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From: Chief, Naval Technical Mission to Japan.
To : Chief of Naval Operations.

Subject: Target Report - Japanese Electronic Harbor Protection Equipment.

Reference: (a)"Intelligence Targets Japan" (DNI) of 4 Sept. 1945.

1. Subject report, covering Target E-26 of Fascicle E-1 of reference (a), is submitted herewith.

2. The investigation of the target and the target report were accomplished by Lieut. C. E. Harper, USNR, assisted by Lt.(jg) E. Snow, USNR, as interpreter and translator.

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31759

JAPANESE ELECTRONIC HARBOR PROTECTION EQUIPMENT

"INTELLIGENCE TARGETS JAPAN" (DNI) OF 4 SEPT. 1945
FASCICLE E-1, TARGET E-26

FEBRUARY 1946

U.S. NAVAL TECHNICAL MISSION TO JAPAN

SUMMARY

ELECTRONICS TARGETS

JAPANESE ELECTRONIC HARBOR PROTECTION EQUIPMENT

The Type 93 contact (horn type) mine was considered the most effective and reliable unit of harbor protection equipment. Type 97 hydrophone, Type 2 magnetic loop detector, Type 92 controlled mine and anti-submarine nets were used extensively, but only as secondary measures.

Some harbor craft (small sub-chasers and patrol boats) were usually equipped with Type 3 Mark 1 Model 3 air-search radar, Simple Type and Type 3 echo ranging equipment, Simple Type hydrophone, and depth charges. Airphones, installed ashore near the harbor, were used in an emergency.

Normally, 14cm, 12cm, and 8cm seacoast guns, and various caliber machine guns were used.

The average harbor defense system was very inefficient because of the excessive amount of maintenance required, and undertrained personnel. The only reason the Type 93 mine became the mainstay in harbor defense was that it was such a simple mechanism and once in place, very little could go wrong with it, while all the more complicated electronic equipment was continually breaking down.

No training films were used in the training of harbor defense personnel.

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REFERENCES

Location of Targets:

Warehouses and caves in the HIZUKUSHI areas of the SASEBO Navy Yard.
Defense Squadron Headquarters, SAEKI, KYUSHU.
Navy Technical Department, TOKYO.
Second Naval Technical Institute, MEGURO, TOKYO.

Japanese Personnel who Assisted in Gathering Documents:

T. NAYASHIDA, Capt., C.O. of Acoustic Section, Navy Technical Dept.

Japanese Personnel Interviewed:

K. KATO, Lt. Comdr., C.O. of Sonar Section, SASEBO Navy Yard.
U. TAKITA, Lt. Comdr., C.O. of First Co., SAEKI Coastal Defense Unit.
T. KUROKI, Capt., C.O. of Anti-Submarine Warfare Section, Navy Technical Department, TOKYO.
K. TSUCHIYA, Comdr., C.O. of Sonar and Magnetic Loop Supply Section, Navy Technical Department, TOKYO.
T. KUYAMA, Capt., C.O. of Acoustic Section, Second Naval Technical Institute, MEGURO, TOKYO.
T. WATANABE, PhD, Professor of Electrical Engineering, TOHOKU Imperial University, SENDAI.

Pertinent, Intelligence Target Reports:

NavTechJap Report, "Japanese Magnetic Airborne Detector", Index No. E-14.
NavTechJap Report, "Japanese Submarine and Shipborne Radars", Index No. E-01.
NavTechJap Report, "Japanese Land-Based Radar", Index No. E-03.
NavTechJap Report, "Japanese Mines", Index No. O-04.
NavTechJap Report, "Japanese Sonar and Asdic", Index No. E-10.

War Department Publication:

Handbook on Japanese Military Forces, TM-E 30-480 C5.

INTRODUCTION

Harbors are the doors of a nation through which the commerce of peace, and the men and material of war must pass. Primary requisites for export and import, and defense against sea power, are free access to the sea and easily defended harbors.

JAPAN'S Inland Sea may be likened to a gigantic harbor with its main entrance through the channel formed by KYUSHU and SHIKOKU, since the only other entrance, between HONSHU and SHIKOKU, is mostly blocked by the island of AWAJI. This channel, therefore, represented the major harbor defense problem in Japan. With this in mind, various Guard Stations (BOBI-SHO) on both sides of the channel were inspected and Japanese personnel were interrogated, especially at Defense Squadron Headquarters (BOBI SENTAI SHIREIBU) at SAEKI, KYUSHU, which controlled all channel entrance defenses. At SASEBO representative equipment was collected for shipment to the United States.

THE REPORT

Part I

ADMINISTRATION

A. General

Standard practice in harbor defense was first to lay a network of Type 93 contact mines at the mouth of the harbor, with appropriate provisions for safety channels. Next, a Type 2 Model 1 or 4 magnetic loop detector was laid parallel to and inside the mine field. This was followed by a number of the Type 97 hydrophones. The last line of defense was the Type 92 controlled mine, any one or all of which could be detonated to destroy any target that succeeded in passing through the outer mine fields. Harbor based sub-chasers were usually equipped with echo-ranging equipment and air-search radar. Shore based and shipborne air-search radar were not primarily considered as harbor protection equipment.

Of course, the number and spacing of the contact mines, magnetic loops, hydrophones and controlled mines was varied to fit the specific requirements of the harbor being defended.

Surface-search radar, stationary echo-ranging equipment and infra-red detection systems did not appear in typical harbor defense installations. Radar was not being produced in sufficient quantities and, furthermore, optimum results were very seldom realized due to component failures and poor alignment by undertrained maintenance personnel. A submarine's periscope or conning tower, or a small sneak craft would have escaped radar detection, in most cases. Stationary echo-ranging equipment was considered impractical because of installation difficulties, and because it let the target know it was being tracked. Moreover, better results were obtained with Type 97 hydrophones. As for infra-red equipment, none had even been designed for harbor defense systems.

B. SAIKI Defense Unit

Now, let us examine the channel defenses between KYUSHU and SHIKOKU. Figure 1 shows the physical layout of all harbor protection equipment. Figure 2 presents the organizational arrangement of this harbor defense system.

If, for example, an incoming target was detected by the SERI-ZAKI Guard Station hydrophones, the Defense Unit at SAEKI and the Guard Station at TSURUMI were to be immediately informed by radio. The Defense Unit had authority to dispatch sub-chasers in an emergency, but the Defense Squadron Headquarters, usually in the same building, had to be notified before airplanes could be sent to intercept the target. The Guard Station at TSURUMI was expected to be able to track the target in on its hydrophones and destroy it when it passed through the Type 92 controlled mine field. If by some chance a target succeeded in passing through either the Type 92 or Type 93 mines, it was to be further tracked by the magnetic loops and hydrophones at OSHIMA, YURA, HODO and HIBURI, and all information transmitted to the Defense Unit which plotted all incoming data. The functions of a Defense Unit simulated those of a ship's Combat Information Center. If it was seen that an incoming target had passed through the mine fields, sub-chasers and patrol boats were to be dispatched to drop depth charges. If it was a surface target, airplanes and shore batteries were to take care of it.

