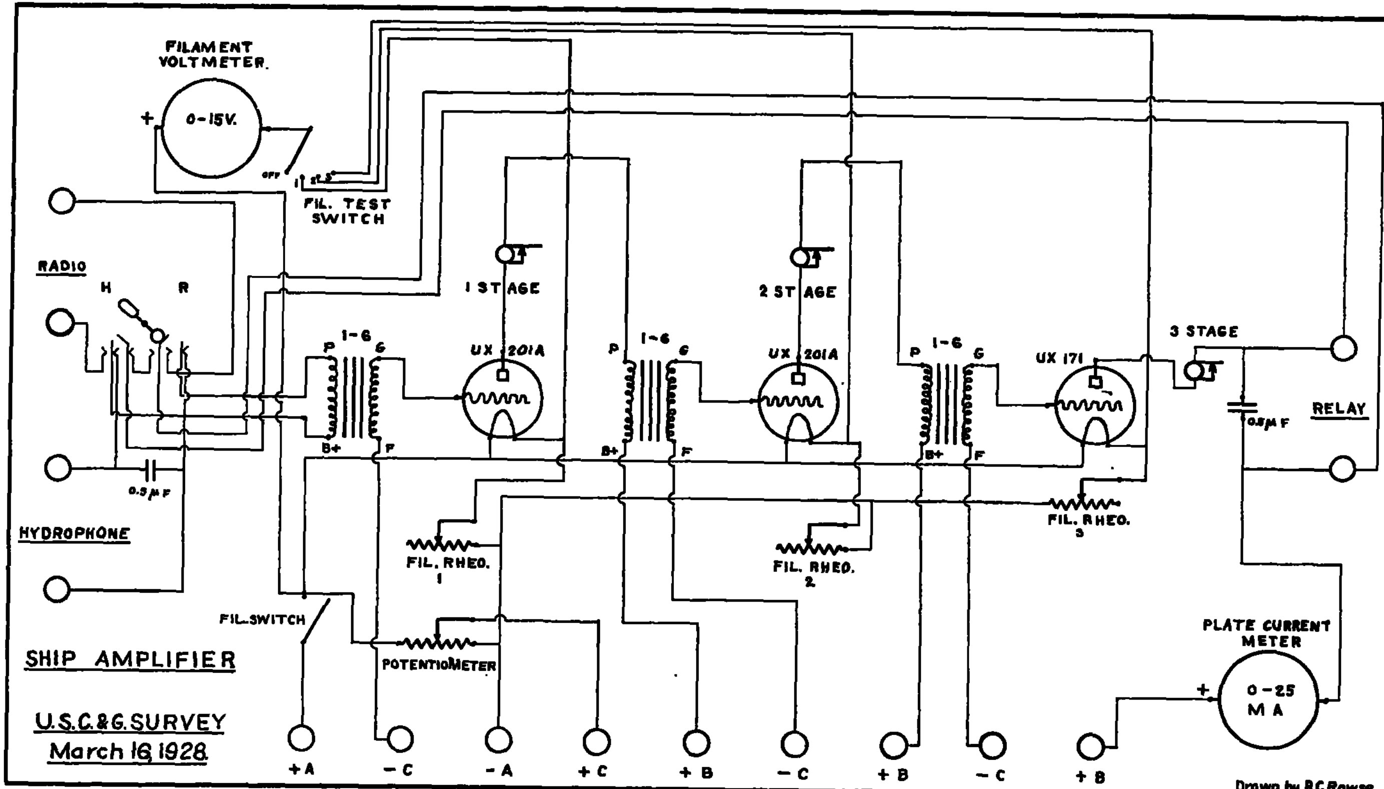

Fig. 4.—Ship amplifier, wiring diagram

RADIO EQUIPMENT

This consists of a short-wave regenerative receiver with plug-in coils having a range from 20 to 200 meters. The regeneration is controlled by a variable condenser at the right of the set, while tuning is done with the left-hand condenser. A small vernier condenser permits of sharper tuning. There is one stage of audio-frequency amplification in this set which is sufficient for communication, but

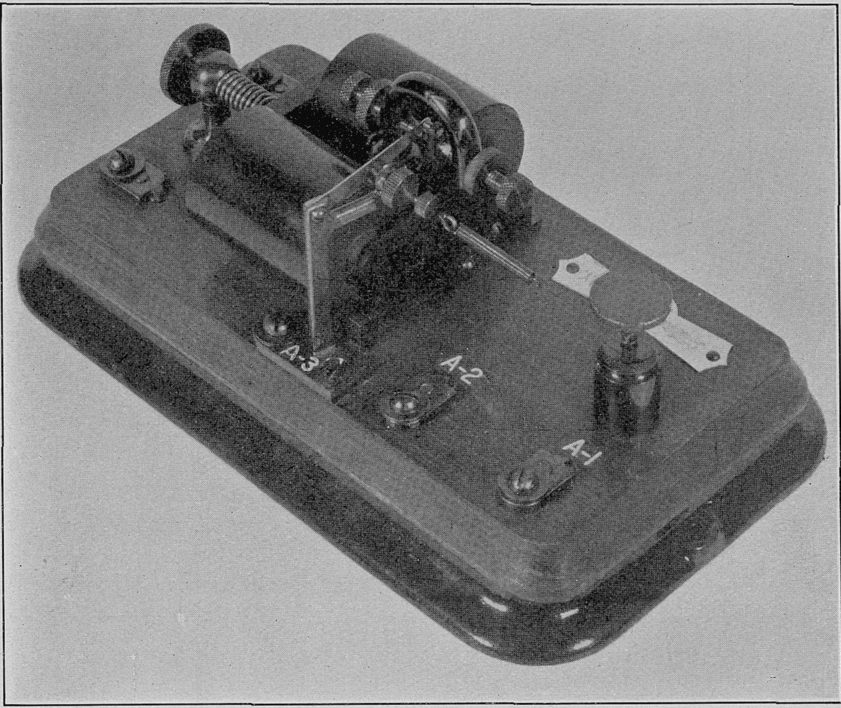

FIG. 5.—Relay

for relay operation the signal is sent through the amplifier, as has already been described. This set operates from a 6-volt *A* battery and 90-volt *B* battery with UX 201A tubes. Regular headphones are used for communications and a loud-speaking unit during operations.

Communication from ship to shore and the dash transmitted when the bomb explodes are usually made with the ship's regular transmitting set operated on 300 meters. As these sets are standard Navy type on most of the ships no detailed description is necessary.

CHRONOGRAPH

The chronograph (fig. 6) sends a strip of paper at a uniform rate under two recording pens, which mark the paper as previously described. A battery-driven motor is connected through a worm gear to a corrugated wheel against which is pressed a rubber-covered wheel. The strip of paper passing between the two is drawn forward over a flat plate above which rest the two pens.

The motor is connected to a 6 or 12 volt storage battery, so that the paper passes at a speed of about three-quarters to 1 inch per second. No governor is used on the motor, as its speed is nearly constant when run on a storage battery without any rheostat in series. Since a chronometer marks seconds on the tape, it is only necessary that the motor speed remain constant during any interval of one second during which a bomb signal is received. Numerous tests have shown that this will be the case within the limits of measurement. The paper reel is shown at the left of the figure, with a spring finger pressing on the roll to put a slight tension on it, so the paper will not unwind faster than it is pulled by the motor. From the reel the paper passes under a table supporting the pen magnets to the driving rolls already described.

The pen armatures are each pivoted between the two driving magnet poles, so that the armature has rotatory motion about a vertical axis. A spring fastened to the top of the shaft supplies return force to the armature which may be adjusted by means of a capstan screw. Another capstan screw below regulates the amount of motion of the armature. At the other end of the armature there is an arm so pivoted that it has motion in a vertical plane. This arm carries the pen, a glass bulb with a metallic capillary point made for recording-instrument ink.

There is a stop for the arms, so that when they are raised they will remain above the paper as shown in the photograph. When lowered, they should be adjusted so that the two will trace the same line on the paper; then from this single line one will produce the time signals on one side of the line, and the other will produce the bomb signals on the other side. The table holding the magnets is hinged about a horizontal axis and may be lifted while cleaning the pens and is adjustable in a vertical direction by a thumbscrew underneath. Binding posts at the left of the magnets, as shown in the photograph, are used to make connections.

Assembly of units.—The assembly of the different units is shown schematically in Figure 7, lower half. The radio transmitting set on the ship is not shown in this drawing nor some of the switches which will necessarily be opened when the apparatus is not in use.

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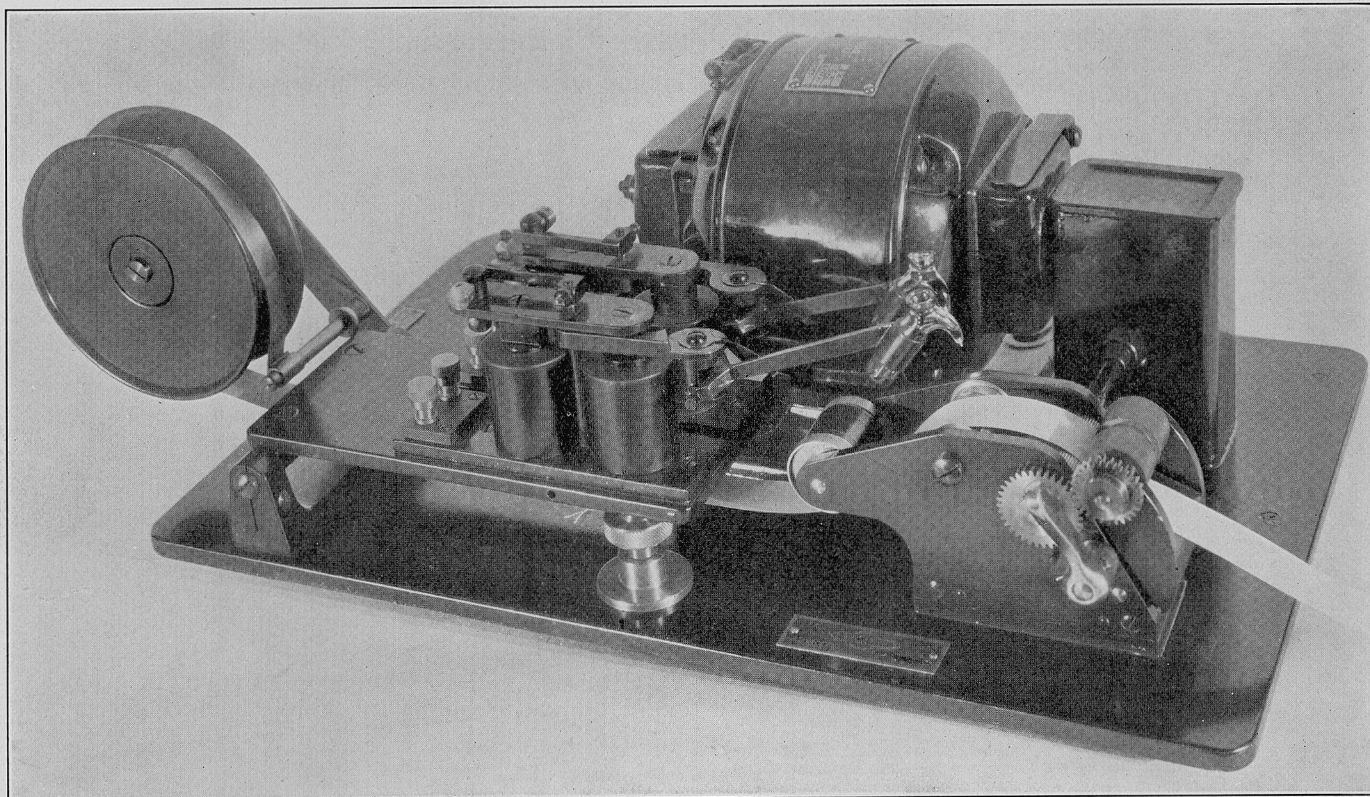

FIG. 6.—Chronograph

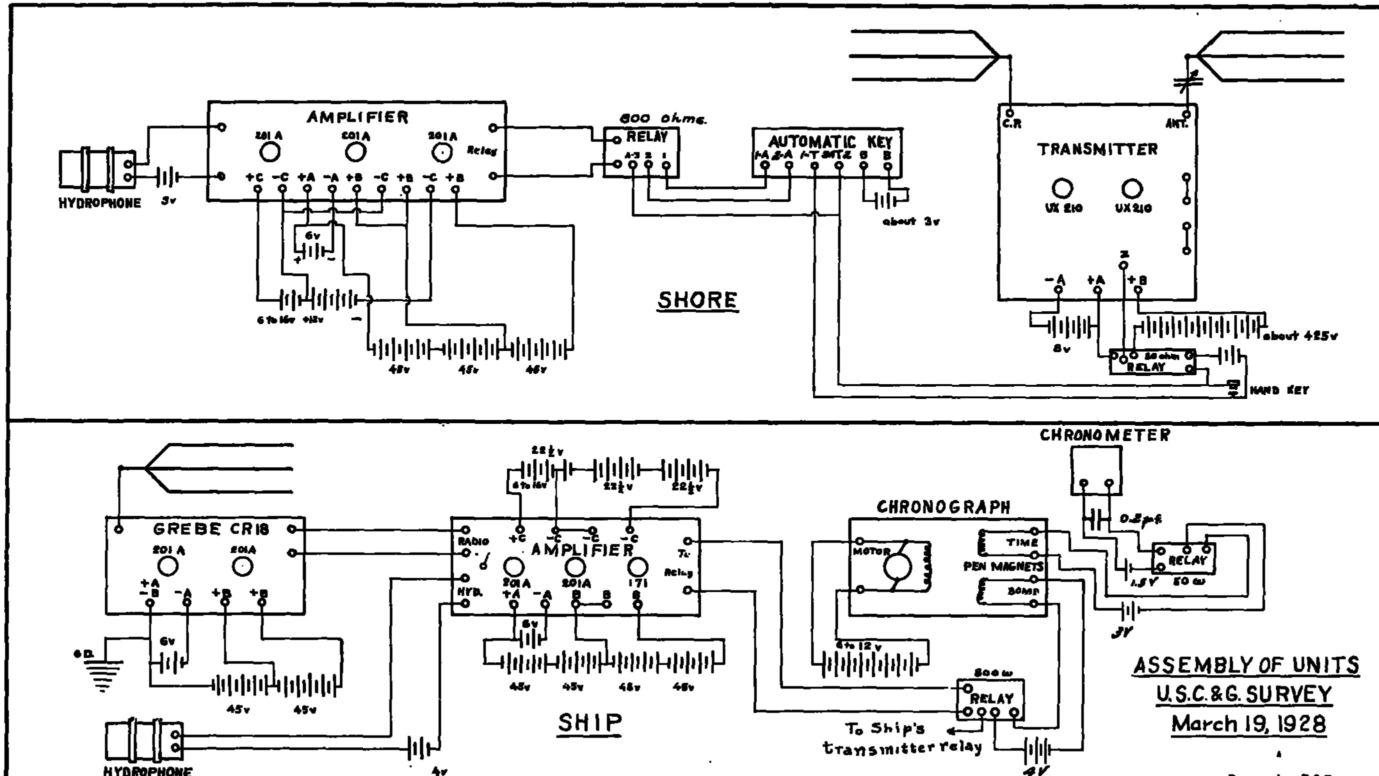

FIG. 7.—Assembly of ship and shore station apparatus, wiring diagrams

The wiring is preferably done with substantial, well-insulated wire, such as No. 14, rubber covered, with all joints soldered and insulated with rubber. It is desirable to have duplicate sets of storage batteries for the radio receiver, amplifier, and chronograph, so that one set may be charging while the other is being used. This assures the possibility of using the apparatus at any time, or all the time if night operation is necessary.

