Paul Langevin and the Discovery of Active Sonar or Asdic

introduced by David Zimmerman

Pendant la première guerre mondiale, le «National Academy of Sciences» des États-Unis a créé le « Research Information Service» dans le but de recueillir des informations militaires européennes pour les forces armées américaines dans les domaines techniques et scientifiques. Le professeur David Zimmerman a trouvé le document suivant dans les dossiers du «Research Information Service» conservés dans les archives nationales au College Park, Maryland. Ils 'agit du rapport de 1918 par Paul Langevin concernant ses recherches importantes et innovatrices sur ce qu'on considère aujourd'hui comme étant le sonar actif Le document original de Langevin rédigé en français fut traduit en anglais par les «Forces navales des États-Unis» au moment où il avait été reçu.

During the First World War U-boats came close to winning the war. Unlike the later Battle of the Atlantic, technological innovation was not a key ingredient in the Allies victory over the U-boat campaign against shipping. Instead, the German submarines were defeated by the widespread application of convoys to shepherd ships through waters patrolled by submarines, radio intelligence which directed convoys away from submarines, and the implementation of huge ship building programs. Despite a large scientific and engineering research effo rt, submerged submarines remained a particularly elusive prey through to the end of the war. Yet, there was a significant legacy left by the First World War research, which would prove to be the foundation for anti-submarine warfare (ASW) in the Second World War.'

Prior to 1914, little thought had been given to the use of sound waves either for military or scientific purposes. Scientific research on the properties of underwater acoustics had been mainly confined to studies of the speed of sound in water. Most of the early research in ocean acoustics was undertaken by empirical inventors so common in the era of Bell and Edison. Their work focused on the commercial development of underwater signaling devices.

Dwight R. Messimer, Find and Destroy, (Annapolis: Naval Institute Press, 2001).

The Northern Mariner/Le marin du nord, **XII, No. 1, (January 2002), 39-52.**

The best known research was carried out by The Submarine Signal Company, which was founded by three inventors in 1901. The company developed a system of underwater bells placed at lighthouses and lightships which could be heard by ships equipped with underwater microphones or hydrophones over 15 kilometers away. According to Hackmann, "by 1912 this system was well established; bells had been installed along the coasts of major importance, and many trans-Atlantic ships were equipped with the receiving apparatus.'2

There had also been some efforts made to utilize subsurface sound waves in collision avoidance systems, work that was given extra impetus by the sinking of the *Titanic.* The day after the *Titanic* went down, M.L. Fry Richardson took out a British patent on one such device. Richardson's sound detector was quite sophisticated since it provided a means to accurately determine the direction of an object. Unfortunately, he relied on bells and whistles which produced a sound with too long a wavelength to produce sufficient reflection from a submerged object.' In April 1914, Canadian electrical engineer Professor R.A. Fessenden tested a device used in the transmission of underwater morse code messages as an echo sounder. The sound was generated by `a reciprocating induction motor' moving 540 times per second attached to a large steel diaphragm. It could detect an iceberg up to two miles away, but because it produced continuous oscillations rather then intermittent pulses of sound it tended to create its own interference.4

Most of the wartime research in underwater detection of submarines focussed on finding either a mechanical means, such as using underwater nets or grappling devices, or in perfecting passive listening devices, hydrophones.. A large number of hydrophones types were developed in Great Britain, the United States, and France. These included simple devices involving one or two microphones, to multiple arrays involving dozens of listening devices. Some of the devices were towed or mounted on towers fixed to the seabed in order to minimize interference. The best indicator of the overall performance of these devices is their comparative lack of operational success. Almost 10,000 hydrophones were delivered to the Royal Navy during the war. By October 1917, there were some 1,201 small RN ASW vessels equipped with the devices, a number that would grew dramatically in the last year of the war. Added to this must be the large number of American and French warships assigned to ASW duties. Given the considerable numbers involved, surprisingly few U-Boats were sunk by attacks initiated or completed through passive acoustical listening. Only 3 or 4 German submarines were sunk in actions in which ship-borne hydrophone detection played a role. One, or possibly two, other U-boats were sunk by mines after being detected by a fixed mounted harbour defence hydrophones. This compares unfavourably to the number of U-boats sunk

Hackmann, 6.