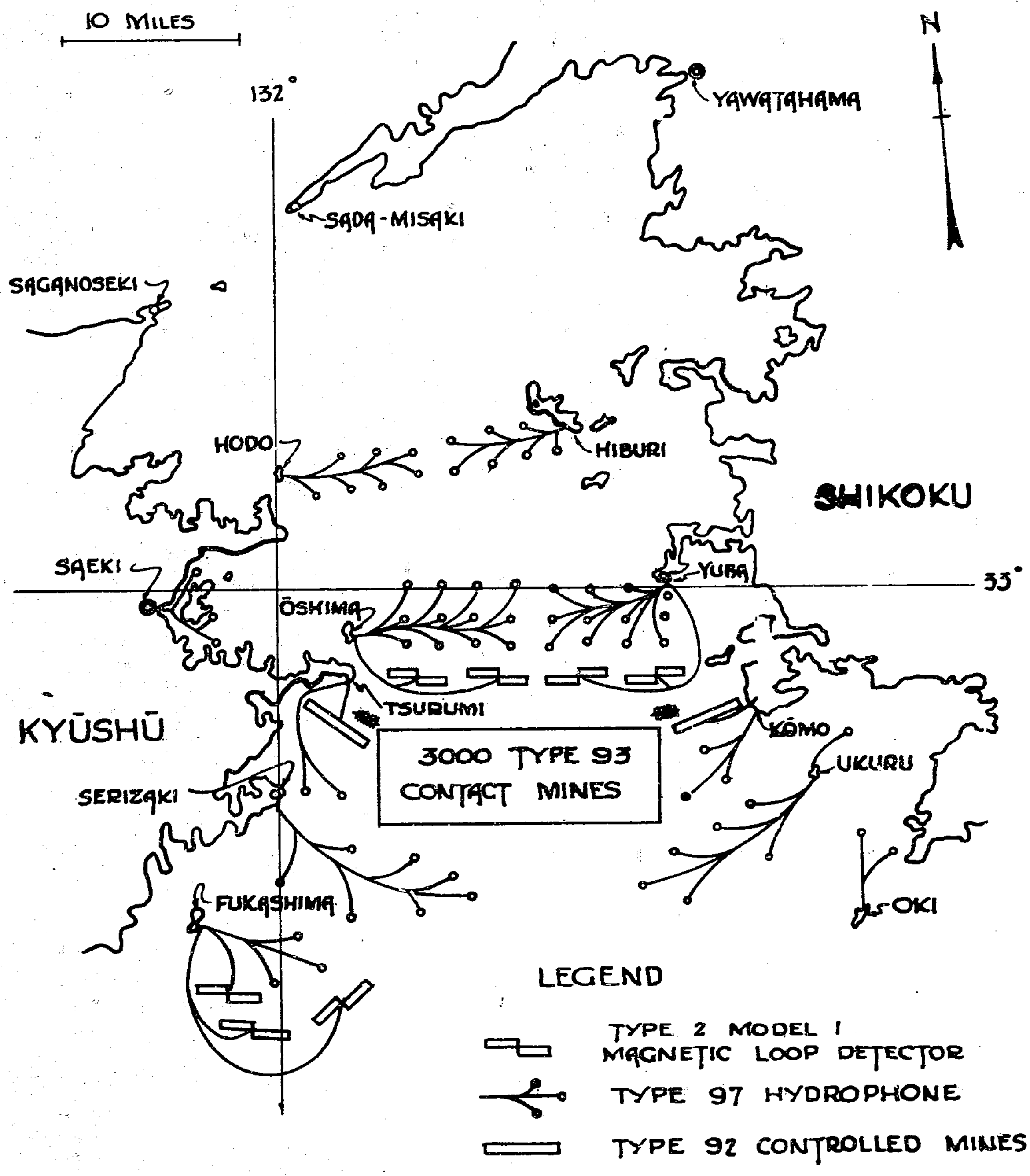


Figure 1

PLAN VIEW OF CHANNEL DEFENSES BETWEEN KYUSHU AND SHIKOKU

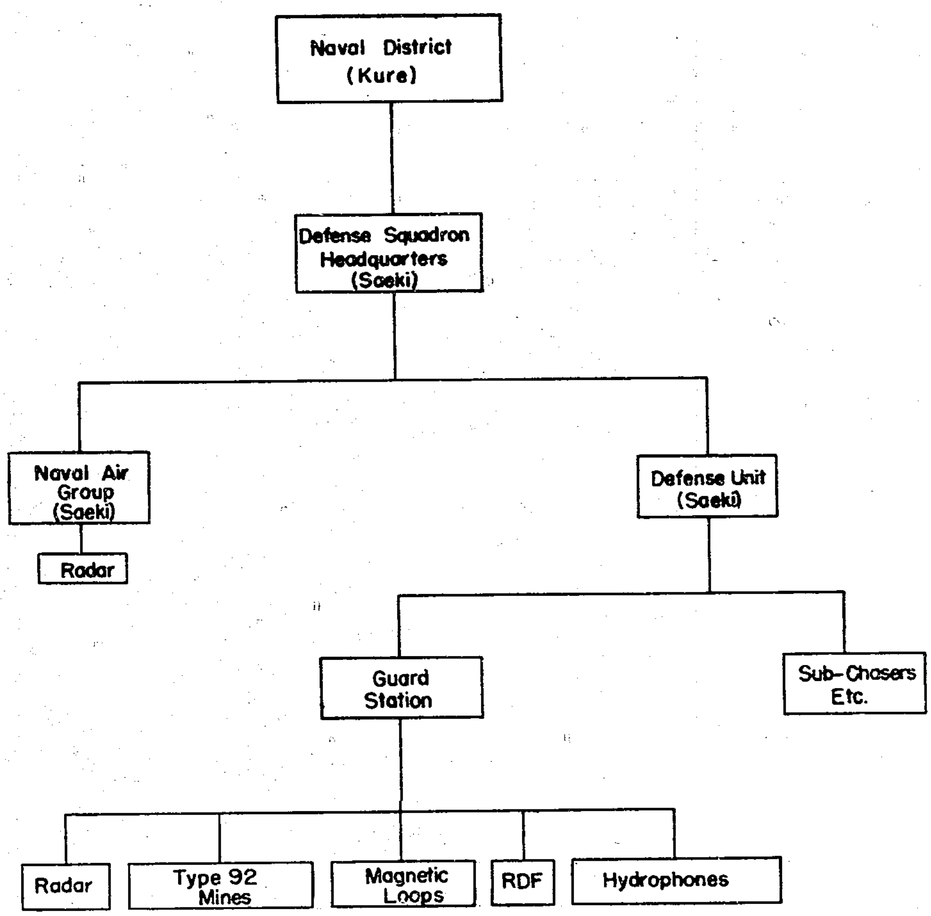


Figure 2
BLOCK DIAGRAM SHOWING ORGANIZATION OF SAEKI DEFENSE COMMAND

It is interesting to note that the Type 97 hydrophone field controlled from OSHIMA and YURA (Figure 1) was of such a width that it took a ship traveling at two knots 30 minutes to traverse it. This was a standard pattern, providing enough hydrophones were available.