The chronometer is the regular ship type but provided with a pair of contacts which are opened a brief interval every second. Since these contacts are delicate, the least current necessary should be used. One dry cell will generally be sufficient to operate the 50-ohm relay, and the latter should be so adjusted that it will operate the time signal pen magnet of the chronograph smartly each second. Two dry cells will generally be sufficient to do this. The relay armature swings away from the magnets at each second, closing the chronograph pen magnet circuit. This is done by having the circuit closed on what is called the back contact of the relay instead of the front contact.

SHORE STATION APPARATUS

The function of each shore station is to receive the sound impulse of a bomb explosion and to notify the ship, by means of radio signals, of the receipt of the sound wave. A radio signal may be transmitted practically at the instant the sound is received or after a definite time interval capable of determination by tests. In either case information is furnished from which the time of arrival of the sound wave at the station can be determined. The apparatus at each station consists of the following:

(*a*) *Hydrophone unit*.—A hydrophone is a device for use under water to detect and indicate the arrival of a sound wave. A hydrophone unit consists of one or more hydrophones supported by a "hydrophone block" and shielded to some extent from water noises by a "hydrophone box," which is a part of the block. At each station a hydrophone unit is established under water near the shore and connected with other apparatus on shore by a submarine cable and land line.

(*b*) *Submarine cable and land line*.—The submarine cable leads from the hydrophone block to the vicinity of the high-water line from whence a conductor, spliced to the end of the cable, leads to the shore apparatus.

(*c*) *Hydrophone amplifier*.—The end of the land line is connected with the input transformer of an amplifier in order that the current effects produced in the circuit by the receipt of the sound waves may be amplified sufficiently to operate a relay.

(*d*) *Relay.*—This is provided with two sets of contacts. One of these closes the transmitter circuit and sends out a dash by radio. The other starts in motion the automatic key.

(*e*) *Automatic key.*—This device when set in motion by the relay causes the radio transmitter to send out a code signal.

(*f*) *Radio transmitter.*—For transmitting the radio signals mentioned above and for general communication with the ship.

(*g*) *Radio receiver.*—For communication with the ship.

Details relative to the above items of equipment are given below. A schematic diagram of the assembly of the various units is shown in the upper part of Figure 7.

HYDROPHONE

The type of hydrophone in general use for radio acoustic work, which is illustrated in Figure 8, accomplishes the purpose desired by converting the pressure variations of a sound wave into variations of an electric current. Its action is similar to that of a telephone

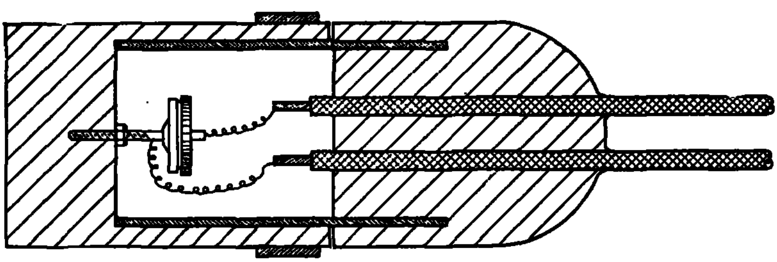

FIG. 8.—Hydrophone, sectional view

transmitter. A brass cylinder is inclosed in a heavy rubber casing. One end of this casing forms a heavy diaphragm, to which is attached the lighter electrode of a carbon microphone, the heavier electrode providing inertia. The space between the electrodes is filled with carbon granules.

When the rubber diaphragm moves as a result of pressure variations in the water, the inertia electrode does not fully share the motion, and there is a relative displacement of the two electrodes with resulting variation in resistance. A constant voltage is impressed on the circuit of which the hydrophone is a part, and resistance variations in the hydrophone, therefore, cause current variations in the circuit.

The hydrophone in use at the present time is manufactured and furnished by the Navy Department under the designation "Unit, Sonic Microphone, type S. E. 1808." It should have a resistance from 400 to 800 ohms; one having more resistance than this is usually not sensitive enough, while one with less, especially in the case of a used hydrophone, is probably more or less packed and unsuitable for use.

In using these hydrophones special care must be taken that excessive current is never passed through them, as this might fuse the carbon granules. This effect, known as "packing," makes a hydrophone much less sensitive. Theoretically, a hydrophone should pack only from surges of current, which can be largely eliminated by suitable condensers, and not from a continual flow of steady current. Actually it has been found that these devices tend to pack with continued use and gradually lose their sensitivity—sometimes slowly and occasionally at a more rapid rate. This fact should be considered in planning field work.

Experiments have been made in the use of a hydrophone of the magnetophone type, but no information relative to the value of this instrument is available at present.

HYDROPHONE BLOCK

A hydrophone block consists of a concrete base and a hydrophone box, the latter being elevated from 3 to 4 feet above the base by wooden or iron uprights. The base should have an eyebolt for securing the submarine cable and a second eyebolt or a wire strap, on the opposite side of the block from the first bolt, for attaching an anchor line. Concrete reinforced with wire or wire mesh and consisting of a 1:2:3 mixture of cement, sand, and broken stone is satisfactory for the base.

Hydrophone box.—Currents, eddies, surface noises, and water friction, all classed as "water noises," cause variations of pressure on the hydrophone diaphragm which interfere greatly with sound reception. To reduce this effect, hydrophones are usually mounted in a wooden box, constructed from 2-inch planks of some softwood such as fir, redwood, or pine. In practice it has been found that such a box transmits sound readily but eliminates interference from other sources to a considerable extent.

A box should be tight enough to prevent any appreciable movement, such as surging due to wave motion, of the water inside. It may be made nearly water-tight with enough leakage to permit water to seep in and fill the box, or as tight as possible by means of white lead, putty, and felt. In the latter case holes are provided in the top for filling the box with water before the block is planted.

Construction of blocks.—The result desired may be obtained by various types of construction. Two hydrophone blocks that have given satisfactory service are illustrated in Figure 9.

The wooden type is constructed as follows: Two 2 by 12 inch planks are set into the base in an upright position, 18 inches apart.

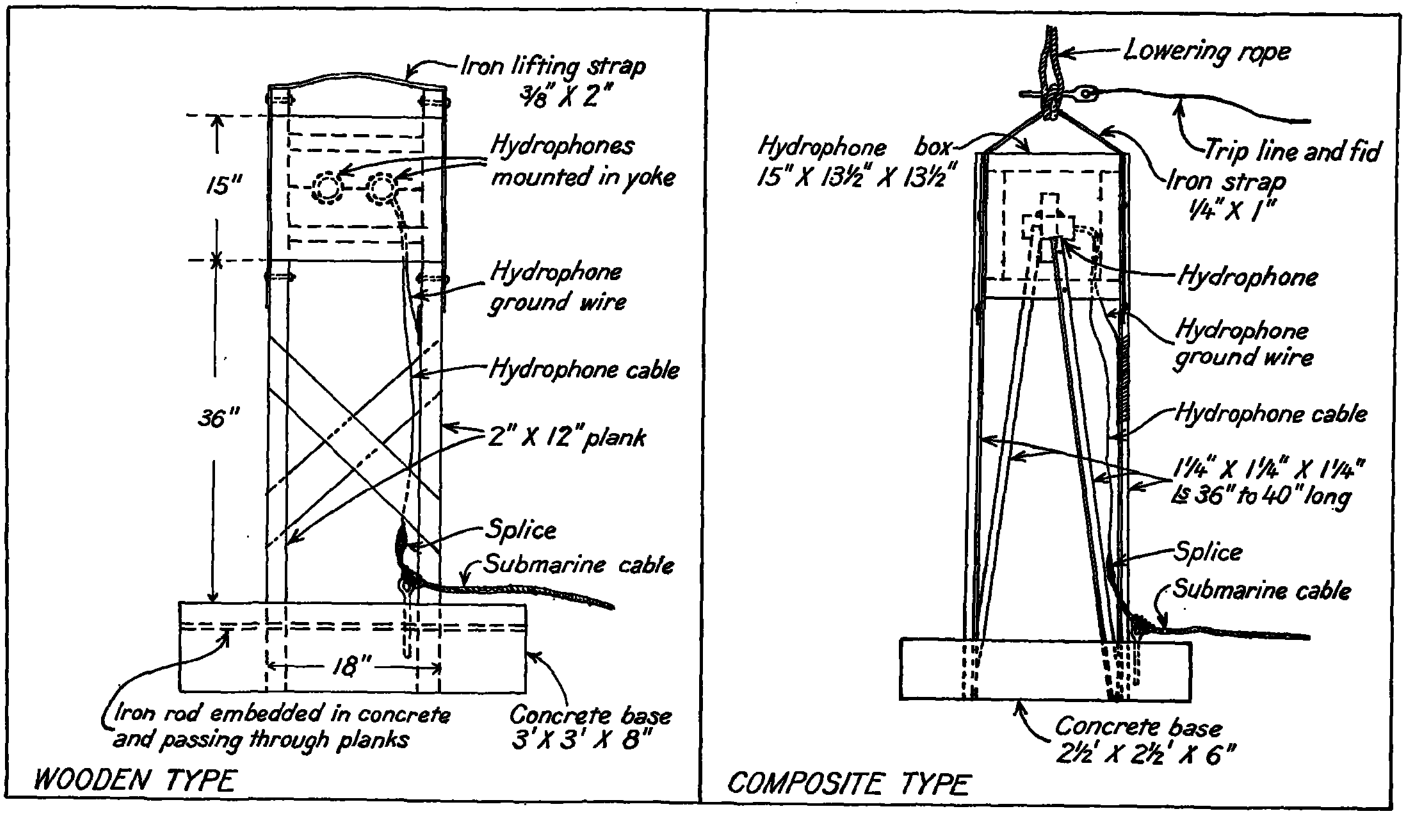

FIG. 9.—Hydrophone blocks

These are secured by two iron rods embedded in the cement. Planks, rods, and eyebolts are placed in position when the base is being cast. The top and bottom planks of the box are nailed in place between the uprights, the bottom plank 36 inches above the base and the top plank 11 inches above the bottom plank. A hole just large enough for the hydrophone cable is provided in the bottom of the box. A front board is nailed in place and another board is provided for closing the box after the hydrophones are mounted. The uprights are cross braced, and an iron strap for handling the block is bolted to the uprights. The wooden structure is usually painted with antifouling paint.

In the composite type the box is constructed of 2-inch planks, with the dimensions given in the illustration, and is supported by four pieces of angle iron embedded in the cement. The handling strap is bolted between two opposite angles. The ironwork is painted with red lead and black asphalt paint, but the box is not painted. In constructing this block care must be taken not to use different metals that might cause electrolysis.

Mounting hydrophones.—From one to three hydrophones have been used for each unit. A single hydrophone has given satisfactory results, but some hydrographers consider that the use of two results in decreased interference in the operation of shore stations when breaks occur in the cable insulation. The reason for using three hydrophones is mentioned in the next paragraph.

Hydrophones are mounted, with their axes horizontal, in a wooden yoke, constructed to fit inside the box. Whether or not a hydrophone has directional qualities is not known, but arrangements are usually made to utilize such qualities, if they exist, by installing the hydrophones with diaphragms toward the source of sound. This may be done by mounting the hydrophones with their axes parallel and properly orienting the block when it is planted. The same result may be attained, without the necessity for orienting the block, by using three hydrophones so mounted that their axis are at angles of 120° with each other. Before installing the hydrophones the stuffing-box nuts should be well tightened; covering the back of the hydrophone with molten pine tar may also aid in preventing leakage.

In the type of hydrophone used at present a double conductor cable extends from the back of the casing. This cable consists of an inner rubber-insulated conductor; an outer conductor, the wires of which are wound over the insulation of the inner conductor; and, finally, a rubber-compound insulation over both conductors. After the yoke holding the hydrophone or hydrophones has been placed in the box, the outer conductor must be grounded while the other is spliced to the submarine cable. All breaks in the insulation and splices must be insulated and waterproofed as thoroughly as possible to prevent water from seeping up the wires into the hydrophone. Several typical methods of connecting the various conductors are described below.

If a single hydrophone is used, a section of the cable insulation inside the box should be cut away, so that the outer conductor may be separated from the inner conductor. The former is then cut and the end leading from the hydrophone is soldered to a ground wire. The latter is usually a strip of sheet copper about one-half inch wide leading through the hole in the bottom of the hydrophone box and secured to the outside of the box. The cut in the outer insulation of the cable is waterproofed by the method described on page 24.

The cable below the ground connection is then led through the hole in the box, cut off near the base, and spliced to the end of the submarine cable (see p. 24). The latter is securely attached to the eyebolt in the base of the block, so that no subsequent strain on the submarine cable will be transmitted to the splice or the hydrophone cable.

The hole in the bottom of the box is sealed by pouring melted tar around the cable; and the cable and splice below the box are usually protected against chafing by parceling and by clamping them to one of the uprights. If the hole in the box is not close to an upright, it may be desirable to use a triangular, grooved, wooden block to provide a firm lead from the hole to the upright. After all connections have been made the box is closed.

Instead of separating the conductors inside the box, a practice sometimes followed is to pass the cable through the hole in the box, to separate the conductors at a point below the box, and to ground the outer conductor by attaching it to an upright. In this case, if the wooden type of hydrophone block is used, the conductor should be stapled and soldered to a copper plate which is nailed to the inner side of an upright and thoroughly cleaned and scraped until bright metal shows.

When multiple hydrophones are used they should be matched for resistance as closely as practicable. The resistances of hydrophones may be compared by connecting the ends of the two conductors of each hydrophone in turn through a battery and milliammeter in series. The hydrophones should be connected in parallel; that is, with all outside conductors spliced together and connected with the ground wire and with all inside conductors spliced together and connected with the submarine cable, usually by means of an intermediate conductor, so that all splices of hydrophone conductors may be made inside the box.