Interallied Conference on Submarine Detection by Means of Supersonics: An Account of the Research Work Carried out in France, October 1918, National Archives RG 189 Records of the National Academy of Sciences Research Information Office, Entry 2, Paris Office Box 11/161.

Hackmann, 6.

by another new military technology, aircraft, which sent at least nine submarines to the bottom. The passive listening systems suffered from a lack of tactical flexibility, particularly since most devices required ships and all nearby vessels to shut off their engines and drift while listening. While good directional sense was developed, distance could generally only be estimated by triangulation using more then one ASW vessel or by a rough measure of sound intensity. Allied navies were also convinced that German tactics, which include sitting on the bottom or moving off on the surface at high speed, also greatly reduced the number of successful hunts. "The contribution of hydrophones" to the anti-submarine campaign, concluded Hezlett, "cannot be classified as higher than a useful bonus."[5]

The comparative lack of success of hydrophones fuelled interest in developing other methods for detecting submarines. Right from the start of the war, some inventors proposed the development of active acoustical systems based on submarine signalling or navigation devices. In active sonar, a pulse of high frequency sound is transmitted through the water. This sound wave is reflected from a submerged target back to the transmitting vessel. It was well understood from prewar work on collision avoidance systems that the use of a narrow sound beam on a trainable transmitter would give the direction. The length of time necessary for the reflection to return to the transmitting ship would provides an indication of range. The main technical difficulty was in developing a way to produce a powerful acoustical signal of the right wavelength.

Serious research on underwater supersonics began in February 1915, when M. Constantin Chilowsky, a Russian inventor, submitted to the French government a plan to detect submarines by transmitting through the water "elastic high frequency waves by transforming the electric oscillations of high frequency, commonly used in wireless telegraphy." Chilowsky proposed to do this by using the medium of magnetic attraction produced by an electric current "acting synchronously on all points of the internal face of a plate of soft iron, finely laminated."[6]

Chilowsky's proposal was forwarded by the French government to Professor Paul Langevin, an early supporter of the theory of relativity and an expert on paramagnetism, diamagnetism, secondary x-rays, and the behaviour of ions.' Langevin concluded that Chilowsky's basic idea had merit, but that his means to produce a suitable sound wave was unlikely to succeed. Langevin decided to begin research into developing a practical means to create an intense pulse of high frequency sound. He asked Chilowsky to join him and a small team of scientists working at his laboratory at the School of Physics and Chemistry in Paris. By April 1916 results were so promising that the French Navy transferred their work to

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[5] Arthur Hezlett, The Electron and Sea Power (London: Peter Davies, 1975) 151-2; Hackmann, 48, 64-71.

Interallied Conference on Submarine Detection by Means of Supersonics: An Account of Research Work Carried out In France, 31 October 1918, NA RG 189 Records of the National Academy of Sciences, Research Information Office, Entry 2, Paris Office Box 11/161.

Hackmann, 78.

Toulon so that experiments could be undertaken at sea. In January 1917, a clear echo was detected for the first time using a cumbersome apparatus that relied on the electrical excitation of mica for transmissions and microphones for reception.

Langevin realized that this method offered neither the range nor the reliability required for a submarine detector. hi February 1917, after numerous experiments with various apparatus and mediums, he turned to utilizing the piezo-electric properties of quartz to act as a receiver. The quartz would transform sound waves into electrical oscillations which could be amplified and played into a headphone. After developing the receiver, Langevin realized that the dual nature of the piezo-electric effect would allow quartz to be used as a transmitter as well, since when the crystal was fed an electrical oscillation, supersonic elastic sound waves would be produced. The French scientists developed a transmitter/receiver which consisted of a sheet of quartz about four millimetres thick, composed of pieces in a mosaic, placed parallel to each other and perpendicular to an electric arc. The quartz mosaic was sandwiched between two pieces of steel of equal thickness, initially of three centimetres for a frequency of 40,000 cycles per second, and was sealed to form an airtight box. One of the steel plates was put in contact with sea water and the other plate acted as an electrical condenser. When an alternating current was fed onto the condenser, supersonic waves were emitted into the water by the exterior plate. During one of the first tests of the device "very clear echoes were obtained for the first time from a submarine."8