This channel defense differed from normal in one respect. The last string of Type 97 hydrophones was not backed up by Type 92 controlled mines, due to the fact that there is a five knot tidal current between SAGANOSEKI and SADA-MISAKI which would have masked any received signals. Actually, Type 97 hydrophones were originally installed there, but were removed when they were found useless. There was no harbor protection equipment further out in the middle of the channel between FUKASHIMA and OKI because the water is too deep.

The ships under the SAEKI Defense Squadron Headquarters command consisted of:

One coastal defense ship (NAWAJIMA).
Two mine layers (KUROKAMI and KATASHIMA).
Two special sub-chasers (Nos. 79 and 86).
One lighter (No. 4).
Three special patrol boats (Nos. 136, 137 and 175).

One Type 3 Mark 1 Model 3, 150 megacycle, air-search radar was installed on NUWAJIMA, and one Type 3 Mark 1 Model 3 Modification 2, 150 megacycle, air-search radar was installed at SERI-ZAKI. Three more were to have been added even though this one never operated properly, due to the lack of skilled personnel and the poor condition of the base. It could pick up B-29's.

One Type 3 Mark 2 radar had been ordered from the Naval Technical Research Laboratory (KAIGUN GIJUTSU KENKYUJO) for the SAEKI base.

Simple Type, Model 1, echo-ranging equipment was installed on the Mine Layers KUROKAMI and KATASHIMA, Sub-Chasers No. 79 and 86, and Lighter No. 4.

Type 3 Model 3 echo-ranging equipment was installed on the Special Patrol Boats Nos. 136, 137 and 175.

Simple Type, Model 1, hydrophones were installed on KUROKAMI and KATASHIMA.

Hydrophones and magnetic loop detectors installed within the SAEKI command were as follow:

Hydrophones	Number	Location
Type 97 Model 0	1	SERI-ZAKI
	1	SAEKI
Type 97 Model 1	1	HIBURI
	1	YURA
	3	SAEKI
Type 97 Model 2	5	HODO
	2	OSHIMA
	2	TSURUMI
	6	SERI-ZAKI
	2	HIBURI
	3	KOMO
	5	UKURU
	4	SAEKI
Type 97 Model 3	7	YURA
	2	OKI
Type 3 Model 1	1	SAEKI
Type 3 Model 3	1	SAEKI

Magnetic Loop Dectectors	No.	Location
Type 2 Model 1	2	OSHIMA
	2	YURA
	3	FUKASHIMA

Japanese Hydrographic Office Bulletin No. 14, contains information similar to that shown in Figure 1, for every harbor in Japan. (NavTechJap Document No. ND50-5400, see Enclosure (A)).

Blueprints of the following equipment are contained in NavTechJap Document No. ND21-6262:

1. Sonic bearing evaluator, manufactured by OKI DENKI MFG. CO. (Part of Type 97 hydrophone).

2. Sonic bearing evaluator, Model 1, manufactured by NIPPON DENKI MFG. CO. (Part of Type 97 Model 1 hydrophone).

Blueprints of the following equipment are contained in NavTechJap Document No. ND21-6263.

1. Type 97 Model 2 sonic bearing evaluator manufactured by NIPPON DENKI MFG. CO. (Part of Type 97 Model 2 hydrophone).

2. Maximum sensitivity type phasing mechanism, manufactured by OKI DENKI MFG. CO.

3. Binaural-type phasing mechanism, manufactured by NIPPON DENKI MFG. CO.

4. Experimental Type 1 phasing mechanism, manufactured by NIPPON DENKI MFG. CO.

5. Model K phasing mechanism, manufactured by NIPPON DENKI MFG. CO.

C. Organization and Tactics

Although the Defense Unit (BO-BITAI) received its orders from the Naval District (CHIMJUFU), via the Defense Squadron Headquarters (BOBI SENTAI SHIREIBU), it was the organizational unit responsible for harbor protection. See Figure 3.

There were two types of this unit, the Defense Unit, and the Specially Established Defense Unit. The only major differences between the two types seem to have been that the strength of the Defense Unit, in terms of personnel and surface craft, was slightly greater than that of the Specially Established Defense Unit, and the latter was located in somewhat more forward areas than the defense force.

The table-of-organization strength of the Defense Unit ranged from 250 to 510 officers and men, with an average authorized strength of about 350. The equipment varied according to the variance in organization. Normally, 14cm, 12cm and 8cm seacoast guns, machine guns, hydrophones, controlled mines, and echo-ranging gear were included. Among the types of surface craft found in these units were sub-chasers, mine-sweepers, cable-laying boats, motor torpedo boats, special light mine-laying boats, converted net tenders, and converted picket boats. It is believed that the departmental organization of the Specially Established Defense Unit was similar to that of the Defense Unit, and that the table-of-organization strength of Specially Established Defense Forces ranged from 125 to 315 officers and men, with an average strength of about 200. The equipment differed according to the variances in organization, and the same types of equipment and surface craft which were found in Defense Units were included.

The mission of both types of units was coastal and anti-submarine defense near the Japanese main islands. Some units appear to have emphasized coastal defense, while others emphasized anti-submarine defense. These units could be attached tactically to a fleet (or to a fleet through a base force), to a naval district,