CABLE

A satisfactory submarine cable for radio acoustic work should be light in weight so that it may be handled easily by small boats; strong enough to withstand strains caused by currents, surf, and handling; well insulated; and sufficiently durable to resist abrasion, due to chafing on the bottom, for a period of at least three or four months.

The first quality is, of course, opposed to the others, so that it is practically impossible to procure a cable that is entirely satisfactory. In order to secure a combination of qualities that will best serve the purpose required it has been the practice to use several types of cable, depending on the conditions encountered. The various kinds of cable that have been used up to the present time are described below. It is considered that this equipment is subject to improvement, and experimental and research work with this end in view is still in progress.

Heavy-duty cable.—Heavy armored cable is used in areas where breakers occur at any time or where the cable is subject to considerable chafing from other causes. A type that has been used to a considerable extent has an outside diameter of from three-fourths to 1 inch. It consists of a 7-strand copper center, covered with 1/8-inch 30 per cent rubber insulation, over which is laid a wrapping of oiled cloth, jute, or similar material. The armoring is made up of 14 strands of galvanized steel wire. In breaker areas this cable tends to bury and protect itself in the sand. Its principal disadvantages are a tendency to kink and the difficulty of handling any considerable quantity in a small boat.

Another type of cable has been secured recently in which the copper center is replaced by aircraft wire. There has been little trouble from breaking of the cable used heretofore, as the armoring provides tensile strength; but the aircraft wire is substituted in order to secure any advantages that may result from the extra strength which is secured without sacrifice of other desirable features. The specifications for this cable are as follows:

Cable, armored, 1/8-inch center of 19-wire tinned aircraft strand, insulated with 3/32-inch rubber plain-ignition cable compound of at least 33 per cent pure rubber, covered with double braid and armored with 14 wires of No. 14, B. W. G., double-galvanized wire.

Medium-duty cable.—In areas where there are no breakers but where the cable is subject to some movement and consequently chafing, a cable with lighter armoring is provided. The specifications are as follows:

Cable, armored, 1/8-inch center of 19-wire tinned aircraft strand, insulated with 5/32-inch rubber plain-ignition cable compound of at least 33 per cent pure rubber, covered with heavy double braid and served with 1/8 by 1/16 inch, halfoval, double-galvanized wire, spirally wound with a pitch of about three-eighths inch.

A leaded and armored cable also has been used to some extent in areas where the bottom is rocky or gravel formation but where the effects of sea and current are not severe enough to require the heavier armored cable. This cable is one-half inch in diameter and consists of a stranded core of 7 copper wires, covered with insulation having a high percentage of rubber. It is protected by lead sheathing covered with tape, with an outer armor of woven or braided wire.

Light-duty cable.—In areas where it will not be subject to chafing a lighter cable is used. The specifications for a cable of this type are as follows:

Cable, ⅛-inch center of 19-wire tinned aircraft strand, insulated with $\frac{5}{32}$-inch rubber plain-ignition cable compound of at least 33 per cent pure rubber.

This cable is easy to lay and splice and is very strong. It will not give satisfactory service, however, on rocky bottom or through kelp if there is any movement to the cable, and it is so light that it will not bury in the sand. Its principal use is in the section between the hydrophone block and the outer line of breakers, but it has been used with fairly good results in to the shore in regions of sandy bottom and moderate breakers.

Various types of ordinary ignition wire have been used in emergencies but are not recommended on account of their low tensile strength, low resistance to abrasion, and the difficulty of locating breaks. They are useless unless the bottom is sandy with no swell or current action. With the idea of reinforcing this wire, the expedient of lashing it at intervals to a steel wire has been tried without success as the steel wire was destroyed by electrolytic action. The land line is described on page 42.

Splicing cable.—In splicing cable great care must be exercised to secure good electrical contact, a thoroughly insulated and waterproof joint, and strength. A study of the information given on this subject in a standard electrical handbook will be of value. Methods of splicing the various cables used in radio acoustic work are described below.

Splicing conductors.—The center of a copper conductor cable usually consists of a center wire and 6 outside wires, while that of an aircraft wire conductor consists of 12 outside wires around an inner layer of 6 wires, which in turn are wound around a center wire. A standard method of splicing is as follows: Having skinned the end of each cable for the same distance, at a point about in the middle of each bare section bend out the outside wires radially. Straighten each wire, clean it with sandpaper, and then cut away the center wire or group of seven wires.

Force the wires back nearly to their normal position and bring the ends of the cables together with the wires laced; that is, with each wire between two wires from the other cable. Next wrap one wire in close turns around all the other wires as far as it will go, then pick up another wire at the end of the turns and repeat the operation. Continue until all wires of both cables are wrapped. If necessary, cut a little off the end of a wire to prevent its overlapping the next wire to be wrapped. This method may be used for splicing copper wire to aircraft wire by dividing the 12 outside wires of the latter into six 2-wire groups.

It is very important that all splices in conductors be so well soldered or otherwise secured that no variation in resistance can be caused by movement of the wires. A considerable amount of interference formerly attributed to water noises has been traced to splices that were deficient in this respect. The usual method of soldering is to dip the splice in molten solder, care being taken that the latter is not so hot as to cause the wire to become brittle. Another method is to drop the solder from a ladle on and through the wires. After the joint is soldered all sharp projections that might break through the insulation should be removed with a file.

Insulating joints.—The method of insulating joints, which is the same for all splices, is as follows: Having connected and soldered the conductors, coat the joint with a thin coat of rubber cement, allowing several minutes for the latter to become nearly dry. Then cover the joint with a number of layers of para rubber, self-vulcanizing, splicing tape, which is extended at least 1 inch over the cable insulation on each side. Over the latter wind several layers of electrical rubber tape and, finally, two layers of friction tape. Cover the tape with a coat of shellac.

Splicing submarine to hydrophone cable.—Skin each cable for several inches and taper the insulation with a sharp knife or razor blade. Connect conductors (the inner hydrophone conductor) and insulate the joint. Dip entire splice in molten pine tar, made more flexible and less likely to crack when dry by the addition of a small amount of machine oil.

Splicing heavy-duty armored cable.—Lay back the armoring of each cable for a distance of about 7 inches over a heavy seizing or an iron collar known as a "Turk's-head." Skin the cable for several inches (not close up to the armoring), splice the conductors, and insulate the joint. If the bottom is rocky, a protective covering of burlap should be wound around the joint, being properly served and coated with tar.

Additional strength for this splice is provided by connecting the ends of the armoring on each side. For this purpose a ¾-inch wire cable, clamped to the armoring just back of the bulge formed by the seizing or collar, may be used. A second method is to use a splice box consisting of a flat iron bar about 1/4 by 2 1/2 by 14 inches, to which the cable is clamped by means of four U-bolts. One of these bolts on each side should clamp just back of the bulge in the armor and the other about 2 inches along the armor. The cable should be slack at the splice to eliminate possibility of strain.

Splicing medium or light-duty aircraft cable.—Skin each end for a distance of about 1 foot, cutting away the spiral armoring in the case of medium duty cable, taper the insulation, splice the conductors, and insulate. In this type of cable the aircraft strand takes the strain, and no splice box or strap is essential. It may be desirable, however, to use the former (the cable being well parceled), as it holds the splice rigid and tends to prevent movement of the conductor wires at the splice.

Splicing armored to medium or light duty cable.—Lay back the armor as described above for about 8 inches, skin the insulation of each cable for nearly the same distance (cutting away the spiral armoring in the case of medium-duty cable), and splice and insulate in the usual manner. If the armored cable has a copper conductor, the splice should be parceled, served, and clamped in a splice box similar to that described above, and such a box may be desirable with aircraft cord conductors as noted above.

Splicing leaded and armored cable.—Cut away the armor for 6 or 7 inches and split and turn back the lead. Skin the insulation for about 3 inches, splice, and insulate. Place the lead back over the splice, cutting away edges to give a fair surface; then wrap the entire splice with thin sheet lead, soldered in place and along all edges. Strengthen with a strap clamped to the armor.

AMPLIFIER

The shore station amplifier (figs. 10, 11, and 12) is quite similar to the ship amplifier. A milliammeter (*0–25*) is placed in the hydrophone circuit, so that the condition of the hydrophone may be known at all times. The same type of transformers is used in all three stages as in the ship amplifier, and UX201A tubes are used for all three stages. The plate-current meter reads from 0 to 10 milliamperes, so that a careful record may be kept of what is transpiring in the hydrophone, since this is really the most delicate part of the whole system and on its proper functioning depends the success of the method.

A negative grid bias of about 6 to 16 volts is kept on the first two tubes and 90 volts *B* battery; about 30 volts *C* battery and 135 volts *B* on the third tube. A single rheostat controls all three filaments, although there are filament-test binding posts at the rear of the transformers by which the filament current may be measured, or, if necessary, additional rheostats could be used for separate filament control. Only in exceptional occasions will this be necessary or desirable.

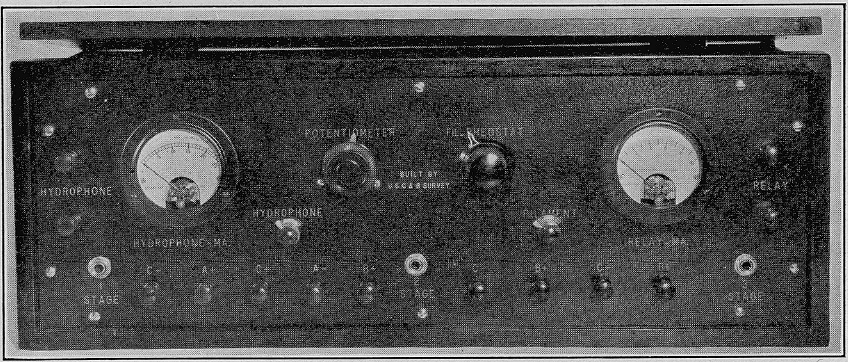

FIG. 10.—Shore station amplifier

As in the ship amplifier, everything should be adjusted to get the greatest amplification consistent with good quality on the first two stages, having the head phones plugged into the second jack. Then with the first two tubes removed the third tube *C* battery should be adjusted so that the plate current is zero. The combination should now be so sensitive that the merest gentle stroke of a finger across

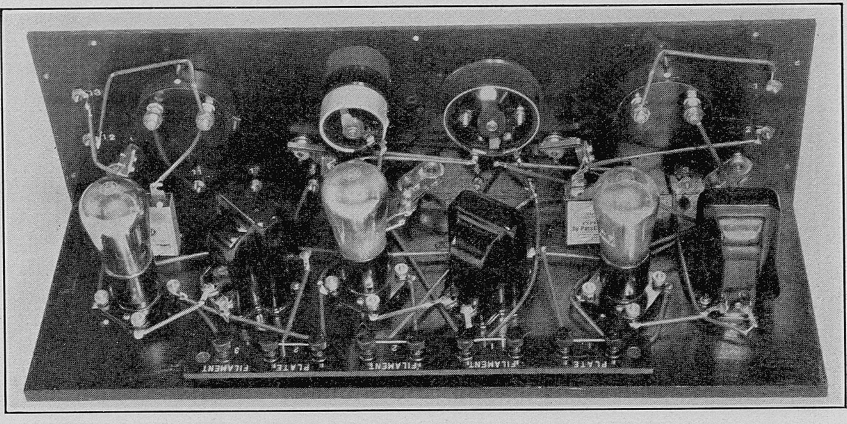

FIG. 11.—Shore station amplifier, interior view

the diaphragm of the hydrophone will throw the plate-current meter clear off the scale and, of course, operate the relay. Another method of testing is to place the hydrophone in a pail of water and drop a buckshot or a tiny pebble into the water. Either one should make a full-scale deflection.

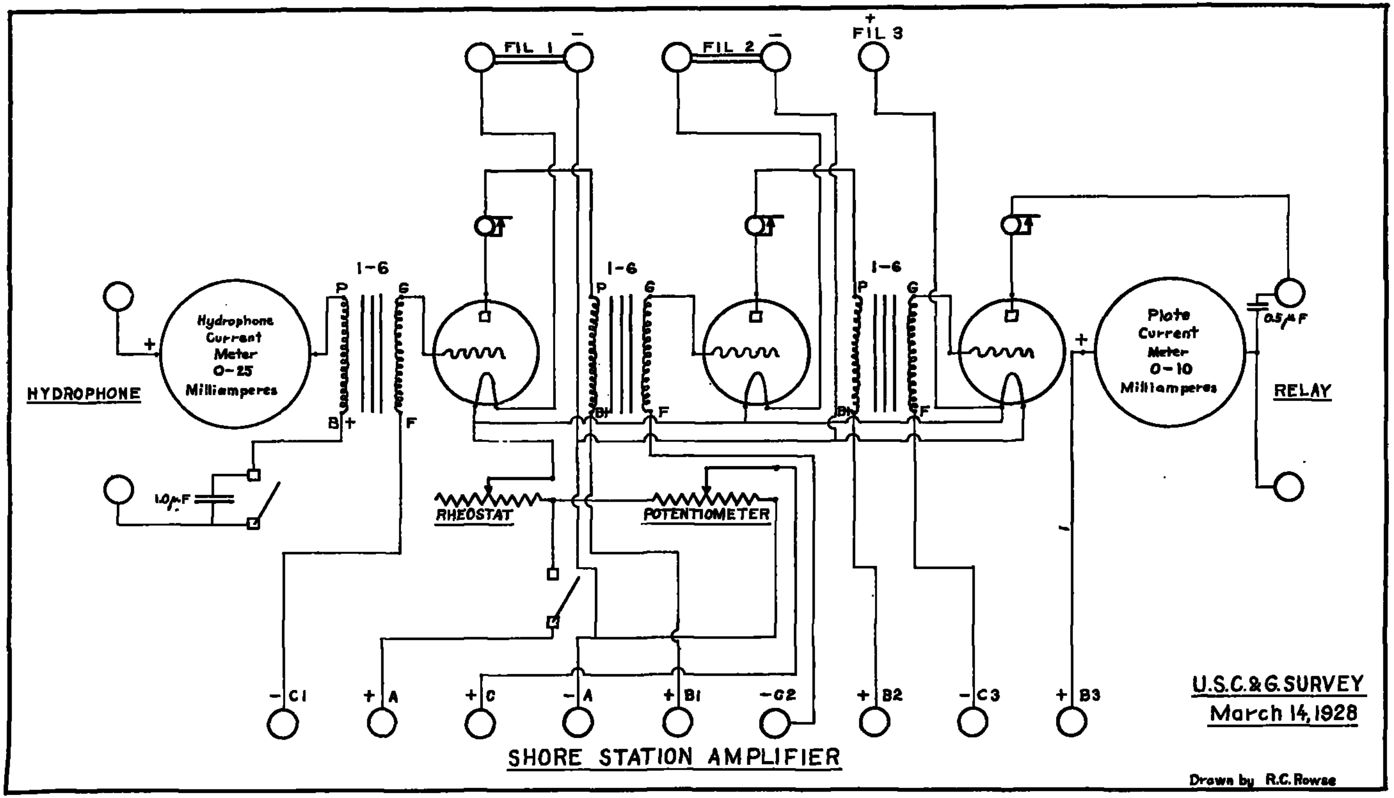

Fig. 12.—Shore station amplifier, wiring diagram

If the hydrophone is disconnected, the entire circuit will probably oscillate; but with the hydrophone binding posts short circuited, the amplifier should be absolutely quiet. Sometimes there is a tendency to oscillate at some high frequency audible or inaudible, in which case there will be considerable plate current in the third tube and great loss of amplification. If this can not be stopped by reversing the connections of the hydrophone or making sure of the insulation of all the different batteries from each other and earth, the oscillations may be stopped by bridging the secondary of one of the transformers by a high resistance, such as a one-tenth megohm grid leak, or a condenser of one hundredth microfarad, or less.

