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SUBMARINE SIGNALING

THE PROTECTION OF SHIPPING BY A WALL OF SOUND AND OTHER USES OF THE SUBMARINE TELEGRAPH OSCILLATOR

BY R. F. BLAKE

ABSTRACT OF PAPER

Submarine signaling has been greatly advanced by the introduction of a powerful sound transmitter and receiver called the "Fessenden telegraph oscillator." By means of this, telegraph messages can be sent and received through the water by moving ships and for short distances speech can be transmitted, icebergs can be located, and soundings taken instantaneously.

The apparatus consists of an oscillating electric motor-generator which has a strong electromagnet surrounding a central core on which is an alternating-current winding. Between the core and the magnet is a copper tube which acts as a closed secondary to the core winding. This copper tube is attached to a large diaphragm. When the alternating current passes through the core winding it induces a current in the copper tube, which, being free to move, vibrates back and forth, thus setting the diaphragm in vibration.

This apparatus is installed in a ship so that the face of the diaphragm is in contact with the water and its vibrations set up sound waves in the water. Signals have been sent a distance of 31 miles.

The oscillator can also be used as a receiver. Sound waves striking against the diaphragm cause the copper tube to vibrate, thereby generating a current in itself which is induced in the core winding. A telephone receiver in the armature circuit enables the observer to hear the sound.

COMPARED with other forms of transportation, the amount of energy necessary to transport water-borne freight is very small and its cost would be cheap indeed if it were not for the dangers of the sea. We have fogs and rocky coasts, shoals and icebergs, currents and storms to guard against, and these add immensely to the expense. Of this we have had a very recent instance, for, as the result of the loss of the *Titanic*, vessels carrying passengers are now constructed with a complete double bottom extending above the water line, in other words, instead of a single ship, we must now have two complete ships, one en-

tirely enclosed by the other. And the loss of the *Empress of Ireland* indicates that even this may not be adequate.

Bit by bit the dangers which beset the early navigators have been overcome. The chart told him the best course to take from one point to another. The mariner's compass enabled him to maintain his course when the stars were blotted out by clouds. With sextant and chronometer he located his position, with log and soundings he guarded himself when a sight could not be obtained. More recently wireless telegraphy has enabled him to call assistance in time of danger. But with all this, many dangers remain. The more important of these are due to fog.

The North Sea, the English Channel and the Grand Banks, the New England Coast, the Western Coast of the United States, British Columbia and Alaska, and other points are all of them subject to fogs, sometimes lasting for weeks at a time, and it is therefore not surprising that thousands of lives are each year still lost at sea.

And there is not only loss of life; the pecuniary loss is also very great. It is no unusual occurrence for a score of steamers to be tied up at one time, unable to enter harbor on account of fog or of the combination of fog and rough weather.

In such a case, the loss to the steamship companies in interest and depreciation on ships and cargoes and in wages may easily amount to more than fifty thousand dollars per day, and this loss occurs not once but frequently during a year, and on many routes.

In addition to this, the danger of collision in fog adds very considerably to the cost of insurance, and some of our worst disasters have occurred in this way.

Aside from those dangers peculiar to fog, there remains a number of others. A continuance of cloudy weather or abnormal ocean currents or both, may throw the navigator out of his reckoning and place him on a rocky shore a score of miles away from the safe route he assumes himself to be following.

Icebergs still remain a menace in spite of all the efforts which have been made to guard against them. From time to time, statements have been made that apparatus has been devised which is capable of locating their presence, but in every instance in which such apparatus has been tested it has proved a failure.

The history of systematic marine protection by means of lighthouses and beacons does not go back very far. It is true that there were a few lighthouses such as the Pharos of Alexandria

centuries ago, but even in quite recent years a European Government received a petition for compensation from the inhabitants of a sea coast district on the ground that the erection of a light-house had deprived them of one of their principal sources of income, to wit, luring vessels on nearby shoals by means of false lights.

The systematic employment of sound signals for marine protection is of still more recent date and has never been carried out fully, in spite of the fact that many of our greatest scientists, for example Tyndall and Rayleigh, have devoted special attention to this matter.

One reason for this is that sound signals produced in air are very erratic in their range and intensity, so much so as to be on many occasions absolutely misleading. This is due to the fact that when a fog-horn is blown, the sound may be carried by the wind or may be reflected or refracted by layers of air of different densities, with the result that the sound may be audible many miles away while there may be a zone of complete silence extending from a few hundred yards in front of the signal to a distance of four or five miles.