A prototype of a service model of the active sonar was tested off Toulon between 5 June and 8 July 1918. The results showed that Langevin's invention was by far the most effective device developed during the war for the hunting of submarines. Initial detection of a submerged target was effected at between 600 and 1300 metres. This range was unaffected by the speed of the submarine, although at depths of less than 35 metres, it was difficult to locate the target. The ASW vessel was underway at five knots, its maximum speed, throughout the test, a major improvements over most hydrophone designs. The directional accuracy of the device and its ability to provide an exact indication of range made it superior to the very best hydrophones.

Work on active sonar was also undertaken in Great Britain and the United States, after the French briefed both countries during a Washington ASW research conference held in June 1917. The British effort was head by University of Alberta Professor R.W. Boyle. The American program was more diverse, but started with Michael Pupin's laboratory at Columbia. Results achieved in both these countries were similar to that obtained by the French. In October 1918, an inter-allied conference on supersonic submarine detection was held in Paris, where information on all three national research programs was exchanged. The

Interallied Conference on Submarine Detection by Means of Supersonics: An Account of Research Work Carried out In France, 31 October 1918.

[9] Report on the Langevin-Colin Board, Toulon, on Tests of Apparatus, 5 June and 8 July 1918, NA RG 189 Records of the National Academy of Sciences, Research Information Office, Entry 4, London Office Box 8/247.

conference goers concluded that given the limitations of passive submarine detectors, scientists should concentrate on active sonar devices.

When the war ended just a few days later, however, it was uncertain if any of the wartime work on underwater acoustics would be utilized in oceanographic research. Most of the scientists involved quickly returned to their peacetime industrial or academic positions and gave little more thought to the ocean environment. A few scientists remained in the field, but they were employed in naval research facilities such as the American Naval Research Laboratories. Their work continued to be focussed on submarine detection and increasingly was shielded from the outside by security restrictions.

The document that follows is Langevin own account of his research into active sonar. It was prepared for the October 1918 Interallied Conference on Submarine Detection, which almost exclusively dealt with the use of the reflection of active supersonic sound waves to detect submarines. The document is highly technical, but well conveys the sense of the urgency of this wartime emergency research program. The document was translated into English in 1918 by the Research Information Se rvice of the American National Academy of Sciences. This organization was established by the academy to gather European military technical and scientific information for the American armed forces. The RIS offices were located in Rome, London and Paris. The records of the RIS are located at the United States' National Archive at College Park Ma ryland.

NAVY DEPARTMENT

Office of the Under Secretary of State for the Navy

INTERALLIED CONFERENCE ON SUBMARINE DETECTION BY MEANS OF SUPERSONICS.

I. AN ACCOUNT OF THE RESEARCH WORK CARRIED ON IN FRANCE

The idea of utilizing elastic waves of high frequency in the water, for the detection of obstacles to navigation, by means of the echo, was made known for the first time the day after the "Titanic" disaster, by an English patent, taken out in England in 1912 by M. L. F ry Richardson. Here the advantage given by the short wave length is clearly shown, facilitating a directional emission — thanks to the phenomenon of diffraction — and permitting the accurate determination of direction of the obstacle. Unfortunately, the means indicated for the production of these waves were mechanical only, by bells or whistles, and gave no results, though given through trials.