It is generally better to do all listening on the first or second stage rather than the third. On the first two stages one learns to recognize the different sounds heard in the hydrophone, and too much listening can not be done here, for it needs all one's ingenuity to tell what may be wrong at times. Furthermore, if the phones are used in the third jack their added resistance to the plate circuit decreases the sensitiveness of the system to a much greater degree than in either of the other two stages.

Needless to say, the contacts of the 800-ohm relay must be kept especially clean. Nothing coarse, like sand or emery paper, should be used. Crocus cloth may be used, or even plain writing paper, drawn between the contacts when pressed gently together, will be sufficient to keep them smooth and clean.

This relay is the same as that described on page 9 for the ship station. The extra contact *A 3* is now used to close the circuit of the transmitting relay, so that a radio signal is automatically sent simultaneously with receipt of the bomb signal in the amplifier. The relay also closes the circuit of the automatic key.

AUTOMATIC KEY

This is shown by photograph in Figure 13 and by schematic diagram in Figure 14. When the relay closes the circuit, the magnet is energized, releasing the stop, so that the pendulum starts swinging about its pivot. Being a metronome pendulum, its period may be adjusted through a wide range by means of a movable weight at the top. After some period has been decided upon it should not be changed, the weight being clamped to keep it constant.

As the pendulum swings a short train of gears turns a notched disk, which operates two sets of contacts. The first set, the locking contacts, closes almost immediately, and since they are in multiple with the relay contacts, the metronome magnet will continue to be energized even though the relay has again opened its contacts. The metronome will continue to run until the notched disk has made one

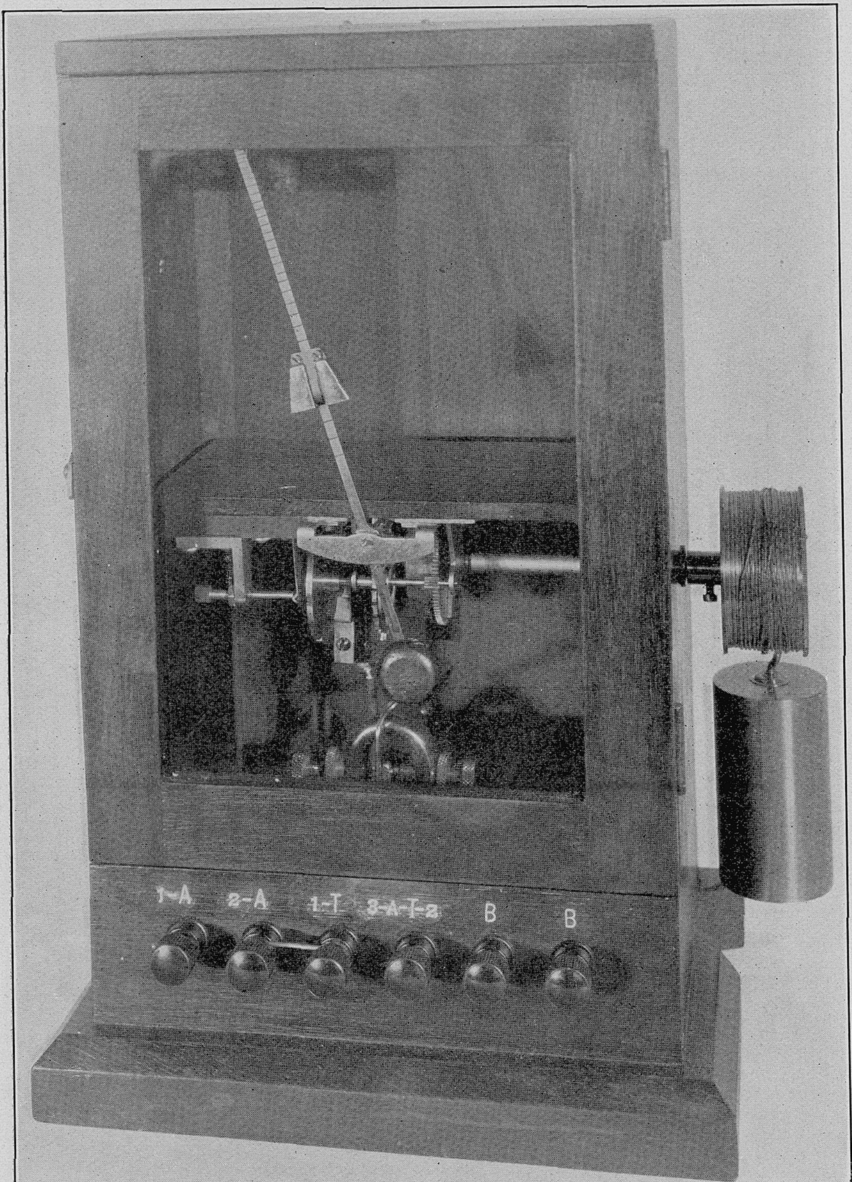

FIG. 13.—Automatic key

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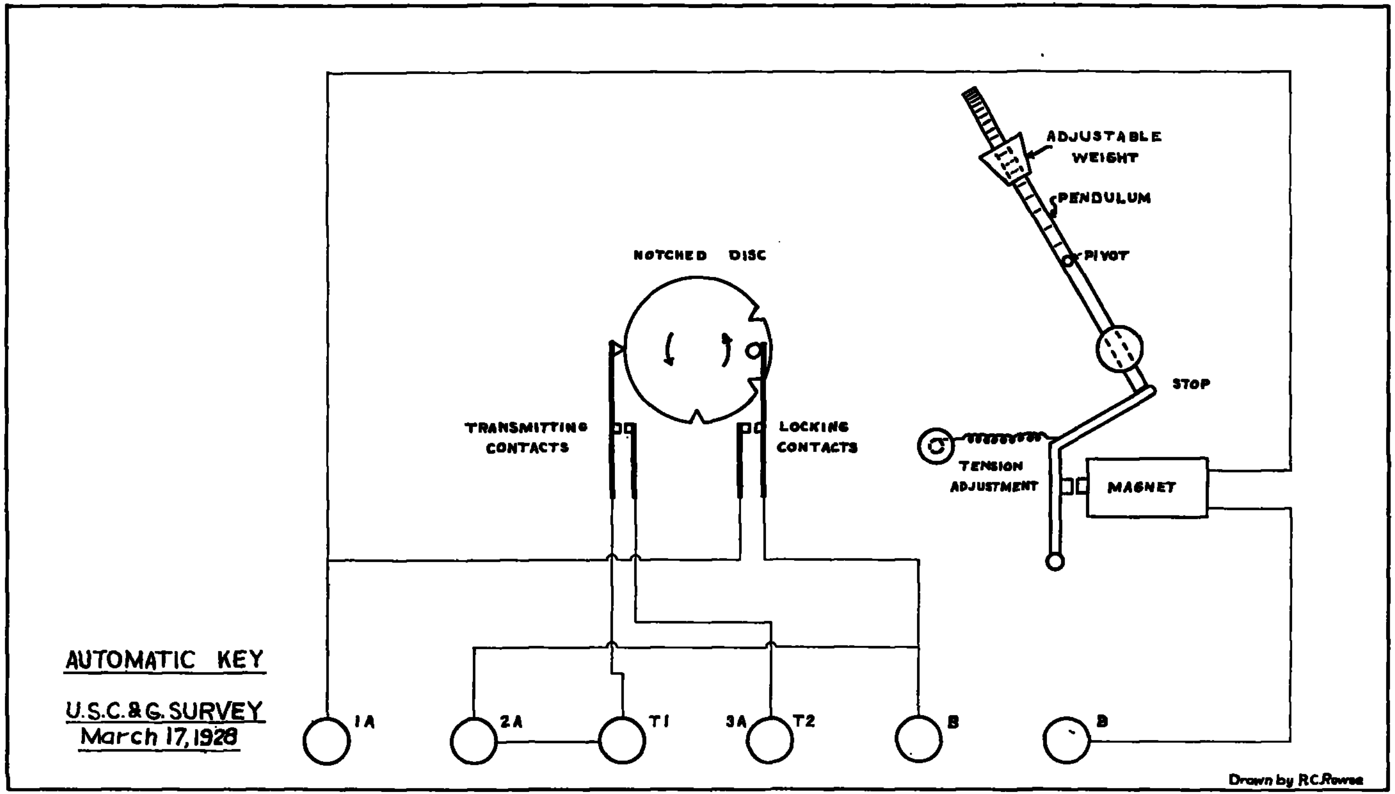

FIG. 14.—Automatic key, wiring diagram

complete revolution, when the locking contacts will automatically open, the magnet will be deenergized, its armature will drop back, and the metronome pendulum will be stopped at its next swing. This may take from 3 to 10 seconds, depending on the position of the adjustable weight.

During this revolution of the notched disk the three notches will pass successively under the wedge-shaped piece of one of the transmitting contacts and close them three times. These contacts close the circuit of the transmitting relay, so that there are sent three radio dashes of definite length and spacing from which the metronome gets its name of "automatic key." The radio signals resulting from the action of the automatic key, however, are usually termed the "metronome dashes" or "signals." The motive power to operate the automatic key is furnished by a weight with a cord wrapped around a drum, which is simply turned backwards to wind up the weight. A hole should be bored through the table, the cord passed through and fastened to the weight below, so that many operations may be made with one winding.

RADIO EQUIPMENT

This consists of a receiver, transmitter, wave meter, associated batteries, and a gasoline or kerosene engine generator for charging storage batteries.

The receiver consists of a two-tube radiola broadcast receiver which, being a standard commercial article, needs no description. To this there is generally added another stage of radio amplification for loud-speaker operation, so that calls may be heard at some distance. A regular single-wire receiving antenna is put up for the receiver alone, as far from the transmitting antenna as convenient.

The transmitter is shown in Figures 15, 16, and 17. The regular Hartley circuit is used, the coil consisting of 25 turns of copper ribbon one-quarter inch wide and one-sixteenth inch thick, the turns being spaced about one-quarter inch apart, making the total length about 12 inches. The inside diameter of the helix is 3½ inches, and the total length of ribbon used is about 23 feet. This coil is mounted on a wood frame, inside a wood cabinet provided with a balkelite front on which are mounted the meters and control instruments.

Seven clips with flexible conductors having porcelain beads for insulation are used to make adjustable connections to the coil. U X 210 tubes are used, and although two are shown in multiple, it will generally be found more satisfactory to use a single tube. The coil is to be tuned to the wave length assigned by moving the clips along the coil to get the right number of turns and by changing the condenser setting, as will be described in detail later.