As this phenomenon is by no means infrequent, the result has been to discredit more or less this type of signal, and it will be evident that the knowledge that a siren had been installed at a certain dangerous point might prove a source of danger instead of a protection.

As already stated many eminent men have worked upon this problem, but it was not until Arthur J. Mundy, of Boston, suggested the use of water instead of air as the medium for transmitting signals and proved its value by practical demonstration that any great advance was made. Water has many advantages over air for this purpose.

1. In the first place it is free from the dangerous zones of silence which occur when the signals are produced in air.

2. In the second place, the absorption of the sound is much less in water and consequently the signal is not only absolutely reliable but is transmitted to a distance many times greater than when it is transmitted through air.

3. The sound is not carried away by the wind in stormy weather, as is the case with the siren.

4. It is not affected by atmospheric disturbances, as is the case of wireless.

5. It permits of the accurate determination of the direction

from which the sound is proceeding, which is not the case with either the air siren or wireless telegraphy.

Some recent instances where ships have signaled by wireless that they were in distress but have had to remain without assistance for many hours, and in one instance for more than a day, because their location could not be determined by the vessels coming to their aid, will be familiar to every one.

All these advantages indicated clearly years ago the advisability of developing apparatus for signaling by means of sound waves transmitted through the water itself.

But it is one thing to conceive the idea, and another thing to develop a practical system, and it may be of interest to know that up to the present time the sum of a million dollars has been invested in developing submarine signaling, so far without monetary return.

The first method which was employed for producing the sound was through the striking of a bell and the method of receipt of the signals was by means of a microphone attached to the skin of the ship. Neither the original bell nor the original microphone attachment was satisfactory.

It would be impossible in the space permitted to discuss even briefly the innumerable experiments made with different sizes of bell, with different materials for the bell, with different methods of producing the blow, the precautions taken to eliminate electrolytic action, with different types of microphone, with different methods of mounting the microphone on the side of the ship, with the experiments made to minimize water and other noises. It will be sufficient to say that finally the work of Mundy, Wood, Fay, Williams and others resulted in a completely practical system.

The submarine bell in use on the lightships is actuated by compressed air stored in a reservoir. The actuating wheel has projections mounted on it so that when the wheel revolves a number of strokes follow each other, the different intervals being peculiar to the different signal stations so that the captain of a ship by counting the strokes of the bell can determine what lightship is producing the sound.

In order to receive the sound, it has been found absolutely necessary to suspend the microphone in a tank of water, for this is the only method of cutting out the water noises and the noises due to machinery, etc., on board the ship, which otherwise drown out the sound of the bell.

One of these small water tanks, containing a microphone of a special type, is attached to each side of the bow inside of the ship. From each tank wires are run to a device which is called the indicator box, so arranged that by throwing the handle to one side, the starboard microphone is connected to the telephone, and by throwing the handle to the other side, the port microphone is connected.

It will be obvious that once the bell is picked up, the captain has only to turn his vessel until the sound is heard with equal intensity on each side, to know that his ship is then pointing in the direction from which the sound is coming, and in this way he can take compass bearings of the lightship on which the bell is situated.

The importance of this method will be at once perceived. No matter how stormy or how foggy the weather may be, it enables the captain of a ship, on making land, to obtain at once the compass bearings of the nearest lightship or lighthouse fitted with a bell.

How many vessels and how many lives this device has saved even in the few years during which it has been in use, it would be impossible to tell. Less sensational than the wireless telegraph, it may be questioned whether its actual practical utility to the merchant marine has not been greater.

Compressed air, or an electromagnetic mechanism, may swing the hammer, or the bell may be operated by the waves themselves. A type much used is a bell buoy which may be anchored off a shoal, and will give submarine warning day and night without further attention. A large vane extends from one side of the mechanism. As the buoy swings up and down in the water, the vane by means of a ratchet compresses a spring which automatically releases and operates the bell hammer.

It will be evident that, even if no further development had been made, the system would be and is a complete and practical one. Its universal adoption would greatly minimize if not entirely prevent disasters due to errors of ship position.

But with the very success of this system, it became evident to those in charge of its development that still further advances might be conceived as possible, especially in three directions.