At the beginning of the war, in February, 1915, when the question of the detection of submarines and mines began to become acute there was submitted to the French

Government by M. Constantin Chilowsky, through M. Painleve, an analogous idea; but indicating the possibility of producing the desired elastic high frequency waves by transforming the electric oscillations of high frequency, commonly used in wireless telegraphy. To effect this result, M. Chilowsky proposed to utilize the medium of magnetic a ttraction produced by the current, acting synchronously on all points of the internal face of a plate of soft iron, finely laminated, in contact with the water at its external face, and of a proper size in relation to the wave-length of the elastic vibrations in the water, so as to produce an emission almost entirely confined to a central cone of diffraction, in accordance with the phenomena of the distant diffraction of plane waves through an opening of the same shape as the plate employed. No method of receiving, however, was indicated.

When this proposition came before me, I was struck by the insurmountable difficulties involved in the magnetic field, and thought that the chances of success, although still small, would be increased by having recourse, in effecting the tr ansformation - to the electrostatic attraction between the armatures of a plain condenser, periodically charged by the high-frequency current. The internal armature of this condenser being insulated, and the other armature in contact with the water by its exterior face, the periodic attraction between them is transmitted to the water, giving rise to the emission of elastic waves of a frequency double the electric frequency and with the maximum of radiation, obtained either by making the external armature sufficiently thin, or by giving it a thickness equal to half the wave length of the longitudinal elastic vibrations in the metal used.

Since the power radiated in the form of elastic waves in water va ries as the fourth power of the amplitude of the electric field between the armatures of the condenser, it was necessary to have an electric field as intense as possible, in order to obtain any considerable power; the more so since the power available at the receiver for detaching the echo diminishes very rapidly as the dist ance increased, varying, (other things being equal), inversely as the fourth power of the latter.

The intensities ordinarily available in gases giving a disruptive discharge being absolutely insufficient, it was necessary to assume as conditions, a very sho rt distance between armatures, and a high vacuum, where experience had shown the possibility of obtaining electric fields of the order of a million volts per centimeter, corresponding to an attraction between armatures of the order of a kilogram per square centimeter, and *an* emission of supersonic power of the order of a third of a watt per square centimeter. It would thus appear possible within easy dimensional limits of the apparatus, to produce a power of the order of 100 watts, capable of giving a sufficient echo, with the aid of converging mirrors for receiving. The receiving would seem to be possible by means of proper microscopic microphones placed in an electric circuit, oscillation in resonance with the elastic frequency; then such methods of amplification and detection could be utilized as are usual in wireless telegraphy.

Under these circumstances, and making all allowances as to results to be expected and time necessary to obtain them, I proposed, in March 1915, to the Navy Department that this research work be undertaken, and that it be initiated in my laboratory at the School of Physics and Chemistry. In view, however, of the fact that we would obliged to work in the neighborhood of the disruptive limit of the elastic fields in order to produce sufficient elastic power it seemed to me that the use of continuous electric oscillations would be comparable to that of a train of damped waves obtained by spark. Knowing the Navy Department was not at the moment using the first arc installations developed by M. Colin and Jeance for their experiments in wireless telegraphy, I asked that these installations be placed at disposal for obtaining the desired continuous electric oscillations. This being offered me, and Captain Colin himself taking charge of the proper operation of the apparatus, I hastened to accept this valuable aid, which has not since failed me, from the beginning of my research work. When the development of the work justified it, the military authorities consented to place at my disposition as collaborators, the services of a M. Marcel Tournier, Director of Practical Work at the School of Physics and Chemistry, and of M. Fernand Holweck of the Sorbonne; the former since September, 1915, the latter since July 1917.

Great difficulties were encountered in the development of the first type of apparatus, which was undertaken in the form of a condenser supporting a high vacuum between two flat metallic armatures, distant 20 microns at all points of their surfaces, one being in contact with the water at its external face. The problem being solved from a mechanical standpoint, I found that at distances of this order, below which it was impossible to go for constructional reasons, the disruptive field was much lower than the valves given by Earhart and other experimenters for less distances, of the order of a few microns. The study of the disruptive phenomena between metallic surfaces very close together in a vacuum showed me that by reason of the action of the reciprocal bombardment of the electrodes, the disruptive field, instead of being constant, as indicated apparently by early experiments, diminished rapidly as the distance increased.