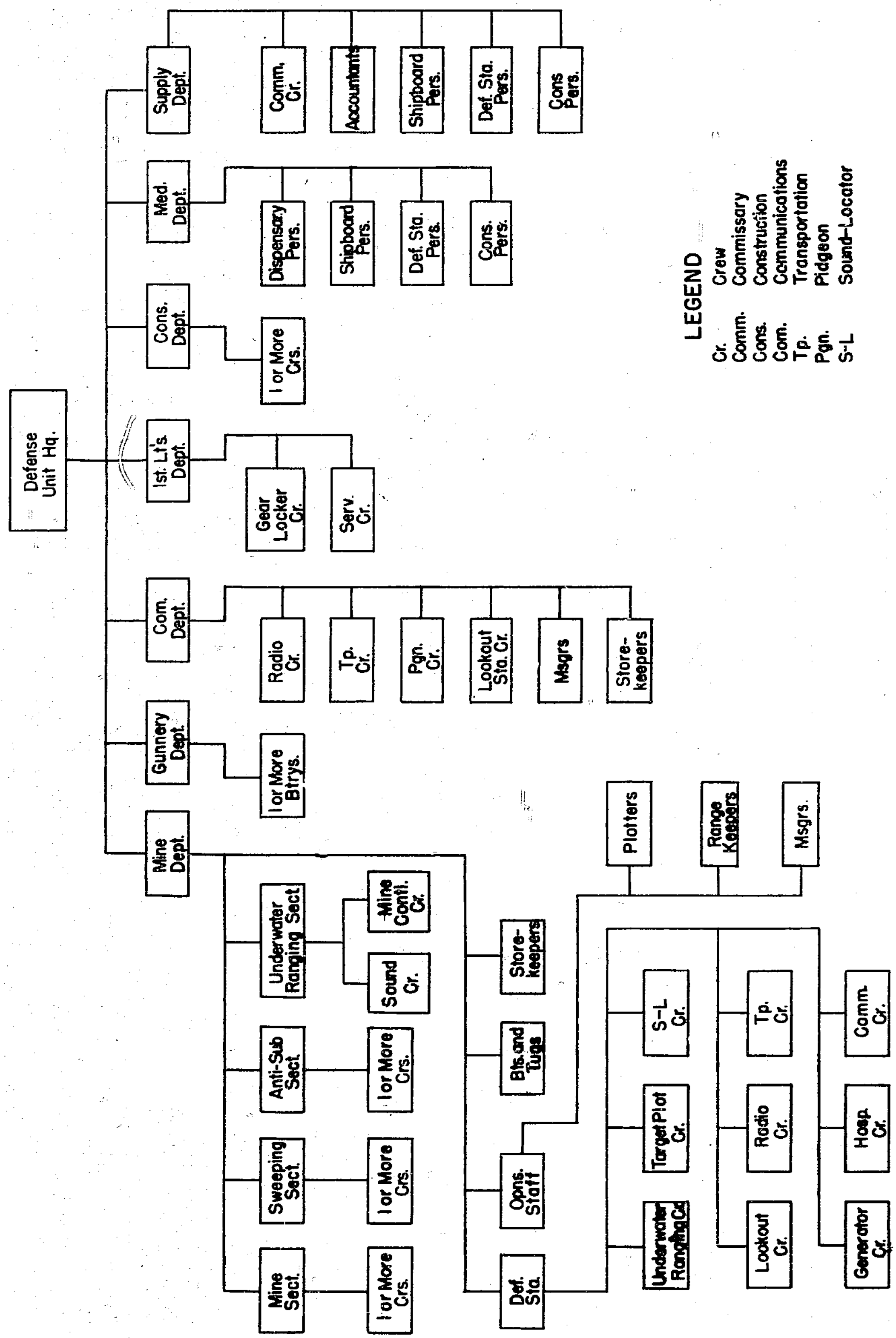


Figure 3

BLOCK DIAGRAM SHOWING ORGANIZATION OF A DEFENSE UNIT (BO BITAI) or to a guard district. They came under the administrative command of naval districts.

Each unit was a nucleus which could be reinforced with the following elements: Coastal batteries, defense stations, radar stations, lookout stations, or surface craft. The organization of defense forces may have varied, but normally it consisted of departments as shown in Figure 3.

A base force (KONKYOCHITAI) was responsible for communications and defense in forward areas, for the security and survey of adjacent waters, and for harbor control.

A guard district (KEIBIFU), of which there were two in Japan proper and three outside of Japan, were of lesser importance than naval districts. Each guard district operated a naval base and had other ground units assigned to it for tactical purposes. The naval office of supplies and accounts, naval establishments department, naval civil engineer department, naval stores department, and naval construction department, all of which performed service functions, had units assigned to each guard district.

Part II

MAGNETIC LOOP DETECTORS

A. History

Considering the different principles involved in detecting a magnetic body, magnetic loop detectors, (JIKI TANCHIKI or JITAN), may be divided into two groups: harbor bed based magnetic loop detectors, and magnetic airborne detectors, respectively. For a discussion of the latter, see NavTechJap Report "Japanese Magnetic Airborne Detector", Index No. E-14.

Sonic and supersonic acoustic detection equipment had been in use for some years before the war. However, the need was realized for a more reliable apparatus based on an entirely different principle.

Magnetic loop detectors used by the British Navy were captured at Hongkong and reported to the Japanese Navy in December 1941. The Naval Technical Research Institute, TOKYO, and the KURE Arsenal began an examination of this equipment with a view to producing a similar device.

Two types were developed and manufactured about October 1942. The first four manufactured, Type 2 Model 1, were installed at OSHIMA and YURA in the channel between KYUSHU and SHIKOKU. Those at OSHIMA and nearby FUKASHIMA were later damaged by bombing raids. (Magnetic loop detectors were sometimes referred to as "Y" equipment).

The first type consists of two loops laid so as to give the impression of an offset figure eight, i.e., two parallel rectangles, corner to corner. Each loop is normally about 1500 meters long and 200 meters wide. However, the dimensions can be varied as was done at OSHIMA, YURA and FUKASHIMA, where each loop was about 3000 meters long and 300 meters wide. Both four and seven core cable was used.

The two loops are so connected that the magnetic fields balance, and only an emf due to a ship passing overhead can cause a signal. The output terminals of the loops are connected to a galvanometer in the Guard Station. A constant source of light, reflected by a mirror on the galvanometer, which rotates in response to a signal, is directed at a photoelectric tube which allows current to pass in proportion to the angle of the beam, and register on an ammeter.

The second type consists of a pair of round coils, four meters in diameter, and of about 1000 turns. Otherwise, the two types are similar. This type can detect a small submarine passing overhead at a speed of two knots, from a depth of 150 meters. This type was used almost exclusively in forward areas, because of its portability.

Following the above research, a similar device to be used on land was developed at the Naval Technical Research Institute in October 1943. About 1000 sets were manufactured but they were never used. This device consisted of a loop about 200 meters in circumference which was buried in the ground. The rest of the equipment was similar to the other detectors. A soldier carrying a rifle could be detected.

B. Theory

Assuming that a vessel such as a submarine, made of ferromagnetic material, behaves magnetically like a magnetic dipole of the magnetic moment, M, we can calculate the distribution pattern of the magnetic field around it. When a long conductor, L, is placed on the sea bottom and a magnetic vessel advances with a velocity of one meter/sec and crosses over the conductor, and electromotive force, E, will be induced in it.

As shown in Figure 4, the position of the vessel is represented by the coordinates x and z.

The vertical component "H_z" of the magnetic field, which is an important quantity, is given by the following equation, ($y = o$):

$$H_z = 3M \frac{zx}{(z^2 + x^2)^{5/2}} \quad \text{.......(1)}$$

Figure 4 represents "H_z" as a function of x, the horizontal distance from the center of the vessel. Then the induced emf is:

$$e = v \int H_z \cdot dy = vy \cdot 10^{-9} \text{ (volts)} \quad \text{.......(2)}$$

where the length of the conductor is measured in meters. The wave form of this integrated value, depending on time as the vessel advances, resembles that in Figure 4. The maximum value of e depends on the product of v (m/sec.) and M ($\gamma . m^3$) and is inversely proportional to the square of the distance z. For example, for a cargo vessel of about 300 tons, this value was found equal to about 10μv, with $z = 50$m and $v = 1$ m/sec $\simeq$ 2 knots. It is noteworthy that the induced emf varies as $1/z^2$, a standard characteristic of magnetic loops.