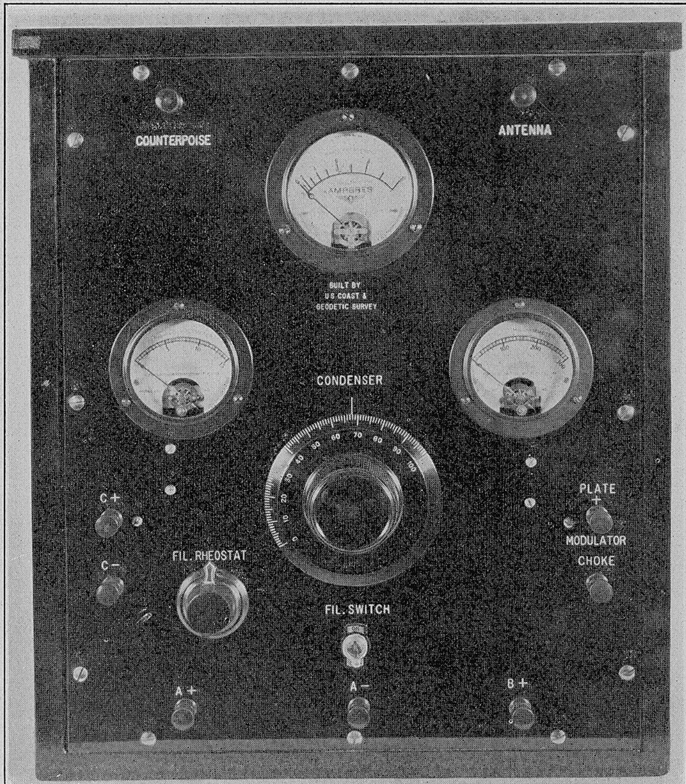

FIG. 15.—Shore station transmitter

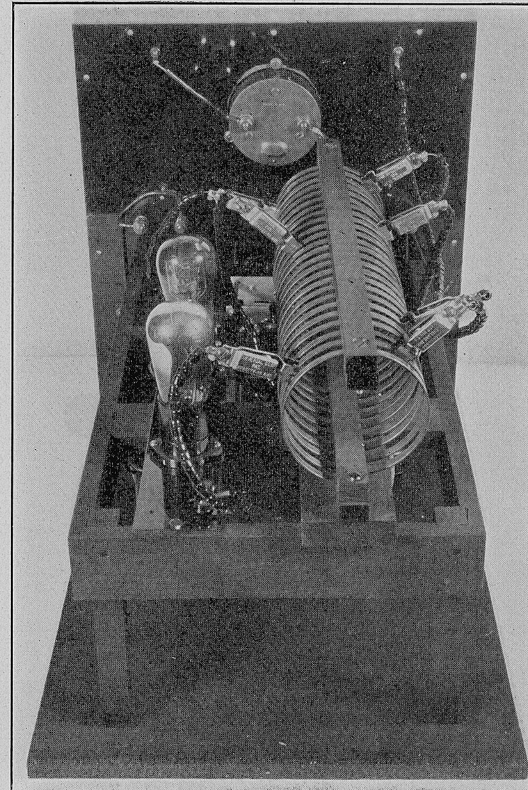

FIG. 16.—Shore station transmitter, interior view

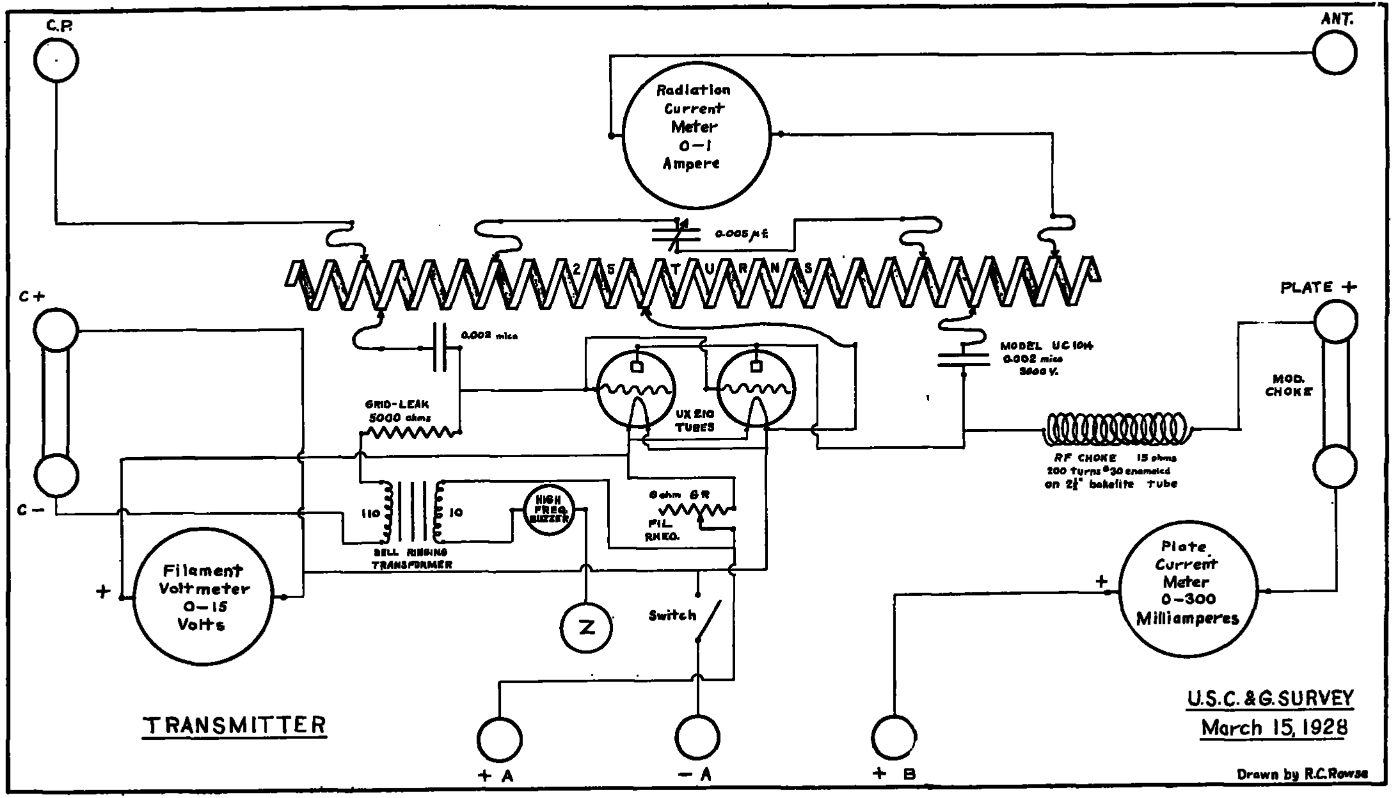

FIG. 17.—Shore station transmitter, wiring diagram

A high frequency buzzer is connected across the *A* battery and in series with the low winding of a bell-ringing transformer of which the secondary is connected in series with a pair of binding posts, marked *C*− and *C*+, and the grid leak. The buzzer modulates the radio signals and makes them easier to read, and as the buzzers at the two stations have different tones it is easy on the ship to identify the stations by the tone of the simultaneous dash. Ordinarily *C*− and *C*+ are connected together but may be opened for connecting in another modulator if voice is to be used. In the schematic diagram (fig. 17) the binding post marked *Z* is connected to the transmitting relay, so that the buzzer is operated whenever the relay is actuated by a bomb or otherwise.

Plate voltage is supplied by 8 trays of 24 lead storage cells each, giving something over 400 volts. The positive wire goes to +*B*

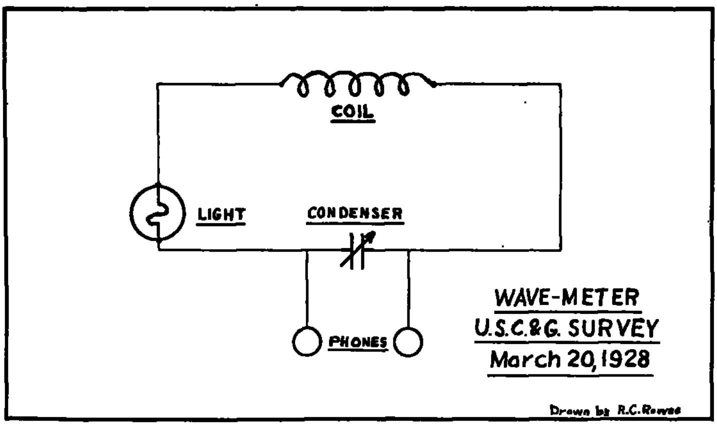

FIG. 18.—Wave meter, wiring diagram

on the transmitter cabinet, whence it goes through the plate current meter, then across the binding posts marked "modulator choke," through the radio-frequency choke to the plate. Ordinarily the modulator binding posts are short circuited but may be opened for a modulator choke-coil for voice work.

A wave meter (fig. 18) is provided with each set to maintain the proper wave length. An ordinary battery lamp is used as an indicator, or a telephone receiver may be connected across the condenser if not sufficiently sensitive otherwise.

The radiation part of the transmitter consists of an antenna and counterpoise. These should both be made of enameled copper wire, and good insulators such as pyrex should be used. The antenna should be the inverted L type of a single conductor placed as high as possible with a total length of about 120 feet, including all the wire from the transmitter to the end of the antenna. This length will permit easy tuning to some wave length within the required limits of 130 to 150 meters which have been assigned to this work. No more guy wires should be used than are necessary to prevent the antenna from swinging. They should be well insulated at the top and bottom.

A single wire counterpoise should be placed under the antenna, about 8 feet from the ground and carefully insulated, the same as the antenna. Joints in antenna and counterpoise should be avoided if possible, but if not they should be carefully soldered.

Tuning transmitter.—In tuning the transmitter it is necessary, first, to have the correct wave length and, second, to have as much radiated power at this wave length as possible in the most efficient manner. Both shore stations must transmit on exactly the same wave length, so that the ship may receive each without changing the tuning of the receiver.

At the beginning of the tuning use only half the *B* battery or about 200 volts on the plate circuit and adjust the filament voltage to about 7 for the U X 210 tubes. This is to prevent undue heating in the tube or possible injury. Have the clips on the coil about as shown in the schematic drawing and disconnect the antenna and counterpoise. Close the transmitting key and relay and turn the tuning condenser at the middle of the set, while watching the plate current meter.

There will be some position where the plate current will be a minimum, showing a resonance point. Keep the key closed only momentarily while making trials of this sort. Now, test with the wave meter to see if this reads any where near the desired value. If this should be the first of the shore stations getting started, the wave length may be anything between 135 and 150 meters; but if it is the second station, its wave length must be approximately the same as the first. If the wave length is not near the desired value, shift the middle or filament clip toward the grid clip (left in fig. 17) and repeat the tuning with the condenser.

When the wave length is somewhere near the desired value, connect the antenna and counterpoise to the set, having a condenser in series with the antenna, as shown in the upper part of Figure 7. Eventually it may be found that this condenser is not necessary, but it makes tuning easier at the beginning. Now, tune the antenna with the series condenser until some radiation is shown by the radiation current meter, shifting the clips and condensers until a maximum of radiation current is obtained with a minimum of plate current at the correct wave length.

The full *B* battery voltage may now be used and the filament voltage increased to 7½. Slight changes may now have to be made to get the best results. The plate current will be less by having more turns in the plate coil than in the grid coil, which means that the filament clip is nearer the grid clip. Once the best conditions have been obtained the values should be recorded, so that if anything is accidently changed the proper setting may be quickly made again.

It is very important that the wave length remains steady and constant day after day, so that no time will be lost by the ship in waiting for a station operator to tune his transmitter at the last minute. A steady and constant signal is more to be desired than greater efficiency on an unsteady signal.

Generator.—The engine-driven generator for charging the batteries is one of the small portable home lighting outfits completely inclosed, giving about 32 volts. It is started by winding a rope around the starting pulley and giving a quick pull on the rope. The *A* batteries are charged by putting enough in series to bring their rated voltage to about 24 and using a series resistance to regulate the current to the correct value.

The most convenient way of charging the *B* storage batteries is to have a separate double-pole, double-throw switch for each tray which will connect all the trays in series when the switches are thrown one way and put them in multiple when closed the other way. In this latter method of charging, about four 6-volt *A* batteries may be put in series with the generator and the combination used for charging the *B* batteries, using a regulating resistance to get the necessary current, which for the eight trays will be eight times the charging rate for a single tray.

OPERATION OF STATION

The shore operator keeps everything in order, batteries charged, etc., and keeps a regular schedule with the ship, at which time he will always be present to receive any orders. During the time that bombs are being fired, if everything is working properly, it may not be necessary for the shore operator to be present all the time, but he should be within hearing distance of his loud-speaking telephone receiver which will be connected to his short-wave receiver. The latter is similar to the one described in the ship apparatus. It is not shown in the assembly of shore units (fig. 7), but is, of course, necessary in order that communication may take place in both directions.

Some days, due to unusual noises or the distance of the ship, there may be little margin between the value of the bomb signal and that given by noises of surf, etc. In such cases it is necessary that the operator remain in attendance nearly all the time and adjust the sensitiveness of the amplifier a few seconds before the arrival of each bomb signal and make a report as to the reliability of the signal and the probability of receiving weaker signals.

ESTABLISHMENT OF SHORE STATIONS

SELECTION OF SITES

The selection of sites for shore stations is important and should be based on a careful reconnaissance. Sites that afford ideal conditions are rarely available, and it is usually necessary to balance various requirements against each other in order to select suitable locations.

In order that an extensive section of coast may be surveyed without moving the control stations, the latter should be as far apart as practicable, *but the distance between them is limited by two considerations*: First, there must be a suitable intersection of distance arcs throughout the area controlled by the stations, and, second, no *station should be so far away from any point on the working grounds* as to prevent the sound of bomb explosions from coming through with reasonable regularity. In general, occasional "misses" from one station in areas outside the 300-fathom curve will not be serious, but failure inside this limit, and especially inside the 100-fathom curve, may interfere considerably with the work.

On the Pacific coast it is considered that bombs are fairly dependable for distances of from 40 to 50 miles, and they have frequently come through for considerably greater distances. Under these conditions, for work within the offshore limits previously mentioned, a distance between stations of from 20 to 30 miles has been found efficient. In practice, however, it may be necessary to modify this spacing in order to obtain suitable locations for planting hydrophones and laying cable, which is the most important feature to be considered.

Other considerations that may affect the selection of sites are facilities for overland transportation, accessibility to water and provisions for the station personnel, and the availability of a structure to house the personnel and equipment.

Sites for hydrophones.—A hydrophone block must be planted in water deep enough not only to prevent destruction of the block by breakers but to eliminate any wave action that might affect the hydrophone or cause the bottom to shift and bury or capsize the block. On the Pacific coast of the United States hydrophone blocks have been set in depths from 6½ to 12 fathoms, but depths from 8 to 10 fathoms are considered most suitable. A greater depth than necessary is undesirable, as the increased pressure may cause leaks in the hydrophones.

The block should rest on level sand bottom, with no rocks. A steep slope to deep water offshore from the hydrophone is desirable. Offshore areas in the vicinity should be as free as possible from shoals and banks in the directions from which bombs will be fired. Obstructions of this nature, even with greater depths than at the hydrophone, will interfere considerably with the passage of the sound waves.

Conditions between the hydrophone and the shore that will affect cable-laying operations are important. Landing of cable through surf is difficult and in general can be done only when there is little swell. In some cases it may be possible to avoid delays in establishing shore stations, due to weather conditions, by selecting a cove or small bay that affords a landing protected to some extent from swell and prevailing winds and has suitable depths for planting the hydrophone block off its entrance.

On a coast exposed to swell a narrow line of breakers is, of course, preferable. Small boats can not carry more than about 2,600 feet of armored cable, and sites where the breaker area is of greater width than this are impracticable, even if the bottom is sandy. Locations where there are more than one line of breakers, with deep water in between, must be avoided.

A smooth, sandy bottom and beach, free from rocks, are most desirable; rocky, kelp-covered ledges afford the most unfavorable conditions. Kelp has been known to part all kinds of cable that have been used to date, and kelp beds, if at all exposed to swell, should be avoided. In some cases it may be necessary to lay cable over rock bottom to a rocky point or shore, but if there is any swell the cable can not be expected to stand up for any considerable length of time.

A hydrographic survey, consisting of a number of soundings in the vicinity of the hydrophone location and one or two lines in toward the beach, is of value and should be made if practicable, usually on a special boat sheet. This will assist in selecting the spot for planting the block and give a good idea of the lengths of different kinds of cable that are required.

HOUSING PERSONNEL AND EQUIPMENT

In some cases it may be practicable to select a site where there is a building that can be used for housing personnel and equipment, and this feature may deserve special consideration if the station is required for only a short time. In general, however, the greater importance of other conditions that must be considered and the facility with which a satisfactory structure can be erected warrant the construction of special buildings for this purpose.

Suitable dimensions for a radio shack, which is the principal building required, are length 10 feet, width 8 feet, height in front 9 feet, height in rear 7 feet. It should have a door in the middle of the front, a window in the back, a shelf across one side for the instrumental equipment, and two bunks, one above the other, on the other side. The shack should be well rain-proofed.

If a battery-charging outfit is used, it should be mounted on a firm foundation near the shack and provided with a suitable cover for keeping out rain and sand. The remaining structure required is a cook tent. This is usually an 8 by 10 foot Army tent with fly and a wooden floor. In order to decrease the possibility of damage by fire, it is advisable, if practicable, to wire the shack and cook tent for electric lights.