In order to avoid this bombardment, and to reduce the limit of the possible field without, however, interfering with the, liberty movement necessary to the electric vibrations, (whose amplitude would be about one-tenth micron) I was led to interpose a thin sheet of mica between the electrodes, as a screen. This at the same times disposed of most of the difficulties of a mechanical nature since it supported the external armature at various points, without interfering with its vibration outside of these points of support under the action of the alternating electric field. There was no further need of making the external rigid, since it was sustained by the mica, and it could therefore be made quite thin. Finally, the fact that the sea-water could be used as a conductor permitted doing away with the external metallic armature altogether. The sheet of thin mica, in contact with the water by its external face, transmitted through this medium the intense electrostatic attraction to which it was subjected everywhere except at points of support of the inner electrode, (consisting of an insulated flat metallic disc).

A Crooke' s vacuum was maintained in the very small space outside of these points of support between the surface of this disc and the internal face of the sheet of mica pressed against it.

The emission ion of a considerable supersonic elastic power was noted for the first time by the aid of the pressure of radiation exercised on a flat pallette of proper thickness, carried on a torsion pendulum. The elimination of the outside armature permits notable increase in the observed deviations, at the same time assuring much greater certainty of operation by diminishing the frequency of disruptive accidents through the mica at the moment of points of torsion unavoidable in the functioning of the arcs in spite of the interposition of a secondary oscillating circuit.

For efficient difference of potential of between 250Q and 3000 volts of high frequency, (about 100,000 periods per second corresponding to 15 millimetres of elastic wave length in the water), the elastic power emitted, measured by a torsion pendulum, proved to be quite as anticipated some tenths of a watt per square centimeter. Experiments on the reflect on and transmission of elastic waves through various filters had confirmed the theory that the effects observed were entirely due to the phenomenon sought; (July 1915).

A receiving device *was* then studied, for the purpose of the inverse tr ansformation of the supersonic elastic waves into electric oscillations of the same frequency, in a proper circuit. I thought at first a mica condenser, polarized by a const ant electric field would solve the problem very simply. The theory tended to show that an optimum valve of this elastic field would permit the complete absorption) of the incident elastic waves, and the total transformation of their energy into elastic oscillations. Great difficulties, not yet completely understood, prevented the employment of this method, and we have recourse to the microphonic device, the use of which, however, is always very delicate.

Laboratory tests having shown that under certain conditions the microphone could be used, thanks to the lamp amplifiers which had just been studied by the military telegraphic service, and experiment in signaling was attempted across the Seine, just below the Pont National.. The sending apparatus comprising the installations for generating electric oscillation maintained between arcs, the mica condenser, and the Gaede pump for producing the vacuum, was installed on the pinnace "Caducee", moored on the left bank of the Seine at the Popp factory, the manager of which very kindly did everything in his power to facilitate our work.

The receiving microphone was submerged on the opposite bank, and the other apparatus, circuits and amplifiers installed in the police box nearby.

Some very clear signals were obtained, and the Navy Department asked that the work be transferred to the sea. The Department, acting with M. Painlevé, then Minister of Public Instruction and of Invention having to do with National Defense, was kind enough to send the Langevin-Colin mission to Toulon, to continue the research work there. At the same time, I applied with M. Chilowsky for a patent on the principle of the method, and on the apparatus actually constructed.

Work under the new conditions was commenced in April,1916, Two vessels were placed at our disposal, and fitted up, one for sending, the other for receiving. This period of adapting the work to special sea conditions, often delayed by inclement weather, was one of great difficulty; it was successfully passed, thanks largely to the devotion and great skill in experimentation of M. Tournier, Various beneficial modifications were introduced at this time; in particular the use of an auxiliary electric field, (constant or slowly variable), which was at first thought of only for receiving with the mica apparatus, was introduced for sending as well. This produced a larger emission of elastic power, (of the order of a watt per cm), with a lower high frequency tension, and consequently greater certainty of operation. At the same time, it permitted the emission of the greater part of the elastic energy, under the same frequency as the electric oscillations used.