Figure 5 shows the connection diagram of an uncompensated loop detector, where a suitable galvanometer is used to measure the induced voltage. The required current sensitivity of the galvanometer is not so high. About 10^{-10} amperes is sufficient for practical use.

When z, the vertical distance of the vessel above the sea floor, remains the same, the response of the indicating meter does not change when the vessel is underway above the loop. This is illustrated by equation (2). However, when the vessel approaches or moves away from the edge of the loop, the response decreases as shown in Figure 6. The distance from the edge of the loop where the response becomes nearly zero, d, is equal to about 1.5 times the vertical distance z.

The major interference associated with magnetic loops is due to the disturbances caused by the earth's magnetic field and heavy direct currents of nearby electric railroads. The disturbance of the former may become as high as 0.1 γ/sec. ($\gamma = 10^{-5}$ Gauss), which can introduce the following noise voltage around the loop:

$$e_N = \text{(loop area in km}^2\text{)} \cdot \text{(disturbance in } \gamma\text{/sec.) millivolts} \quad \text{.......(3)}$$

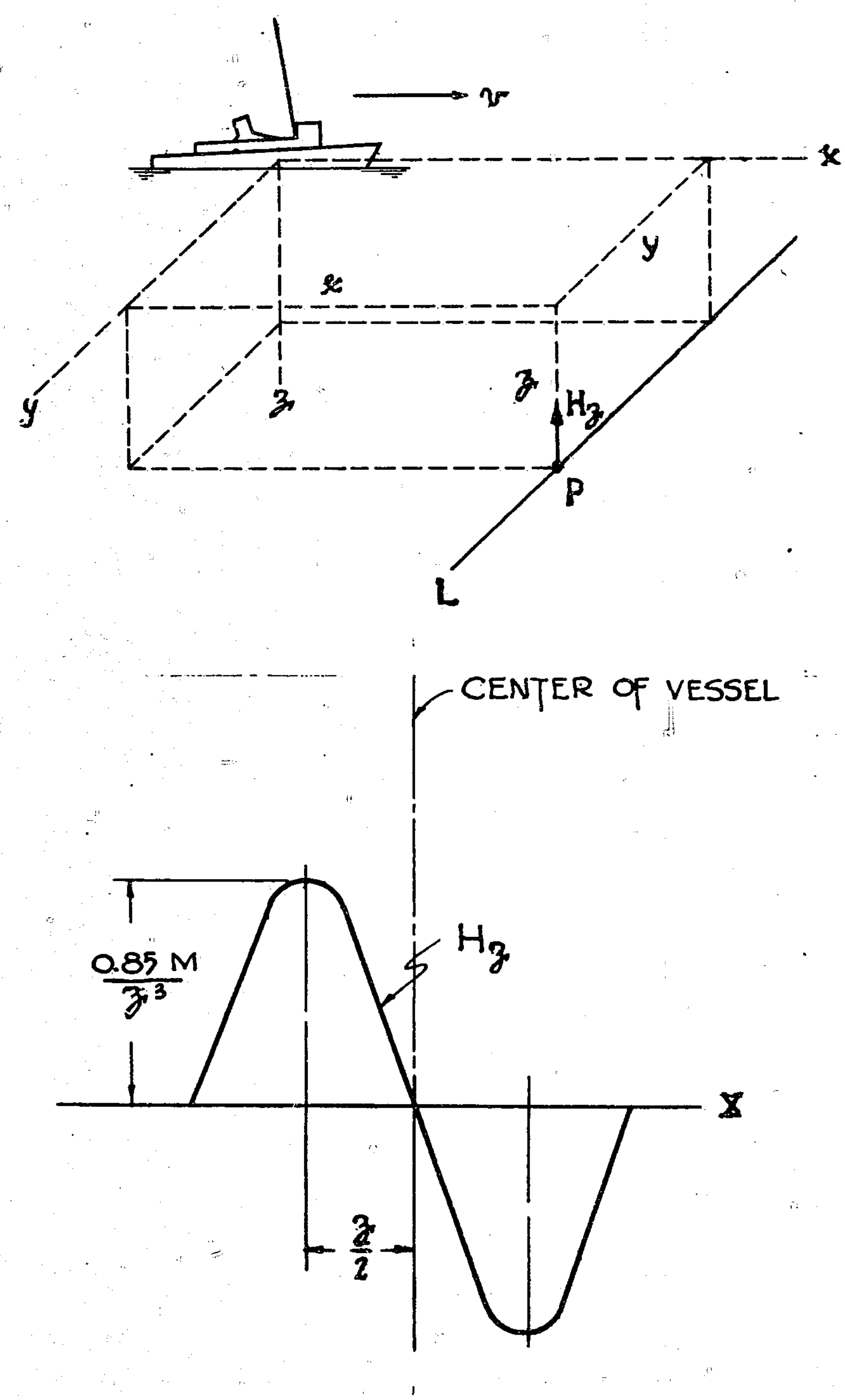


Figure 4

DIAGRAMS USED IN CALCULATING THE EMF INDUCED IN A LOOP WHEN A SHIP PASSES OVERHEAD

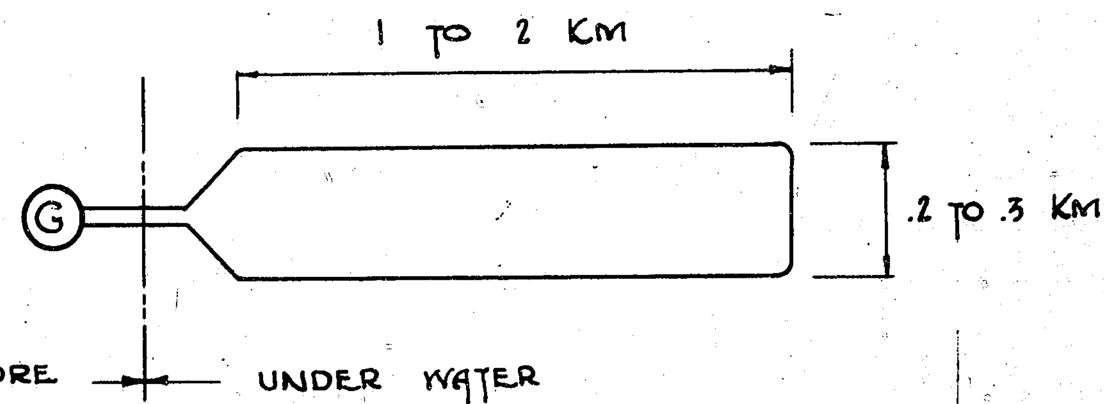


Figure 5

CONNECTION DIAGRAM OF AN UNCOMPENSATED MAGNETIC LOOP

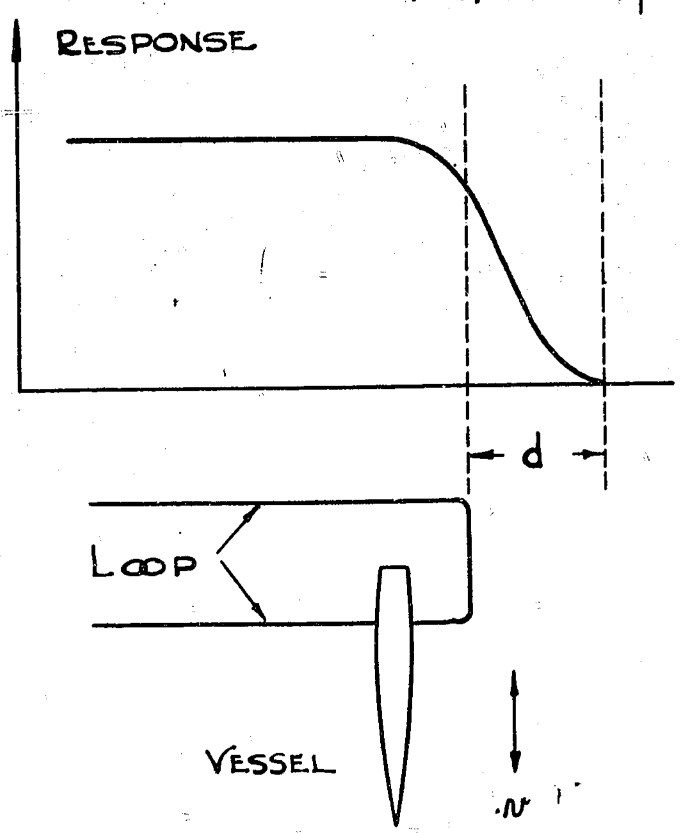


Figure 6

RESPONSE CURVE RESULTING WHEN A SHIP APPROACHES OR MOVES AWAY FROM A SIDE OF A MAGNETIC LOOP

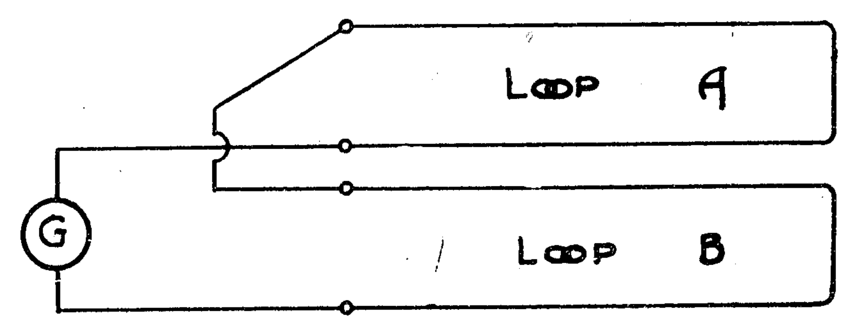


Figure 7

CONNECTION DIAGRAM OF COMPENSATED MAGNETIC LOOP

In order to compensate for this inevitable disturbance, two loops must be installed and connected as shown in Figure 7, thus neutralizing the induced noise voltages.

Despite the drawback in construction of the compensated loop detector, it is preferable to the single loop because of its effective suppression of noise voltage.

C. Efficiency

The efficiency of the loop depends on its condition, its steadiness on the sea bed, and the strength of the induced emf.

Installation of the loop in the proper pattern is quite difficult, and even after installation the long conductor, in most cases, is gradually displaced by tidal currents, with a resulting decrease in sensitivity as well as compensating effect. Also, there is a noticeable noise disturbance if the shape of the loop changes rapidly due to a violent tide. Ordinarily, a Type 2 Model 1 or 4 magnetic loop at 100 meters depth can detect a small submarine passing overhead on the surface at a speed of two knots.

Since the range depends on $\nu \cdot M$ it is impossible to determine it accurately, but it may be estimated that the detectable range is within two or three hundred meters for an ordinary submarine.