The buildings mentioned above can be erected easily by the shore-station personnel, assisted for a short period by a few men from the

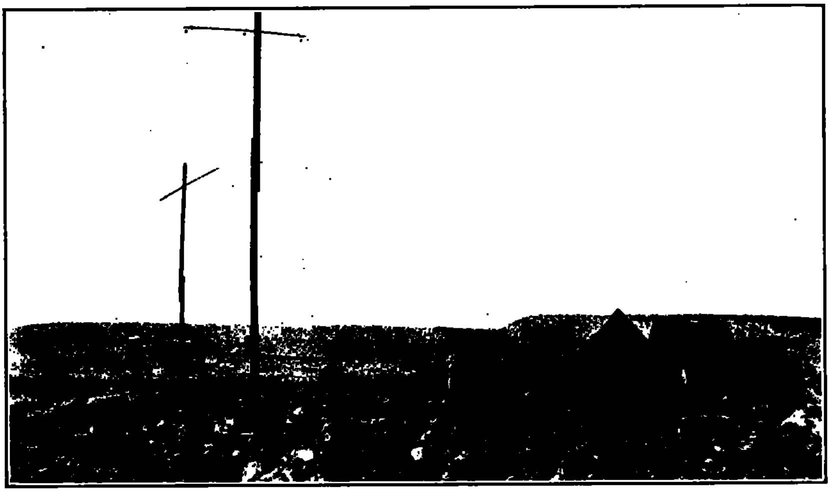

FIG. 19.—Shore station

ship. The materials required for the buildings and the antenna poles are listed below:

Five hundred and fifty linear feet, 2 by 4 inch lumber, dressed four sides; 1,150 linear feet, 1 by 8 inch ship-lap; 1 roll roofing paper; 1 glazed window sash; nails, hinges, screws, etc.

The antenna poles are erected near the shack, and the location of the shore plant is governed to a considerable extent by the necessity for selecting a suitable site for the antenna (see p. 34). A site close to the end of the submarine cable is, of course, desirable but not essential, as land lines a mile or more in length have been used with satisfactory results.

It is advantageous to have the personnel actually living at the station, so that they will be subject to call by the ship at any time.

CABLE LAYING

In the operations of cable laying described in this section it is assumed that armored cable is to be used between the shore and the outer limit of breakers, from which light-duty cable is laid to the hydrophone. The most difficult operation is landing the heavy cable through the surf. Before it is started the usual practice is to establish the shore instruments and personnel so that the latter will be available to assist with the cable laying and testing. This procedure, however, is not essential and may be reversed in order to take advantage of suitable weather for cable laying. Several methods that have been used for landing cable are described below.

If the swell is not too heavy, the cable may be carried ashore by a small boat. The ship is anchored as near the hydrophone site as

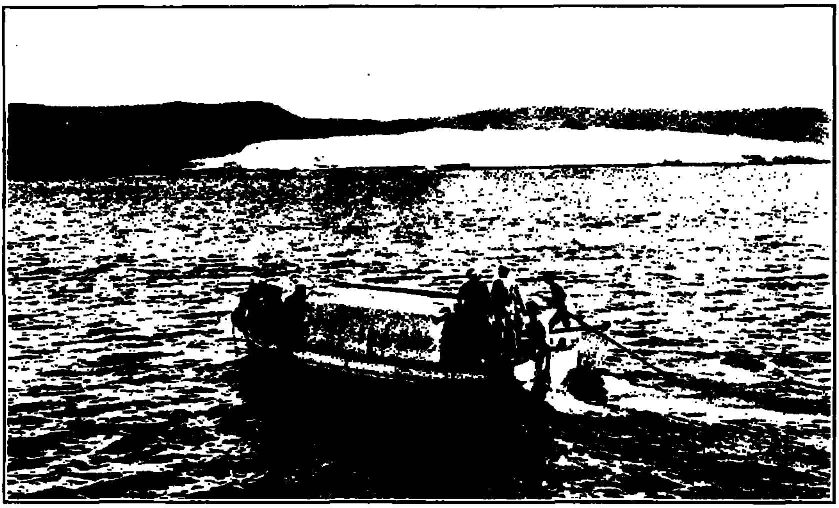

FIG. 20.—Small boats planting hydrophone block and laying cable

practicable, and a launch and whaleboat are lowered. An empty cable reel is securely mounted in the launch and filled with cable, after the launch is in the water, from a reel on the ship. Launch and boat then proceed to a safe location outside the breakers, where the former is anchored. A sufficient amount of cable to reach the shore is coiled in the stern of the whaleboat, alternate coils being turned over the preceding coil in the form of a figure eight with one loop turned over the other. The whaleboat is then rowed to shore, laying the cable as it goes. The cable extending astern takes the place of a steering oar. In this operation care must be taken to avoid kinking the cable.

If the whaleboat can not carry enough cable to reach high-water line but can reach low-water line, the cable may be landed at low tide and hauled up on the beach by a team of horses or a tackle, the launch paying out more cable as required (see remarks below relative to the importance of keeping the cable moving). Additional cable might also be provided on shore and a splice made near the low-water line, but this should not be done unless absolutely necessary.

If there is too much swell to land a cable in the above manner, it is often practicable to shoot a line ashore and haul the cable in to the beach. For this operation a number of men must be landed. If there is a settlement near the station, one man from the ship or the men at the station may be able to hire the labor required or a team of horses. A reel of cable is mounted in a launch or whaleboat in which is coiled a sufficient amount of 2½-inch rope to reach through the breakers. The boat then proceeds to a position outside the breakers and upon a signal from shore shoots a light line to the beach. If the breakers are close to shore, a shoulder gun may be used for this purpose; if the breaker area is wide, a Lyle gun, which has a range of about one-fourth mile, may be required. The light line is used to haul the rope ashore, and the latter is then used to haul the cable in to the beach. If the distance through the breakers is short, a few men can do the hauling; otherwise it may be necessary to employ a team or to use a tackle. Once the cable is in the water and under way toward the shore every effort must be made to keep it moving before it becomes buried in the sand.

If the breakers are too wide for the Lyle gun, it is necessary to wait for favorable weather and either lay the cable with a boat, as mentioned above, or carry in a hauling line. In the latter case it may be desirable to buoy the cable. Oil cans are excellent for heavy cable, while wooden floats may serve for lighter cable. Lashings that will wear away quickly should be used, as it is undesirable to have the cable buoyed for a longer period than is necessary to get it ashore.

After the heavy cable is ashore it is secured above high-water line, and the boat having the reel on board lays the remaining cable toward the hydrophone site and anchors and buoys the offshore end. If the first cable is long enough to reach beyond the storm-breaker line, the next operation is planting the hydrophone block. Otherwise additional cable must be obtained from the ship and spliced to the first length.

Officers and men engaged in laying cable through the surf should wear life belts at all times, and the boats should be well supplied with bailing buckets.

Cementing cable to rocky shore.—When the shore line is rocky, the cable should always be cemented as firmly as possible to the rocks between high and low water lines, so that it will not chafe at this point.

Land line.—Any insulated electric wire with the proper conductivity may be used to connect the inshore end of the cable with the instruments in the radio shack. The splice to the cable and any splices in the land line should be soldered and insulated as previously described. Interference from static and possibility of damage will be decreased if the land line is run underground, and this should be done wherever possible.

A wire, which need not be insulated, should also be run from the shack to a ground, preferably the outside sheathing of the submarine cable or to a near-by stream. The ground is very important and should be as nearly perfect as possible.

PLANTING HYDROPHONE BLOCK

The hydrophone block may be planted by the ship, if the latter can anchor safely at the hydrophone site; otherwise it is planted by a launch assisted by a whaleboat. If a launch is employed, the use of the composite type of block, which is lighter in weight than the wooden block, is desirable.

The submarine cable that is to connect with the cable already laid is secured to an eyebolt in the base of the block and spliced to the hydrophone cable, as previously described. To a wire strap or second eyebolt is attached one end of a buoy line. If it is desired to orient the block so that the hydrophones will point in a certain direction, this may be accomplished by having a small boat hold a tension on the buoy line in the proper direction when the block is lowered. The boat can best hold this line in the direction of the prevailing current, and the point of attachment of the line to the block should be provided with this fact in mind.

A well-painted spar buoy of softwood, preferably cedar, about 5 feet long and 6 to 8 inches in diameter, is securely attached to the free end of the line, and a 75-pound boat anchor is secured at some point on the line. The object of the buoy line is to provide means of recovering the block; the purpose of the anchor is to stretch a part of the line on the bottom away from the block, so that the upright part will never touch or foul the block. Contact between the line and the hydrophone box may produce the same effect as the explosion of a bomb.

The length of the ground part of the line will depend on conditions relative to current, etc. It must be at least several fathoms greater than the depth and may be as long as 30 fathoms. The upright part should have a length of about 20 fathoms. In some regions it may be necessary to use a concrete block or other substitute for the anchor to avoid loss by theft. Wire rope five-eighths inch in diameter is used for the buoy line of the wooden type block and three-eighths inch in diameter for the composite type.

A 3-inch rope with a large eye spliced in the end is used for lowering the block. This is attached to the iron strap of the block by passing the eye under and over the strap and through the standing part of the eye where it is secured with an iron or wooden fid (see fig. 9). A rope strap passing under the iron strap and through the eye of the lowering rope will serve the same purpose. The fid and the rope in contact with it should be well greased. A trip line of 12-thread stuff is attached to the fid.

If the ship is to plant the block, the lowering line is taken over a davit block, the hydroplane block is swung clear and lowered to the bottom, and the lowering line is released by pulling the trip line. The buoy line is used, as mentioned above, to orient the block, and is then hauled taut away from the block and anchored. The assistance of a small boat will usually be required, but at times the current and wind will hold the ship in such a position that a small boat will not be needed. After the block is planted, the attached cable is passed to a launch or whaleboat which lays the cable in to a junction with that already laid and splices the two ends.

If a launch is to plant the block, the cable is first transferred from the ship, taking care that it leads in the proper direction for laying. The buoy, anchor, and line are next placed on board the launch, after which the lowering line is led through a cleat on the bow of the launch and a few turns taken around a bit. The block is then lowered overboard by the ship until it is suspended from the bow of the launch. Both boats proceed to the hydrophone site, where the launch anchors. The buoy line is passed to the whaleboat which orients the block, while the launch lowers it to the bottom and then anchors the line. After the lowering line has been released and hauled aboard the launch lays the cable, as described above.

If a hydrophone box is water-tight, it is filled just before it is lowered. As soon as a block is planted, sextant angles to locate it are taken.

Some hydrographers follow the practice of attaching a buoyed anchor at each cable splice to aid in recovering the block if the buoy line is lost.

In some cases, where the bottom is irregular or composed of soft sand, it may be advisable to lash a false bottom to the hydrophone block to prevent its shifting, sinking, or capsizing. A bottom about 8 feet square, constructed from 2 by 4 inch boards, has been used for this purpose.

Recovering hydrophone block and cable.—If the buoy is still in place, raising a hydrophone block, to substitute a new block, or to discontinue the station is easily accomplished by means of the buoy line. If the buoy has become detached, it is necessary to pick up the cable. Aircraft cable is strong enough to lift the block, provided that it has been properly attached to the eyebolt in the base of the block. To replace the block, the cable is cut and the end insulated and buoyed. The new block is planted and located by angles, and the cable is spliced.

The cable may be picked up by means of the anchored buoy lines mentioned previously or by dragging with a grapnell if the bottom is sandy. The time required for the latter operation is uncertain, but the cable can usually be recovered unless it has been laid so long that it is buried deep in the sand. A heavy grapnell, dragged slowly over the cable, should be used. After the cable is brought to the surface it may be underhauled in the desired direction.

A swivel in a buoy line just below the buoy will aid in the preservation of the latter, and frequent angles or ranges observed when laying cable will be of use in recovering the cable.

TESTING HYDROPHONES AND CABLE

In order to insure satisfactory operation of shore stations and to avoid costly delays and the inconvenience of making repairs after the under-water equipment has been installed, tests should be made whenever possible during the operations of planting hydrophones and of splicing and laying cable. Tests recommended and the methods of making them are noted below.

Testing hydrophones.—Each hydrophone should be tested before being installed in the box by connecting the two conductors to a battery of known voltage and a milliammeter in series. The resistance of the hydrophone should be between 400 and 800 ohms. (See p. 17.) This test should be repeated after the hydrophone or hydrophones have been installed in the box with all splices made, and again repeated (using the same voltage) after the hydrophone block has been planted.

The last test should show some increase in the current passed due to the effect of water pressure on the hydrophone. Effect of ocean swell will be indicated by a smooth movement of the milliammeter needle, a jerky movement indicating leaks or breaks in the circuit. A record of hydrophone tests should be kept for comparison with later tests.

Testing cable and splices.—Every section of cable, even if new, and all splices, if practicable, should be tested as follows:

(*a*) Test cable when dry for breaks by connecting the two ends through a battery and ammeter (or voltmeter) in series and noting if cable passes the full current applied to it.

(*b*) Test cable for leaks by insulating one end and by grounding the other end through a battery and milliammeter. The entire reel of cable, except the grounded end, can then be lowered overboard for a considerable period, or the cable can be passed through the water in sections (a running bight), the latter method being better for locating leaks. In either case if the milliammeter shows a passage of current a leak is indicated. As leaks of any size cause considerable trouble, it is best to remove defective sections by cutting and splicing the cable, and it is often desirable, especially with the heavy cable, to remove sections where future leaks may develop, as at spots where near-kinks exist.

(*c*) Test all splices, if practicable, for breaks and leaks by the method described above.

(*d*) After laying cable to the shore the inshore end should be insulated, and the boat at the outer end should test for leaks by grounding this end through a battery and milliammeter in series.

(*e*) Test same cable for breaks by grounding the inshore end through a battery and milliammeter in series. Repeat this test after hydrophone has been planted and all cable has been laid. After land line has been spliced to the submarine cable and led to the radio shack test complete circuit in the same manner.

(*f*) Finally, test complete shore installation by under-water sounds produced by the ship's oscillator or by exploding a detonator.

(*g*) A possible test of leaks during the season is to connect the conductor and sheathing of the cable through a milliammeter. A passage of current may indicate a leak, though this may possibly be caused by electrolytic action.

DETAILS OF OPERATION

Hydrographic methods.—In considering the use of radio acoustic position finding it should be borne in mind that this method is not intended entirely to supplant position finding by visual means. Each method has its advantages and its limitations. When suitably located, fixed objects are visible; the latter method is preferable, as it requires less time and effort than any other means of position finding. The offshore distance to which it can be carried, however, is limited by conditions of visibility as noted previously.

On the other hand, the offshore limit of radio acoustic control does not depend on the conditions that affect the visual positions, but the new method is not adapted for work close inshore; mainly because of the close spacing of control stations that would be required, possible uncertainty in the velocity of sound, and the large number of positions necessary to control closely spaced sounding lines.

It should be apparent from the above facts that the two methods are admirably suited for use in conjunction in order that accurate control may be carried farther offshore and that loss of time due to weather conditions may be reduced to a minimum. Their use in this manner has also made possible an important and very desirable change in the procedure of hydrographic surveying.

Formerly, in order to carry on fixed-position surveys with any degree of economy, it was necessary to utilize the clearest weather for offshore work. As a general rule, good visibility is accompanied by other weather conditions most favorable for depth-measuring operations. With radio acoustic control available, this procedure has been reversed and a more logical arrangement of work is possible. Inshore areas are usually the most important, as they may include the approaches to harbors, depths are less, and dangerous shoals are more likely to exist. Surveys of such areas, which are best controlled by visual means, can now be carried on during weather most suitable for careful and accurate sounding operations.