1. Suppose the sound-producing apparatus could be so constructed as to be operated from moving ships by a telegraph key. If this were achieved, it would be possible for one ship to signal to another in fog, to communicate its position, its

direction and its speed, and eliminate all dangers of collision. It would also be possible to signal between submarines or between battleships and submarines, and to communicate between battleships in action without interference from the enemy and though all masts were shot away.

2. Suppose the range of the sound-producing apparatus could be extended so as to cover a radius of 25 or 50 miles. Then it would be within our power so to encircle the coast of every nation, with what has been felicitously termed "a wall of sound," that no vessel under whatsoever circumstances of loss of reckoning, of variable currents, of fogs, and storms could approach the coast without being warned of that fact and notified of its exact position on that coast and of the direction of the nearest lightship.

3. If the sound-producing apparatus could be constructed so as to be actuated by telephonic currents, it would be possible to transmit speech through the water.

It will be of interest to consider some of the difficulties which had to be overcome before the desired results could be obtained.

The most serious of these obstacles was the fact that water is almost incompressible.

Now since sound is a compressional wave in the medium through which it is transmitted, it is evident that any apparatus which is to transmit sound through water must be capable of exerting very great force. In the bell, this is accomplished by the hammer blow of the clapper, and any electric or other apparatus which is to be used for submarine signaling must have a force comparable with that produced by the impact of a hammer on an anvil.

A second and very grave difficulty arises from the fact that if the water is to be compressed, some material object must be set in motion to compress it, and that object, which must have sufficient mechanical strength to stand the stress, and must therefore be of considerable size, must start from rest, reach its highest velocity, and come to rest in one-thousandth part of a second, if a musical note having a pitch of five hundred per second is to be produced. The forces of acceleration thus necessitated are very large.

A third difficulty arises from the fact that in order to telegraph at a speed of twenty words per minute the time allowable for a single dot is very small. As the average word consists of five letters, and the average letter has a length equivalent

to seven dots, an apparatus capable of telegraphing at the rate of twenty words per minute must be capable of making seven hundred dots per minute, or a single dot in something less than one-tenth of a second.

If the signal is to have individual quality, so as to be readily distinguishable from other noises, and so as to be separable by resonance from other notes, each dot must consist of at least ten impulses.

Thus we arrive at the conclusion that whatever device is used, it must be capable of producing at least 100 compressional waves in a single second, in order to telegraph satisfactorily at the rate of twenty words per minute.

If this same apparatus is to transmit speech through the water, it must be still more rapid in its action and must be capable of producing several thousand compressional waves per second.

The above were the three main difficulties in the way. Of course there were many others, for example, the apparatus must not weigh too much; it must not be affected by water or change of temperature; it must be simple in construction; it must be easily applied to the ship; positive in its action; must not require adjustment after being once set up and must be able to stand all kinds of ill-treatment at the hands of unskilled operators. It will be unnecessary to go over the ground taken by the development, and we will therefore proceed at once to describe the apparatus as finally developed by Professor R. A. Fessenden.

The device used is termed an oscillator and its construction is shown in cross-section in the drawing, Fig. 1.

In the drawing, the iron of the magnetic circuit and the copper tube are shaded. The magnetizing coil is cross hatched. The moving part is the copper tube *A*. This lies in the air gap of a magnetic field formed by a ring magnet *B*, built up in two parts, as shown in longitudinal section in Fig. 2.

The ring magnet is energized by the coil *C*, and produces an intense magnetic flux which flows from one pole of the ring magnet across the air gap containing the upper part of the copper tube, thence through the central stationary armature *D*, thence across the other air gap to the lower pole face of the ring magnet and thence through the yoke of the ring magnet back to the upper pole face.

This field is very much stronger than that in the ordinary dynamo, there being more than 15,000 lines for each square centimeter of cross-section.

Around the armature is wound a fixed winding, which we will call the armature winding, and which is reversed in direction so that one half of the winding is clockwise and the other counter clockwise.

When an alternating current is passed through this armature winding, it induces another alternating current in the copper tube.

Only by this construction has it been found possible to obtain the enormous force and rapidity necessary to compress the water

FIG. 1

and to overcome the inertia of the moving parts of the mechanism.