This loop detector does have two excellent characteristics: a sensitive indicating apparatus, such as a galvanometer, installed on shore, and a long conductor which is able to guard a large area, about 0.6 square kilometers.

The compensated loop detector performed rather successfully for warning purposes. The only further development considered necessary was a decrease in the size of the loop. Samples of the Type 2 Models 1 and 4 magnetic loop detectors have been shipped via OIL to NRL, Anacostia, Maryland. The NavTechJap numbers assigned are JE 10-6052 and JE 10-6053, respectively.

Part III

TYPE 97 HYDROPHONE

A. History

Research on hydrophones for use on submarines was first carried out by the Japanese Navy, beginning in 1925, and the first complete instrument was installed in a submarine in 1934. At that time, plans were developed for use of hydrophones in harbor defense, but research was not actually started until 1935. The basic knowledge for this research was obtained from the research on hydrophones for use on submarines, therefore, the theoretical basis was the same. In 1937, the Type 97 Model 1 hydrophone was perfected, the first actual tests for its use in harbor defense were carried out, and it was found suitable for practical use.

Research on the Type 97 Model 1 hydrophone was completed, as described above, in 1937. After that year Model 1 was improved and the manufacture of Model 2 was begun. At the same time, experimental improvements were made and research, trial manufacture, and mass production of Model 3 resulted. Mass production of Models 1, 2, and 3 was started in 1937, 1938 and 1939, respectively. Production of these three models continued through 1942. However, the need for hydrophones on anti-submarine craft became so urgent in 1943 that the manufacture of hydrophones for harbor defense was stopped.

Before 1937, when the Type 97 hydrophone was developed, there was also a Type K hydrophone for harbor defense use. This type could be used only up to 40 meters. The bearing accuracy was poor, and binaural reception made it difficult to train operators. As a result, it was not used in practice and was completely replaced by the Type 97 hydrophone. The differences in the types and models, as to the depth at which they could be laid, are approximately as follows:

Type and Model	Depth (m)	Principle
Type K	40	Binaural
Type 97 Model 1	80	Max. signal
Type 97 Model 2	150	Max. signal
Type 97 Model 3	250	Max. signal

B. Theory

The Type 97 hydrophone used a combination of many underwater microphones. When the differences in phase of the sound waves which reached each microphone were superimposed in phase, the direction of the target could be determined by the maximum signal intensity method. The Type 97 had 13 microphones arranged in a circle three meters in diameter.

Figure 8 shows the relation between the direction of propagation of the sound waves and the arrangement of the microphones.