A coastal survey for which both methods of control are used will usually proceed in the most economical manner when the two classes of work progress at about the same rate along the coast. Careful consideration, in connection with prevailing weather, spacing of sounding lines, etc., should therefore be given to the above conditions in fixing a boundary line between the two methods.

On the Pacific coast it has been the general practice to use radio acoustic control outside the 50-fathom curve, which lies from 10 to 15 miles offshore, and it has been possible to approximate the ideal arrangement indicated above by taking all possible advantage of clear weather for work inside this limit.

Position intervals.—The number and spacing of radio acoustic positions should be such that all sounding lines are located with sufficient accuracy for charting purposes, and that the course of the vessel may be directed so as to run the lines in an economical manner. On the Pacific coast these conditions have been secured by taking bomb positions about as follows:

(*a*) At the beginning and end of each sounding line except as noted in the next paragraph.

(*b*) Either at the end of one line or the beginning of the next when the two points are so close together that a bomb position at each is impracticable.

(*c*) At all radical changes of course on a sounding line.

(*d*) At the following intervals on a sounding line: Between the 50 and 100 fathom curves, 15 minutes when running at 10 knots and 20 minutes when running at two-thirds this speed; outside the 100-fathom curve, 25 to 30 minutes.

At each bomb position readings of the log and revolution counter are taken and recorded, and intermediate positions are provided by such readings at all changes of course (both when the turn is started and completed), at all radical changes of speed, and at intervals not greater than 15 minutes on the sounding line.

Personnel.—The usual organization of a party engaged in radio acoustic position finding is as follows: On board ship the officer of the deck stands bridge watch and performs the customary duties of watch officer modified in accordance with usual surveying practice. Another officer, stationed in the chart room, is in direct charge of obtaining time intervals, computing distances, plotting positions on the sheet, and setting courses to run the proposed sounding lines. A division of these duties between two officers speeds up the work and, when the complement permits, is very desirable, especially on inshore work when positions are taken frequently.

The chief radio operator operates the radio apparatus, under the direction of the officer in charge of the chart room, and supervises the operation of shore stations. A second radio operator relieves the chief operator and is available for duty ashore in emergencies.

One member of the crew is especially designated to make up, care for, and fire the bombs. He should have considerable experience with explosives and should be a man who will always exercise the utmost care and precautions in his work.

The complement of each shore station consists of a radio operator, who has complete charge of his station under the general supervision of the chief operator, and a man as cook and helper. The latter may be dispensed with if living accommodations near the station are available.

Radio acoustic position finding is a specialized branch of radio and electrical work and, as the success of hydrographic work controlled by this method depends on the satisfactory operation of ship and shore station apparatus, it is essential that the radio personnel be of the highest type and thoroughly trained. Such training can be obtained only by actual operation of the equipment under competent instruction. Operators should have special knowledge of vacuum-tube work and be of an experimental turn of mind. It has been found that the best operators are men who have graduated from a first-class radio school, or have been enthusiastic amateurs, or have been connected with broadcasting or experimental operations. Commercial operators without these qualifications rarely succeed in radio-acoustic work.

Determination of lags.—Before starting the day's work the operator at each shore station, when directed by radio from the ship, sends a series of lags (usually five or six sets). The means of these are used during the day unless, as rarely occurs, later information indicates a change in the lags at the station.

To determine the lags at a shore station, the operator opens and closes the hydrophone switch, which will cause the plate-circuit relay to operate. One pair of contacts closes the circuit of the transmitting relay, so that a radio dash is sent out; another pair of contacts closes the circuit of the automatic key, causing the transmission of the three metronome dashes. All dashes are received and recorded by the chronograph on board ship, and the lags, which are the intervals between the first dash and the succeeding metronome dashes, are scaled to hundredths of a second in the same manner as for a bomb position described later.

Condition of shore circuits.—Some hydrographers consider that a record of the condition of the hydrophone circuit at each shore station is of value in carrying on work. This may be compiled from a daily report following the lag signals. Such a report usually consists of three figures—the first being the amount of steady water noises in the circuit (the normal reading of the milliammeter when no bomb signals are coming through); second, the milliammeter reading at which the relay will trip; and, third, the number of times that the relay will trip during a certain period, due to water or other noises that are above normal.

ROUTINE OF POSITION FINDING

Before a position is to be obtained the officer in charge of the chart room has the radio operator call the shore stations to make sure that they are ready and properly tuned in, the bomber is instructed to have a bomb ready, and the chronograph is tested. Usually a 30-second stand-by notice is also given to the bridge, the bomber, and the shore operators. A definite system of signals by bell or other means between the bridge and chart room, to cover the usual operations of position finding, is desirable. When time for the position, the bomber is instructed to fire the bomb.

Bomb firing.—A bomb is lighted by holding the fuze against the electric heater until a spurt of flame and sparks comes from the fuze. The bomb is then held for a second or two until only smoke is emitted, which indicates that the fuze is burning entirely on the inside and will not be extinguished by the water. It is then dropped overboard with as little splash as possible; this being especially important in the case of cast-iron containers. If practicable, the bomb should hit the water bottom first.

At the instant of dropping the bomb the bridge is notified, so that the course or speed will not be changed until the bomb explodes and the log and revolution counter are read and recorded.

Fuze interval.—This term is applied to the interval between the times of dropping the bomb and its explosion. It must always be obtained for use in computing the "run," which is discussed later. The fuze interval is measured to the nearest second, with a stop watch, or by marking the chronograph tape, either with a pencil or by tripping the signal-pen relay.

Depth of explosion.—The depths to which various types of bombs will sink during any given fuze interval may be determined by experiments. When surveying in shoal water, this depth may be such that the bomb will reach bottom before exploding. This is undesirable, and may be prevented by supporting the bomb at any desired depth by means of a temporary buoy and string. An inflated paper bag will serve for the former. The string should be so light that it will break if it fouls anything.

Receiving signals.—As soon as the bomb is dropped overboard the officer in charge of the chart room throws the "hydroradio" switch (see fig. 2) to close the sound-receiver circuit. When the sound of the explosion is received, a long dash is transmitted by radio (by means of a transmitting key relay in the signal-pen circuit) to notify the shore stations that a bomb has been fired, after which the ship's antenna is connected automatically to the radio receiver. The "hydroradio" switch is then thrown to close the radio receiver circuit for reception of the radio signals from the shore stations.

Additional data from shore stations.—After the signals from control stations have been received the radio operator calls the shore stations and obtains the milliammeter readings caused by the bomb explosion. These give an approximate measure of the intensity with which the sound strikes the hydrophones and, together with the size of the bomb and distances from the stations, form a valuable record for the determination of the sizes of bombs to be used under various conditions.

When a simultaneous dash is transmitted from the stations, the intervals between this dash and the succeeding metronome dashes give a set of lags for each position by means of which the operation of the stations may be checked. Otherwise, one set of lags at each station is obtained in the manner described above after each position. The next steps are the scaling of time intervals from the chronograph tape, the computation of distances, and the plotting of the position, all performed on board the ship.

CHRONOGRAPH RECORD

As the chronograph tape passes under the recording pens, the time pen draws a base line about in the middle of the tape and each second makes a short offset in this line. The signal pen draws a second line, coincident or nearly so with the first line, from which it makes an offset when actuated by the bomb explosion or by a radio signal. Signal offsets are on the opposite side of the base line from the time offsets.

The appearance of the tape and the method of scaling time intervals from it are illustrated in Figure 21, which shows the signals from one shore station only. The first signal offset of a position is that caused by the bomb explosion, and varies considerably in length. In Figure 21 this offset starts at the point marked *B*. The next offset of a normal record is that caused by the receipt of the radio dash transmitted at the instant the sound reaches a shore hydrophone (if the shore station is arranged to transmit a simultaneous dash) followed, at intervals caused by lags in the metronome circuit, by three offsets caused by the receipt of the metronome dashes. In the illustration the first radio offset starts at point A^2 and the metronome offsets start at points M^1, M^2, and M^3. After all signals from the control stations have been received the tape is torn off at a point beyond the last offset and the time intervals are scaled.

Scales.—A scale of even seconds may be prepared by adjusting the chronograph for constant speed and running off a length of tape covering about 100 seconds. The time offsets on this tape are numbered consecutively, and the tape is secured to the top of a table or desk near the chronograph. Later irregularities in the speed of the chronograph motor will be indicated by lack of coincidence between the time offsets on the tape record and those on the standard scale. For intervals less than one second a glass or celluloid scale graduated to hundredths of a second is used.

Time intervals.—For convenience in scaling time intervals the time offset immediately preceding the offset caused by the bomb explosion is used as an initial point from which all intervals are scaled (point *I* in fig. 21). In scaling to offsets the point at which the signal pen leaves the base line is used. The intervals scaled or computed are as follows, points and intervals designated by letters are those shown in Figure 21.

Initial interval.—This is the interval *IB* scaled from the initial point to the bomb offset.

Run.—The position determined is that at which the bomb is thrown overboard. As the ship is under way, it will be some distance from this point when the bomb explodes, and an appreciable length of time will be required for the sound to reach the ship's receiver. The actual time of the explosion, therefore, is always earlier than is indicated by the bomb offset. For the purpose of illustration, this interval is exaggerated to show the actual time of explosion at the point on the tape marked by the arrow A^1. The interval A^1B,

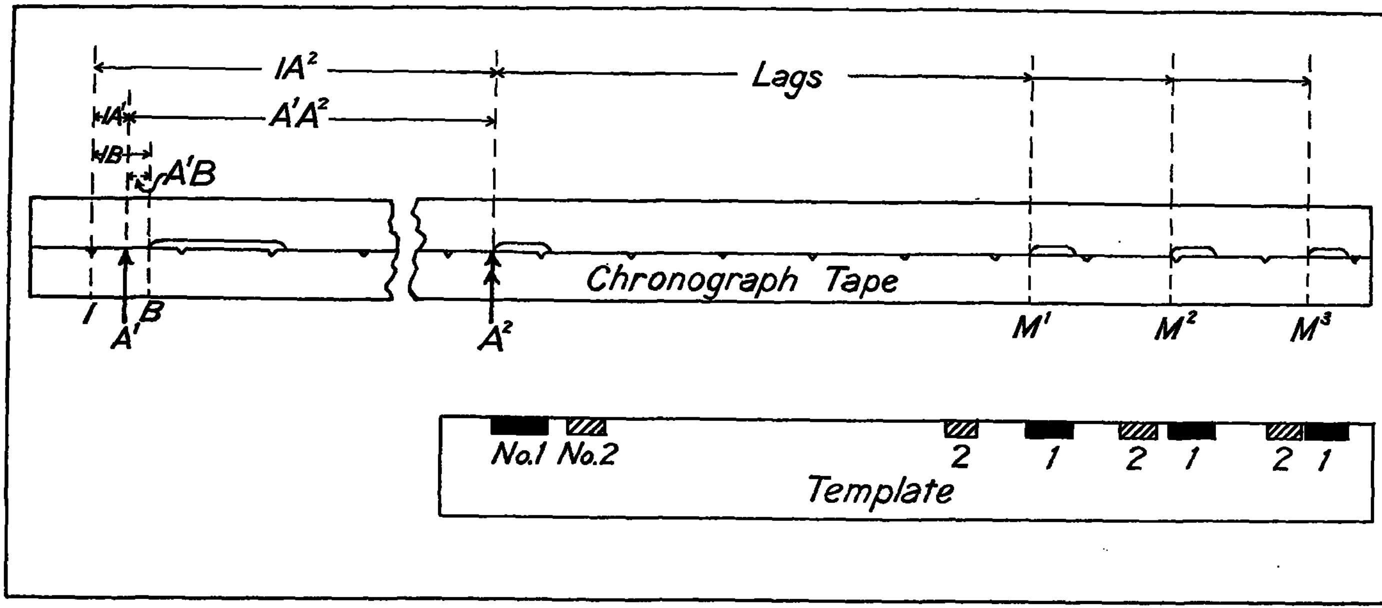

FIG. 21.—Chronograph record tape

termed the "run," is computed from the speed of the ship, the fuze interval, the distance that the bomb sinks during this interval, and the velocity of sound in water.

In practice it has been found that a table for various fuze intervals and speeds of vessel, made up in advance, is convenient for use. In preparing this table it is desirable to measure the sinking speed of various sizes of bombs and to use an average speed rather than a different speed for each type. Such tables should be used for final computations, but for preliminary computations for use in field work time can be saved by obtaining an approximate value in the following manner: Multiply the speed of the ship in knots by the fuze interval in seconds; divide by 30, and the result will be the run in hundredths of a second.

Initial correction.—This is the interval IA^1 between the initial point and the actual time of the explosion, obtained by subtracting the computed run A^1B from the scaled initial interval IB.

Time from initial.—This is the interval IA^2 from the initial point to the point on the tape marked by the double-headed arrow A^2, indicating the time of receipt of the sound by the shore-station hydrophone. If the station is arranged to transmit a simultaneous dash, the proper point on the tape is indicated by the first radio signal offset. The interval is checked by scaling from I to M^1, M^2, and M^3 and subtracting mean lags, and this is the only method available for obtaining the interval IA^2 if the station does not transmit the simultaneous dash.

Elapsed time.—The interval A^1A^2, which is the elasped time between the explosion of the bomb and the receipt of the sound by the shore-station hydrophone, is obtained by subtracting the initial correction IA^1 from the interval IA^2.

Template.—When the position is about equidistant from the control stations, the signal offsets may intermingle on the tape. Confusion may also be caused at times by static, which produces offsets similar to those caused by the radio signals. As the length of an offset caused by any particular radio dash and the intervals between these offsets remain constant for each station, a template, as illustrated in Figure 21, will often be found valuable for identifying the radio signals from the stations.

After a series of lags that show no variation have been taken rectangles, corresponding in length and spacing with the radio signals from each station as shown on the tape, are laid off on the edge of a strip of celluloid or boat-sheet paper. By using different-colored ink and proper notation the signals from two or more stations can be shown on the same strip. When laid on the tape as the signals come in this template, in addition to aiding in identification of signals, will indicate any irregularities in the operation of shore stations.

Recording.—Time intervals for each station used for control are recorded in a bomb record. A sample page illustrating the recording and computation of data for one position is shown in Figure 22. In this figure the columns have been numbered for convenient reference.

The page is divided into alternate four and two line spaces by heavy lines, a four-line space being used to record the data for each station. In the first two columns the position number, time of dropping bomb, and name of station are recorded. The entries in the third column are described above. The scaled times in the fourth column are the intervals between the initial point and the various radio-signal offsets. In the case of the simultaneous dash, the scaled time and time from initial are the same. For the metronome dashes mean lags are entered in the fifth column and subtracted from the scaled times to obtain the times from initial. If any radio dash is missed, the appropriate line is left blank. The elapsed times in the eighth column are obtained as described above.