Thanks to the use, for receiving, of a concave mirror in the focus of which the microphone was placed, we were able to obtain favorable conditions for receiving signals at 2 kilometres from the sending apparatus. At the same time the introduction of a proper commutator, susceptible of being placed alternately for sending and receiving enabled us to obtain for the first time a very clear echo, from an obstacle consisting of a sheet of armor plate, placed perpendicular to the beam at about 200 metres from the source, and from the miorophone receiver carried side by aide on the same vessel.

Had not numerous other characteristics, such as the existence of a clearly defined beam at emission, and the amplification produced by the converging mirror at the receiver already disposed of all doubt as the realisation of the transmission of elastic waves in water, this observation of the deferred echo would have been sufficient to show that we were making good progress along the lines indicated. (April 1916 - January 1917).

UTILIZATION OF QUARTZ

In spite of these encouraging results, it was still very difficult to use the apparatus. Beside the disruptive accidents already mentioned in the mica condensers, which I was trying at that time to avoid by substituting heterodyne lamps for the arcs used in the sending apparatus, – the microphone gave very irregular results, and required delicate regulations in order to keep the sensibility of the carbon contacts approximately constant against the variations in outside pressure due to the movement of the sea.

In order to avoid these difficulties, I thought (February 1917) of utilizing the piezo-electric properties of quartz, first of all for receiving. The great pressure amplitude, corresponding in the water to power given off in the form of elastic waves, permitted the hope that in spite of the feebleness of the piezo-electric phenomena, we should be able to take advantage of the remarkable properties of quartz, under perfect conditions, from the standpoint of strength and reliability. Instead of the disposition of it made by Pierre Curie in apparatus for electrostatic measurements using this same property, I thought it preferable to make use of the compression of the quartz in the same direction as its electric axis, instead of by traction in a direction perpendicular to the electrical and optical axes.

The first receiving apparatus tried was also composed of a thin sheet quartz,. (or several parallel plates in juxtaposition), placed perpendicularly to an electrical, axis, and in contact with the water on one side, (either directly, or by the medium of a thin protective sheet attached, mica for example); and on the other side with an insulated metallic plate forming the internal armature of a condenser in which the quarts forms the dielectric, and the salt-water the external armature, This condenser forming part of an attuned oscillating circuit, the periodic electric polarization produced in the quartz by the arrival of the incident waves plays the part of an alternative electromotive force for the oscillation circuit, and permits the transformation of at least part of the incident elastic energy into electric energy easily observable by the ordinary methods of wireless telegraphy.

The result was excellent from the first, and relieved us of all the annoyance caused by the microphone up to that time. We could also dispense with the use or a mirror to concentrate the waves, although the surface of the receiving sheet of quartz was only about a decimeter square. So that a few months later, November, 1917, the installation of the "Vigoureaux", begun at the end of the preceding year, enabled us to make trials of signaling at considerable distances; and this quartz receiver, with the mica senders, gave very good results up to six kilometres.

This success in the use of quartz as a receiver led me to try (April, 1917) [to see] if it would not be possible to utilize it as well for sending supersonic waves, thanks to the inverse phenomenon of piezo-electricity, – that of the deformation of the quartz under the action of an electric field following the direction of a binary axis of the crystal. This experiment was equally successful, the same quartz serving for the transformation of elastic waves into electric oscillations and vice-versa.

It was readily seen that the most favorable conditions for this transformation would be realized ten the quarts sheet employed, (or rather, the ensemble of this sheet with the metallic armatures attached to it), had in the direction of thickness, a fundamental period of elastic half-wave vibration, equal to the period of the electric oscillations to be transformed. Several different dispositions were tried, giving quite the expected results.