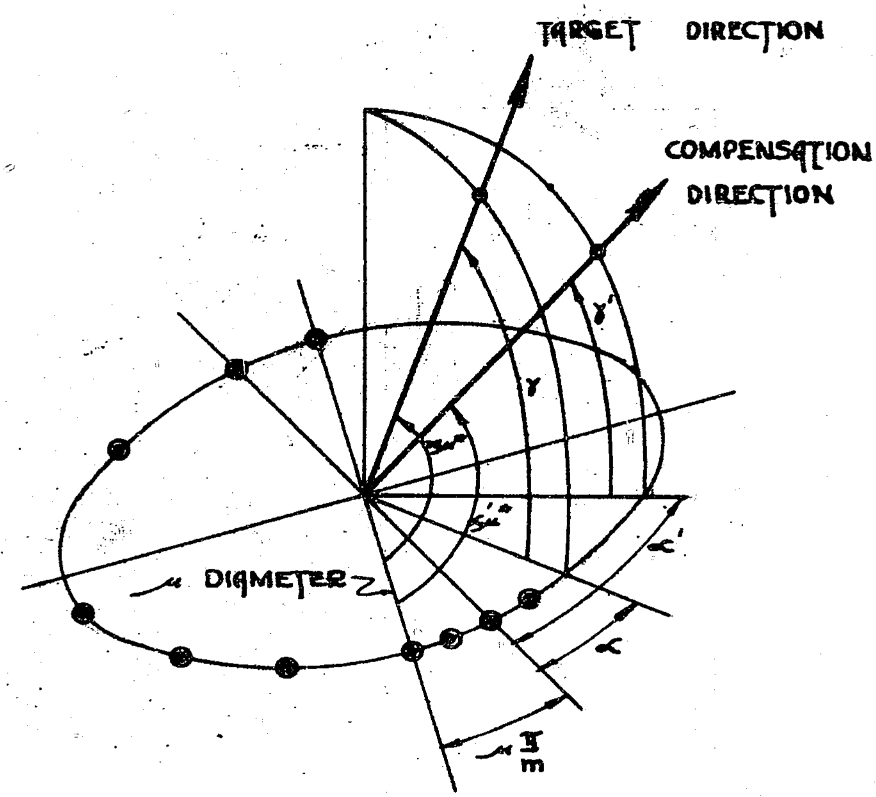


Figure 8

DIAGRAM SHOWING RELATION BETWEEN DIRECTION OF PROPAGATION OF SOUND WAVES AND ARRANGEMENT OF MICROPHONES

First, we imagine n number of hydrophones arranged in a circle, equidistant from each other. To simplify the calculation we arbitrarily make n an even number, equal to 2 m, so that a diameter can be drawn between any opposite pair of microphones.

Now, consider two microphones on the diameter, μ, as shown in Figure 8.

α and γ are the horizontal and vertical target bearing angles, respectively.

α' and γ' are the horizontal and vertical direction of compensation angles, respectively.

The diameter connecting the μ hydrophones forms angles $\alpha\mu$ and $\alpha\mu'$ with the target and the direction of compensation, respectively.

In this case, make the resultant amplitude of sound signals received by all microphones "A" resultant (or A_{res}), and the directional characteristics, S. Then:

$$S = \frac{A_{res}}{\sum_{v=1}^{n} A_v}$$ where A_v is amplitude (sound pressure) of v hydrophones.

$$A_{res} = 2A \left| \sum_{\mu=0}^{\mu=1} \cos \left(\frac{2\pi D}{\lambda} \frac{\cos \alpha\mu^{*} - \cos \alpha\mu'^{*}}{2} \right) \right|$$

Here D is the diameter of the circle and λ is the wave length of sound waves.

$$S = \frac{A_{res}}{\sum_{v=1}^{n} A_v} = \frac{2}{n} \left| \sum_{\mu=0}^{\mu=1} \cos \left(\frac{2D\pi}{\lambda} \frac{\cos \alpha\mu - \cos \alpha\mu'}{2} \right) \right|$$

From Figure 4:

$$\left.\begin{aligned} \cos\alpha\mu^{*} &= \cos\gamma \cos\left(\alpha + \mu\frac{\pi}{m}\right) \\ \cos\alpha\mu'^{*} &= \cos\gamma \cos\left(\alpha' + \mu\frac{\pi}{m}\right) \end{aligned}\right\}$$

Therefore:

$$S = \frac{1}{m} \left| \sum_{\mu=0}^{\mu=1} \cos \left(\frac{2\pi D}{\lambda} \frac{\cos\gamma\,(\alpha + \mu\frac{\pi}{m}) - \cos\gamma' \cos(\alpha' + \mu\frac{\pi}{m})}{2} \right) \right|$$

Now $\gamma = \gamma'$, so that it is a constant and the relation between S and α becomes:

$$S_{\gamma = \gamma'} = \frac{1}{m} \left| \sum_{\mu=0}^{\mu=1} \cos \left[\frac{2\pi D}{\gamma} \cos\gamma' \sin\frac{\alpha - \alpha'}{2} \sin\left(\frac{\alpha + \alpha'}{2} + \mu\frac{\pi}{m} \right) \right] \right|$$

Now if $\alpha = \alpha'$, a constant, the relation between S and γ becomes:

$$S_{\alpha = \alpha'} = \frac{1}{m} \left| \sum_{\mu=0}^{\mu=1} \cos \left[\frac{2\pi D}{\lambda} \frac{\cos\gamma - \cos\gamma'}{2} \cos\left(\alpha' + \mu\frac{\pi}{m} \right) \right] \right|$$

Or:

$$S_{\alpha = \alpha'} = \frac{1}{m} \left| \sum_{\mu=0}^{\mu=1} \cos \left[\frac{2\pi D}{2} \sin\frac{\gamma - \gamma'}{2} \sin\frac{\gamma + \gamma}{2} \cos\left(\alpha' + \mu\frac{\pi}{m}\right) \right] \right|$$

But these are the following relations:

$$\cos(x \sin\omega) = J_0(x) + 2\sum_{\rho=1}^{\infty} J_{2\rho}(x) \cos 2\rho\,\omega$$

Here $J_0(x)$, $J_{2\rho}(x)$ is the Bessel function.

Therefore:

$$S_{\gamma = \gamma'} = \left| J_0\left(\frac{2\pi D}{\gamma}\cos\gamma \sin\frac{\alpha - \alpha'}{2}\right) + 2\sum_{q=1}^{\infty} J_{2qm}\left(\frac{2\pi D}{\lambda}\cos\gamma' \sin\frac{\alpha - \alpha'}{2} \cos nq\frac{\alpha + \alpha'}{2}\right) \right|$$

$$S_{\alpha = \alpha'} = \left| J_0\left(\frac{2\pi D}{\gamma}\sin\frac{\gamma - \gamma'}{2}\sin\frac{\gamma + \gamma'}{2}\right) + 2\sum_{q=1}^{\infty} (-1)^{qm} J_{2qm}\left(\frac{2\pi D}{\lambda}\sin\frac{\gamma - \gamma'}{2}\sin\frac{\gamma + \gamma'}{2}\cos nq\,\alpha'\right) \right|$$