On the right-hand side of the page the velocity of sound is entered, space being provided for an assumed velocity in case work is started before actual tests are made. Distances are obtained by multiplying elapsed times by the velocity of sound. The last column is used for entry of data indicated by the heading.

A distance can be obtained from any one of the dashes received from a station, and this is often done in field work when the position is desired as quickly as possible. At a later time, however, all of the entries described above are carefully made and checked, after which the tape is no longer required as a permanent record. At the end of each day in the record the names of the persons who compiled and checked the record are noted.

In the sounding record positions are recorded by noting the name or call letters of each station, the distances, and the readings of the log and revolution counter. Rubber stamps are provided for this purpose.

PLOTTING POSITIONS

As the distances to shore stations are frequently great, and as intersections of distance arcs are occasionally somewhat flat, exceptional care must be taken in preparing projections. Well-seasoned paper of the best grade should be used both for boat and smooth sheets, and projections should be as accurate as possible.

Hydrophone positions.—As soon as possible after a projection is completed the positions of the hydrophones and the distance arcs mentioned below should be plotted thereon. The former may be plotted with a three-arm *protractor*, but it is usually desirable to compute the geographic positions of the hydrophones from the ob-

BOMB RECORD

Locality *Coast of Oregon*

Year 19*27* Month *June* Day of Month *10* U. S. C. and G. Survey Ship *Guide* ; *M* day

1 2 3 4 5 6 7 8 9 10 11 12 13

POSITION NUMBER	TIME OF DROPPING BOMB AND NAMES OF STATIONS	INITIAL INTERVAL / RUN / INITIAL COR.		SCALED TIMES		LAGS		TIME FROM INITIAL		MEAN OF METRONOME SIGNALS		ELAPSED TIME		VELOCITY OF SOUND METERS PER SECOND: ASSUMED	VELOCITY OF SOUND METERS PER SECOND: FROM TESTS	DISTANCES IN METERS: ASSUMED	DISTANCES IN METERS: FINAL	DESCRIPTION OF BOMB / SPEED OF SHIP / FUSE INTERVAL / REMARKS
37	5-00-00	0	90	98	67	—	—	98	67	—	—	97	84	1479	1481	144705	144901	1-pint can
	Orford	0	07	105	57	6	88	98	69									10 knots
		0	83	107	06	8	38		68									20 secs
				108	55	9	91		64	98	67	97	84					
	Hunter			89	43	—	—	89	43	—	—	88	60			131039	131216	
				97	18	7	75	89	43									
				97	85	8	43		42									
				98	57	9	11		46	89	43	88	60					

No. 22

Times scaled by *J.P. Smith*
Times checked by *A.R. Jones*
Computations by *J.P.S.*
Checked by *A.R.J.*
Velocity tests recorded on page *3-6* vol. *1* of *Bomb* record.

This information inserted at end of each day.

FIG. 22.—Sample page of bomb record

served sextant angles. The symbol for a hydrophone station is a square 2 millimeters on a side with a dot in the center, indicating the position of the station. Stations are distinguished by using ink of a different color for each and by the name or call letters of the station lettered with ink of the same color as the symbol.

Distance arcs.—For convenience and accuracy in plotting positions, distance arcs from each station are drawn at regular intervals on the sheet, the arcs from each station being linked with the same color as the station symbol. For scales from 1:80,000 to 1:120,000, which are generally used, an arc interval of 10,000 meters is satisfactory. The distance of each arc from its station is lettered on the edges of the sheet at each end of the arc.

The sheet should be measured for distortion just before the arcs are drawn. If there is no distortion of practical importance, the arcs may be swung from the stations with dividers or beam compass. Otherwise allowance for distortion should be made by computing the geographic positions of three well-distributed points on each arc and drawing the arc of a circle through these points.

Points on true east-west or north-south lines passing through a hydrophone station are most easily computed, as in this case the distance of a point along such a line from the nearest parallel or meridian can be obtained by using the total distance desired, the distance of the station from the nearest parallel or meridian, and the length, in meters, of intervening projection intervals as tabulated in the projection tables. Special attention should be given to distortion when it is necessary to draw additional arcs on a sheet that has been used for some time, as when a new control station is established during the season.

Positions.—When the position distances have been computed, the distance from the nearest distance arc of each hydrophone station is obtained. Then, using a meter scale corresponding to the scale of the projection and knowing the location of the position within reasonable limits, the distance from one arc is set on a pair of dividers, a point at the proper distance from one of the stations is plotted, and a short arc is swung in pencil with a beam compass centered on the station. The position is then plotted on the pencil arc with dividers set at the proper distance from the nearest distance arc of the other station.

When for any reason only one distance is obtained, a position may be plotted by various means—such as the intersection of the single distance arc with the course from a previous position—with a line connecting two positions if there has been no change in the course, or with an arc swung from an adjacent position using the log distance as radius. In such cases the method used should be stated in the record.

The symbol for a bomb position is an inked section of the distance arc from each station, each arc extending 2 millimeters on both sides of its intersection with the other arc or arcs, the point of intersection being the position. Each arc is inked with the color of its station. The symbol for a position obtained by using only one distance arc, as indicated above, is an inked section of the distance arc extending 2 millimeters on both sides of the position which is marked by the intersection of the arc and a straight line extending about normal to the arc and 1 millimeter on each side of it. In this case both arc and intersecting line are inked with the color of the station from which a distance is obtained.

The symbol for a visual position used in conjunction with a bomb position for the determination of sound velocity is a square, 1 millimeter on a side, with the visual position in the center. When only one station is used, the entire square is inked with the station color. If two stations are used, two adjacent sides of the square are inked with the color of one station and the other two sides with the color of the second station.

Time required for position.—When only one radio dash is used, about three minutes are required to scale time intervals, compute distances, and plot a position. When all dashes are used, the time required is generally a little over four minutes.

VELOCITY OF SOUND

Accurate knowledge of the velocity of sound in sea water is obviously of vital importance in radio acoustic position finding. Considerable study of this subject by scientists and engineers of the United States[2] and other countries has shown that this velocity depends on the salinity, temperature, and pressure of the water through which the sound passes, and tables have been prepared giving theoretical velocities for different values of these variables.

In radio acoustic work, however, little is known of the path taken by the sound of a bomb explosion in reaching the shore stations, and it is, of course, difficult to determine the conditions affecting the velocity throughout the area traversed by the sound waves. It is therefore considered advisable to measure the velocity of sound by actual tests on the working grounds.

Determination of velocity.—This is accomplished by exploding bombs at suitable points where accurate visual positions of the ship can be obtained. The time required for the sound of a bomb explosion to reach the shore hydrophones is determined by the standard methods described heretofore, and the distances are computed or scaled from the plotting sheet.

[2] For a description of the experiments of the Coast and Geodetic Survey on this subject and an account of the results obtained see Velocity of Sound in Sea Water, Coast and Geodetic Survey Special Publication No. 108.

The conditions under which tests are made should be carefully selected. Bombs should be fired at points where strong visual positions on well-located objects are obtainable and where the distances to hydrophones are as great as possible. The latter is necessary in order to minimize instrumental and other errors; it is customary to use only the results of tests on stations not less than about 15 miles distant, or at least to give greater weight to such results.

The position should be taken at the instant the bomb is dropped, and the distance and bearing between the point on the ship where the position is taken and that from which the bomb is dropped should be considered in plotting the position. Great care should be taken to determine the "run" accurately and to obtain good lag observations before and after each test. Bombs of sufficient size to produce strong effects at the shore stations should be used, and results that are questionable in any way should not be used for computing velocities. Positions should be plotted on a well-seasoned and accurate projection.

It is also desirable to make such tests when there are opportunities during the progress of hydrographic work, but these as a rule will not give as good results as the special tests on account of weaker positions or shorter distances from hydrophones.

In order to provide data for theoretical investigations of velocity it is desirable that serial water temperatures and water samples at various depths be taken at fairly frequent intervals during the season. These should be well distributed over the area under survey and should be supplemented by surface-water temperatures and samples, taken daily at different points on the working grounds. Usually the collection of these data will not interfere with other work, as they are required for the reduction of echo soundings. Instructions for securing temperatures and water samples and for recording the data obtained will be found in the Hydrographic Manual published by the bureau.

Frequency of tests.—It is the practice to make as many velocity tests as possible within reasonable limits during the progress of hydrographic work. They should be taken frequently during the season and should be as well distributed as practicable over the working grounds. The number of tests on each hydrophone should be approximately equal.

During a short season it is often practicable to adopt one average velocity for use during the season. For longer seasons, however, and especially in regions where considerable variations of salinity and temperature may be expected, it may be necessary to adopt different velocity values for certain periods and possibly for different sections of the working grounds.

FAULTS IN OPERATION

Satisfactory results in the use of radio acoustic ranging depend on the efficient operation of every one of the units of which the equipment is composed, and it is therefore necessary to have everything in the best possible condition at all times.

At the beginning difficulties may be experienced in getting bombs to explode, but these troubles will decrease with experience. The end of the fuze next to the detonator must be freshly cut and dry, and the joint between fuze and detonator must be absolutely watertight. The fuze and detonator must not be pulled out of the explosive in throwing it overboard, and the powder must be ignited inside the fuze, not merely the tarry compound surrounding it. If these and the instructions previously given are carefully followed, the bombs should give no trouble.

The ship's hydrophone must be covered with water. There is no excuse for storage batteries not being charged, and dry batteries should be tested often enough to be replaced before they cause trouble.

There is always a possibility of the ship's amplifier getting salt spray on it, and for this reason every precaution should be taken to locate it in a protected place and then keep it closed and free from moisture and dust. The tubes should be operated slightly below their rated voltage rather than at or above, as the latter lowers their efficiency and life very materially. If anything is suspected of being not up to standard, it should be overhauled and put in condition at the first opportunity when the ship is not working on R. A. R.

The relay contacts should be cleaned occasionally by drawing crocus cloth or paper between them, so that they are free from dirt. The chronograph motor should be examined once or twice a season and brushes and commutator cleaned and bearings oiled. The paper should be renewed in time, so that it does not run out just after a bomb is fired. The loss of a position costs more than several rolls of paper.

Pens should be cleaned and ink frequently renewed. Some ships use fountain instead of stylographic pens and a good rule is to refill the pens daily before work is begun. The set screws on the magnet armatures, the stops, etc., should be kept tight, so that they may not work loose at a critical moment and spoil a record.

The contour of the ocean bottom may have considerable effect on the distance that bombs will carry, and intervening shoals may sometimes prevent the sound of a bomb explosion reaching a shore station. In the case of off-lying shoals there is no remedy for this condition, and it is not especially serious, as the interference will be felt in only a small area. If there is a shoal a short distance off from the hydrophone, however, it may interfere with the reception of sound from all directions, making it necessary to move the hydrophone either outside the shoal or a short distance along the shore, so that the shoal will be off the line between the hydrophone and points where bombs will be fired. Rough seas may also cause a decrease in the strength of bomb signals.

Probably more trouble has been experienced in the combination of shore hydrophone, cable, and amplifier than in all the rest of the apparatus. Naturally, the hydrophone and cable are more inaccessible than any other parts, so that if anything goes wrong with them there is nothing to do but take them up. Consequently, the greatest care should be exercised that no electrical accidents occur to the hydrophone, such as using too high voltage on it for testing. While high voltage, such as furnished by a megger, is handy for testing the cable insulation, it should not be used on the hydrophone circuit. Many noises attributed to the hydrophone and called water noises are due to troubles in the cable and the amplifier itself. These troubles may be due to tubes, batteries, poor contacts at joints, poor insulation with consequent leakage, and " static " received on the cable itself.

When searching for troubles in the amplifier circuit, remove the hydrophone wires and connect the hydrophone binding posts together. If the circuit is not absolutely quiet when listening on the third stage, try listening with only the third tube in its socket, then with second and third only, and then with all three, and start listening on the first stage with the first tube only, second stage with second tube, etc., to see if the noises can be located in any one stage or if it is always present. Try changing to new tubes.

Make sure that all the connections to the *A* battery are tight, as well as the connections between cells. With lead batteries the connections have a tendency to work loose, especially where a different metal is used with the lead. The best connectors are spring clips coated with lead, as the springs always produce a pressure regardless of temperature changes.

The *B* batteries may be in poor condition. They may be tested, 1 block at a time, with an ammeter and should give at least 1 ampere or be thrown away. This test should be made with the circuit closed only a very brief interval of time or the battery will be injured. If no ammeter is available for this test, the battery may be tested by fastening a short piece of copper wire to one terminal and snapping the other end across the other terminal. If a spark is visible, the battery may be used and will probably not be noisy, but if no spark can be seen it will be inefficient even if it shows a fair voltage on a voltmeter. It is not economy to try to work with poor dry batteries.

If batteries and tubes are good, noise may be due to moisture causing leakage. It is assumed that a defective transformer would be quickly detected. It sometimes is beneficial to put the amplifier in an oven or near a source of heat where it can be warmed up to a temperature not above the boiling point. This will drive out all the moisture without injuring the insulation. When the amplifier and its circuits are quiet, connect the hydrophone and its battery.

There will generally be a slight noise from any hydrophone, due to the carbon itself, variously spoken of as frying or burning. A crackling noise is generally due to leakage through the insulation of the cable, or it may be due to atmospheric or earth currents or noise in the ground connection at the radio shack. Sometimes a condenser of as much as 1 microfarad shunted across the cable and ground will sufficiently reduce this noise so that it will not be bothersome.

Hydrophone cable troubles may be due to breaking or injury to the insulation. In the first case no sound can be heard from the hydrophone at all. In the latter case if there is only a slight leakage through the insulation it will act as a shunt around the hydrophone and decrease its sensitiveness and probably also produce the crackling noise mentioned above, since the resistance of such a leak seldom remains constant. If any considerable portion of the insulation is injured, amounting to an inch or two of bare wire being exposed to sea water, it is practically the equivalent of a short circuit being made at that point between the cable and ground.

When first put down, the insulation resistance of the cable should be a megohm or more. However, as the insulation deteriorates its resistance decreases, and some stations have been operated a short time with the cable insulation as low as a few hundred ohms. These are exceptional cases, however, and in general operation at any considerable distance will fail before the resistance has dropped to anywhere near this value. If the insulation is impaired, the usual procedure is to send out a boat and bring the cable to the surface and examine throughout its full length while the boat is moved along slowly. Any doubtful-looking places should be repaired by retaping with rubber to make a water-tight covering.

Sometimes fishing boats may anchor near the hydrophone and make so much noise that no adjustment of the relay can be made which will distinguish between bombs and boat noises. Nothing can be done but remove the boats. One source of trouble was traced to fish bumping against the hydrophone box; another to crabs climbing over the hydrophone block. In one locality the present method has failed to work more than a few miles, with the cause not yet definitely known.

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