A quartz crystal of exceptional size and purity gave me some sheets in one piece of about a square decimeter of surface, and of fifteen millimetres thickness. Placed in resonance in its fundamental elastic vibration, one of these sheets permitted the sending of elastic power of the order of ten watts per square centimeter, that is about a kilowatt for its entire surface. The effects obtained, (although difficult to utilize for our purpose because of the high value of the necessary differences of potential between the armatures of the quartz condenser), were particularly powerful; fish placed in the beam in the neighborhood. of the source were killed immediately, and certain observers experienced a painful sensation on plunging the hand in this region.

The development of an apparatus for ordinary use involved the use of lower tensions, and consequently of sheets of quartz thin enough so that the intensity of the electric field would still be sufficient . In order to utilize at the same time the optimum furnished by the elastic resonance, and in order to place the quartz in that part of the vibrating plate where it would be most efficient I was led to the construction of the type of apparatus we use at present, a sheet of quartz of about four millimetres thickness composed of pieces in mosaic, placed parallel to each other and perpendicular to an electric arc, is placed between the two pieces of steel [of] equal thickness (three centimeters for a frequency of 40,000), so that it will be in node where the pressure amplitude is at a maximum.

Adhesion between the quartz and the steel plates is obtained by the use of a layer or insulating cement as thin as possible; a mixture off wax and rosin in proper proportion. One of the steel plates, (the one in contact with the water at its outer face), forms one face of a tight box, inside of which are placed the other plate constituting the insulated armature of the condenser, the opposite face consisting of the quartz, in contact with the air inside the box. In this way the two steel plates with the quartz plate between form a rigid block which is put in vibration in the direction of its thickness, when the condenser is fed with an alternating difference of potential. Supersonic waves are emitted in the water only by the exterior face, in contact with it.

Trials have shown, (in complete quantitative accord with the theory), that a very marked maximum of the power given off for a given amplitude of the difference of potential, is obtained at the moment of elastic resonance. Under the same conditions, the apparatus presents a very clear maximum of sensitiveness.

The first trials of apparatus of this sort were made in February 1918, and gave a a signaling distance or eight kilometres, while at the same time, very clear echoes were obtained for the first time from a submarine.

In the meantime the progress made in the construction of an installation for the production off electric oscillations maintained by heterodyne lamps, permitted us to complete what was our first actual apparatus where the same condenser was used for sending and receiving.

INTERALLIED CONFERENCE ON SUBMARINE DETECTION BY MEANS OF SUPERSONICS

II. DESCRIPTION OF THE PRESENT APPARATUS.

The apparatus at present in use have been studied in all their details in a way to permit rapid quantity production. They will be described before the conference. They consist of:

A. The Oscillator Quartz

It has already been indicated that this essential organ, remarkably robust is composed of a layer of quartz in the form of a square mosaic 4 millimetres thick and 20 centimetres on a side, cemented by hot rosin (and beeswax) between two square plates of steel each three centimetres thick and whose faces in contact with the quartz have been carefully dressed, as much as possible by grinding.

The speed of propagation of longitudinal elastic waves in qua rtz and in steel being in the neighborhood of 5000 meters per second, the natural frequency of the quartz-steel block vibrating as a half wave in the direction of its thickness is about 40,000 (length of electromagnetic wave 7500 meters) and corresponds to a wave length in water of about 4 centimeters.

The side of the square source, excited synchronously in all its surface, being about five times the length of a wave in water, the phenomenon of diffraction to which the emission gives rise in both horizontal and the vertical sense when the square plate is suspended with two parallel sides vertical to points of minimum intensity in the directions at about 12° from the normal to the surface of emission, with a very marked p rincipal maximum in the direction of this normal and secondary maxima beyond the minima. The greater pa rt of the emitted energy is therefore located in the central beam whose angular spread horizontally and vertically is about 250.

The sensibility for reception va ries with the angle of incidence of the wares according to laws reciprocal with those which govern emission. The maximum intensity observed when the receiver is turned exactly toward the source is particularly marked, so that the apparatus gives the direction with very great precision. Furthermore it is sensitive only on one side, that on which the quartz steel plate is in contact with the water, and only responds to waves from the back of very great intensity. Errors of 180° are therefore not to be feared.