In order to apply this force to the work of compression, the copper tube is attached to solid disks of steel, which in turn are attached to a steel diaphragm one inch thick which may be made part of the side of the ship. In practise the tube is provided with lugs, and is held between two disks drawn together on the tube by a one-inch vanadium-steel rod and a right- and left-handed screw thread.

Telegraphing is accomplished by means of an ordinary telegraph key placed in the main armature circuit.

Although an ordinary telegraph key is used, there is no

sparking at the contacts. This may surprise electrical engineers familiar with the sluggish action and vicious arcing commonly found associated with the operation of electromagnetic apparatus of this size and power, more especially in view of the fact that a very high frequency is used, five hundred per second, and that there is no laminated iron used in the construction of the apparatus.

The secret of this lies in the fact that the armature has substantially no self-induction, and no eddy currents are generated in the apparatus. This is because the copper tube forms, as will be seen, the short-circuiting secondary of a transformer, of which the armature winding is the primary.

FIG. 2

This eliminates the self-induction of the armature winding. In addition the upper and lower portions of the winding are wound in opposite directions, and therefore there is no mutual induction between the field coil circuit and the armature circuit. With this construction, the amount of magnetic leakage in the armature circuit is very small, only a trifle more than if the armature core were of wood, and as there is no alternating magnetic flux in the iron, there are no eddy currents.

As regards the capacity in kilowatts of this apparatus, it is large. The armature, being wound in grooves in the armature core, so as to withstand the mechanical forces acting upon it, is well cooled.

The copper tube has no insulation to be affected, and on account of its large cooling surface and high permissible temperature of operation, can carry very high currents without injury.

When the oscillator is placed on a vessel or hung overboard from a lightship, a large water-tight diaphragm is attached to the oscillator. This particular type of oscillator was first tested by suspending it in twelve feet of water at the Boston lightship and the signals were heard plainly with a microphone lowered overboard from a tug at Peaked Hill Bar Buoy, thirty-one miles away. Since that time tests have been made with oscillators installed in the fore peak tank of the *Devereux*, a collier of the Metropolitan Coal Company, and also with an oscillator mounted on a diaphragm made part of the hull of the vessel. The signals have been heard upwards of twenty miles from the *Devereux* running at her regular speed of eight knots. Full power has not been employed on any of the tests, and it is more than probable that much longer distances can be obtained in the future.

In addition to the tests already described the oscillator has been temporarily installed on submarine boats, and proved itself of immense value and demonstrated that a flotilla of submarines equipped with oscillators will be able to make a combined attack on an enemy, only one needing to show its periscope in order to direct the others, or all of them can be directed by the mother ship. It therefore makes possible a whole field of submarine manoeuvres heretofore out of the question; and perhaps most important, it removes the principal danger these boats have had to face, the risk of being run into.

So much for the apparatus when in use as a sound generator. The signals produced by the oscillator can of course be received by water-immersed microphones of the usual type, but one would perhaps not anticipate the possibility of using the oscillator as a receiver, in view of the fact that the diaphragm is of solid steel, and weighs, with the copper tube and its attachments, considerably over 100 pounds; but the oscillator, like the ordinary electric motor, is also capable of acting as a generator, and on account of its high efficiency as a motor, is a very efficient one.

The same oscillator is therefore used for sending and for receiving, a switch being thrown in one direction when it is desired to telegraph under water, and thrown the other way when it is desired to listen in.

In addition to telegraphing and receiving messages, the

oscillator can also be used for telephoning under water. Sentences have been transmitted at 800 yards and conversation at more than 400 yards, and this was accomplished with the use of an ordinary telephone transmitter and 6 dry cells.

It seems evident, therefore, that with more power much greater distances can be reached. Long distances are not, however necessary, as even with a distance of one mile it will be readily understood that this method of under-water telephoning will be of great use as a means of communicating between submarines while submerged, and between ships in fog, as the captains of the vessels can talk directly to each other, instead of transmitting and receiving through a telegraph operator.

Some other uses to which the oscillator may be put may be mentioned briefly.

One which will at once suggest itself is the steering of torpedoes by sound under water. The idea of so operating torpedoes is not a new one, and has occurred to a number of inventors, but until the present time no method of accomplishing it has been developed. With this new source of sound, however, the method should be practicable.