It is very important, from the viewpoint of output of energy and sensitivity of reception, that the inside face of the quartz-steel block be in direct contact with air, without the interposition of any other substance.

The ordinary conditions of use for emission correspond to a difference of potential of 3000 to 5000 volts of high frequency between the two steel plates and to an emission of elastic power of 50 to 100 watts per second.

B. Apparatus for Producing Electrical Oscillations

The apparatus which produces the high frequency electrical oscillations uses two large heterodyne lamps of the type studies by Mr. Bauvais for the firm Grammont of Lyon. These lamps are few ordinarily by a musical alternating current of 500 cycles which offers the advantage of permitting the observer to hear in his telephone the corresponding note during emission and enables him to determine the time intervals between emission and reception more accurately than if the lamps were fed by an alternating current of low frequency.

The two lamps function alternately, each during a half cycle, each of the plates being connected to one of the extremities of the secondary of a musical frequency tr ansformer whose middle is connected to the common pount (earth). The effective voltage feeding each plate is about 4000 volts. The high frequency is produced by induction on a secondary circuit comprising the quartz condenser to which is connected in paralled a va riable condenser for the regulation of the elastic resonance.

This adjustment may be made either by seeking the position of the variable condenser for which an echo from the musical note of the feeding current is perceived with maximum intensity, or by being guided by the indications of a thermic ammeter placed in the secondary oscillating circuit. The intensity of the high frequency current received by this instrument passed thin a minimum at the moment of elastic resonance, because of the important sub—traction of power which the supersonic emission produces at this moment in the electric circuit, or, in other words, because of the increase in the resistance of the emitting quartz condenser at this moment, like a submarine antenna.

C. <u>Common Circuits of Emission and Reception</u>

The same circuits serve for reception, consisting of the quartz functioning now as a primary in which the electrical oscillations are set up by the alternate electric polarization of the quartz under the action of the incident supersonic waves, and the other circuit functions like a secondary to the terminals of which is placed the amplifier.

Theory has shown me, and experience has confirmed it, that when elastic resonance is obtained an optimum coupling between the two circuits exists for which the energy of the incident elastic waves may be completely absorbed by the quartz receiver, without any reflection, and transformed in toto into electrical energy available for the receiving circuits. We have exerted ourselves to obtain there (sic) optimum conditions.

It is thus possible to obtain on the first grid of the amplifier an amplitude of potential greater than if an oscillating circuit alone were employed. In this latter case, in fact, the amplitude of the difference of potential between the armatures of the quartz is, at most, equal to that which would permit the quartz to radiate, if functioning as an emitter, a power equal to that which is brought to it by the incident waves. On the other hand, it is possible to obtain more at the terminals of a secondary circuit suitably constructed and coupled.

D. <u>Amplifier</u>

The amplifier which we use at present is of the R 6 eight lamp type of the Telegraphie Militaire. It is usually necessary to retouch the amplifier a little by modifying the circuit of its fourth lamp in order to avoid the disturbance from the oscillations set up in its interior. Its first lamp is especially arranged. in order that its grid may support, during emission, the high tension (about 1500 volts) which is produced between the terminals of the circuit for emission and secondary for reception) to which it is permanently connected.

We have stated that it is impossible to obtain this result and t thus avoid all complication of commutation to pass from the sending of a train of waves to the reception of its echo.

The sending is done by closing the primary circuit of the transformer of the feeding current of musical frequency. During this time the high tension impressed on the first grid of the amplifier prevents all functioning of the high frequency states and only those of low frequency are directly influenced by the magnetic field of musical frequency. The telephone gives the corresponding note.

Then sending is stopped by opening the primary circuit of the feeding transformer, the quartz is ready to receive the echo and this is perceived by the note of the *beats* which are furnished by a heterodyne specially arranged for this purpose. This may be regulated so that the note of the beats from the echo is clearly distinguished from the musical note set up during emission. The interval of time between the departure and the return of the waves may be remarkably well perceived.