Another use is as a means for obtaining soundings. If we take a commutator wheel, with one live segment and two brushes, one connected to the alternating-current generator and the other to the telephone receiver, it will be evident that when the commutator segment makes contact with the brush connected to the generator, a sound will be produced by the oscillator. When the live contact passes away from the brush, the sound will cease. This sound wave will travel outward and on reaching the bottom will be reflected and travel back again to the ship. Meantime, no sound will be heard in the telephone receiver, but if the brush connected to the telephone receiver be shifted in the direction of rotation of the commutator until it makes contact with the live segment of the commutator, at precisely the instant at which the reflected sound wave has come back and impinged on the oscillator diaphragm then a sound will be heard. Since sound travels in water at a velocity of approximately 4000 feet per second, if the distance be 100 feet, the time taken by the sound in traveling from ship to bottom and from bottom to ship will be approximately one-twentieth of a second.

In April, 1914, some tests were made on the U. S. revenue cutter *Miami* to see whether soundings could be taken in the

manner above indicated. As the commutator had not been completed a temporary apparatus with a stop watch was used. The echo from the bottom was plainly heard not only on the oscillator, but in the wardroom and in the hold of the ship without any instruments whatever. The elapsed time corresponded to the depth shown on the chart and the proposed method was proved to be feasible.

The chief object of the tests on the *Miami* was, however, to determine whether a reflection from icebergs could be obtained, and this was proved beyond question. The apparatus used was the same as for taking soundings.

A signal was sent on the oscillator, the echo from the bottom heard, and then the echo from the iceberg came in. To make sure that the second echo was not also from the bottom, the distance from the *Miami* to the iceberg was varied from about 100 yards to $2\frac{1}{2}$ miles. The elapsed time between the signal and the echo from bottom remained the same, but the elapsed time of echo from the iceberg varied with the distance and corresponded very closely to the position of the iceberg determined by the range finder. Moreover it was found that it made no difference whether the face of the iceberg was normal to the path of the sound or not, thus showing that the echo was due not to specular reflection but to diffraction fringes.

When the *Miami* had gone $2\frac{1}{2}$ miles from the iceberg a heavy storm made it necessary to postpone further tests, and continued rough weather made further tests impossible, as the oscillator was not permanently installed but had to be lowered overboard. The echoes at $2\frac{1}{2}$ miles were, however, loud, and there can be no doubt that they would have been heard at greater distances. (See appendix).

To sum up: The oscillator represents an important step forward in the science of navigation. It makes it possible to surround the coasts with a wall of sound so that no ship can get into dangerous waters without warning, to make collisions between ships possible only through negligence. Although no sufficient tests have been made to warrant the statement that icebergs can be detected under all circumstances or that soundings can be taken at full speed, what evidence there is points that way. For naval purposes it provides an auxiliary means of short distance signaling that is available at all times and that cannot be shot away, and it widens the possibilities of submarine boats to an extent we cannot yet fully grasp.

REPORT OF CAPTAIN J. H. QUINAN OF THE U. S. R. C. *Miami*
ON THE ECHO FRINGE METHOD OF DETECTING ICEBERGS
AND TAKING CONTINUOUS SOUNDINGS.*

We stopped near the largest berg and by range finder and sextant computed it to be 450 feet long and 130 feet high. Although we had gotten within 150 yards of the perpendicular face of this berg and obtained no echo from the steam whistle, Professor Fessenden and Mr. Blake, representatives of the Submarine Signal Company, obtained satisfactory results with the submarine electric oscillator placed 10 feet below surface, getting distinct echoes from the berg at various distances, from one-half mile to two and one-half miles. These echoes were not only heard through the receivers of the oscillator in the wireless room, but were plainly heard by the officers in the wardroom and engine room storeroom below the water line. Sound is said to travel at the rate of 4400 feet per second under water. The distance of the ship, as shown by the echoes with stop watch, corresponded with the distance of the ship as determined by range finder. On account of the great velocity of sound through water, it was our intention to try the oscillator at a greater distance for even better results, but a thick snowstorm drove us into shelter on the Banks again.

* * * *

On the morning of April 27, anchored in 31 fathoms of water with 75 fathoms of chain in order to make current observations. . . . Professor Fessenden also took advantage of the smooth sea to further experiment with his oscillator in determining by echo the depth of water; the result giving 36 fathoms, which seemed to me very close.

*From the *Hydrographic Office Bulletin* of May 13, 1914.