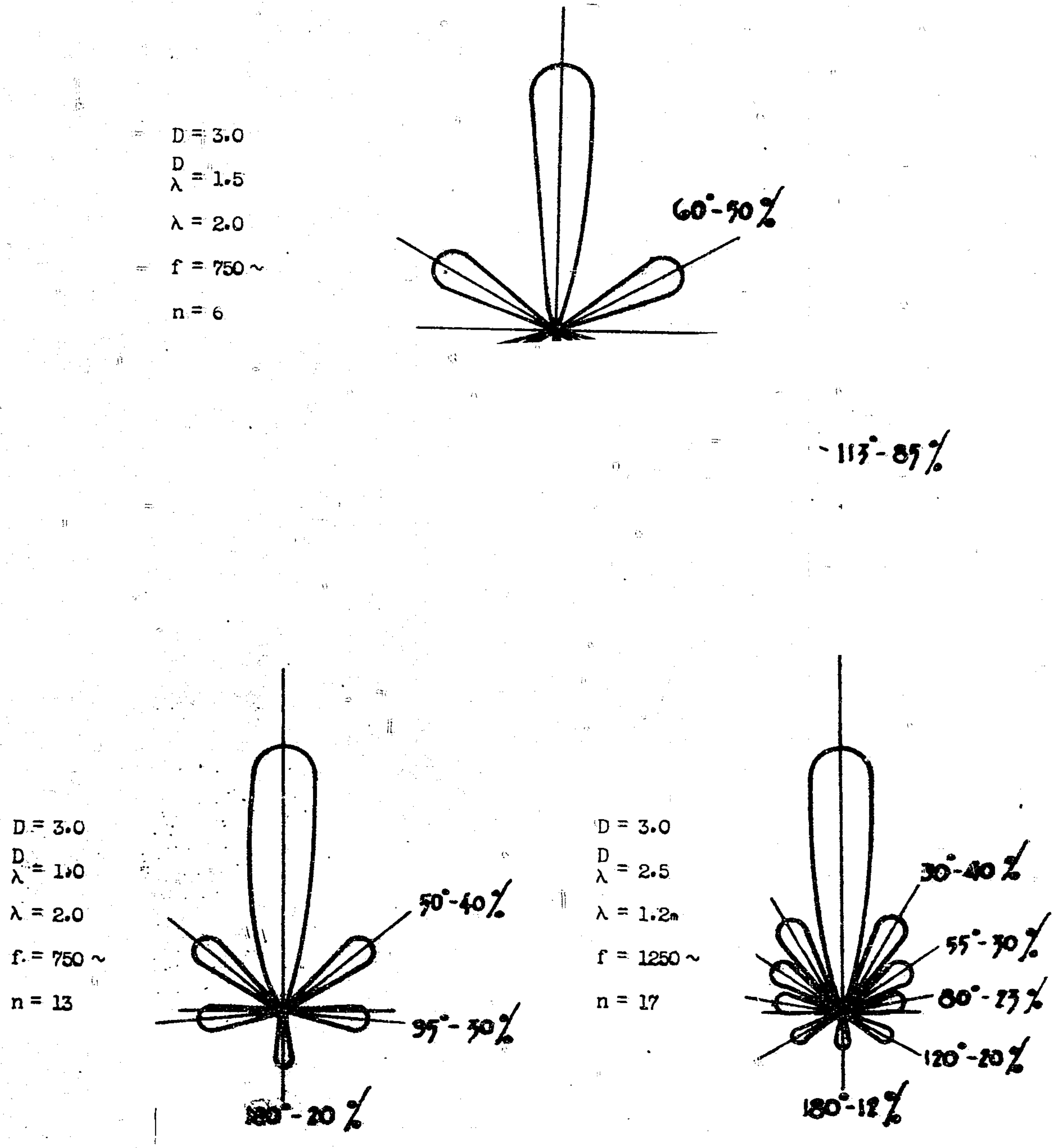


Figure 9

DIRECTIONAL CHARACTERESTICS IN THE HORIZONTAL PLANE FOR 6, 13 AND 17 MICROPHONES, RESPECTIVELY

Thus, in a circular arrangement, the directional characteristic will be represented by the Bessel function. In the circular plane of the arrangement, the directional characteristic is always symmetrical for all directions. Therefore, the directional characteristic is the same for any bearing of α'. This is the most important characteristic of the circular arrangement.

By the character of the Bessel function, the terms of the higher order will be smaller. and when:

$$\frac{2\pi D}{\lambda} \leqq 2m - 2$$

Then:

$$| J_v (v - 2) | < 0.07$$

Therefore, in this case, the second term of S may be neglected, i.e.

$$n \geqq \frac{2\pi D}{\lambda} + 2$$

Therefore, if the number of hydrophones, n, is posited to satisfy the above condition, S, in the horizontal plane, will become:

$$S_{\gamma = \gamma'} = \left| J_0 \left(\frac{2\pi D}{\lambda} \cos \gamma' \sin \frac{\alpha - \alpha'}{2}\right) \right|$$

And in the vertical plane:

$$S_{\alpha = \alpha'} = \left| J_0 \left(\frac{2\pi D}{\lambda} \sin \frac{\gamma - \gamma'}{2} \sin \frac{\gamma + \gamma'}{2}\right) \right|$$

Or:

$$S_{\alpha = \alpha'} = \left| J_0 \left[\frac{\pi D}{\lambda(\cos \gamma - \cos \gamma')}\right] \right|$$

And if γ' is 90°, then in the plane perpendicular to the plane of the circle S will be:

$$S_{\alpha = \alpha'} = \left| J_0 \left(\frac{\pi D}{\lambda} \cos \gamma\right) \right|; \ (\gamma = 90°)$$

This may be considered the natural directional characteristic in the plane perpendicular to the plane of the circle, and it will be satisfied by the following condition:

$$n \geqq \frac{\pi D}{\lambda} + 2$$

In harbor defense hydrophones it is very convenient if both α and γ can be measured together, but it is very complicated from the standpoint of construction of the equipment. In the Type 97 hydrophone, only α is measured. γ is always made zero, i.e., it is assumed that the sound source is in the horizontal plane, According to actual experience, this equipment, designed to measure only horizontal bearings, could measure α for a target where $\gamma = 45°$.

Figure 9 shows examples of directional characteristics in the horizontal plane.

From these directional characteristics, we can see that as the frequency of the sound waves becomes greater, the bearing becomes more accurate, but the chance of the occurrence of the sub-maximum increases. In order to reduce this sub-maximum, it is necessary to increase the number of microphones. Especially, when there are few microphones the sub-maximum may be as great as 85%, as shown in Figure 9, so that there is danger that it cannot be used in practice.

For these reasons, the frequency of underwater sound waves from 500 ~ to 2000 ~ was considered. The diameter was made three meters and n was made 13.

In the Type 97 hydrophone, the induced voltages of the microphones, arranged as described above, are all collected in parallel and the phase perfectly adjusted so as to hear the maximum intensity. From the amount of adjustment we can

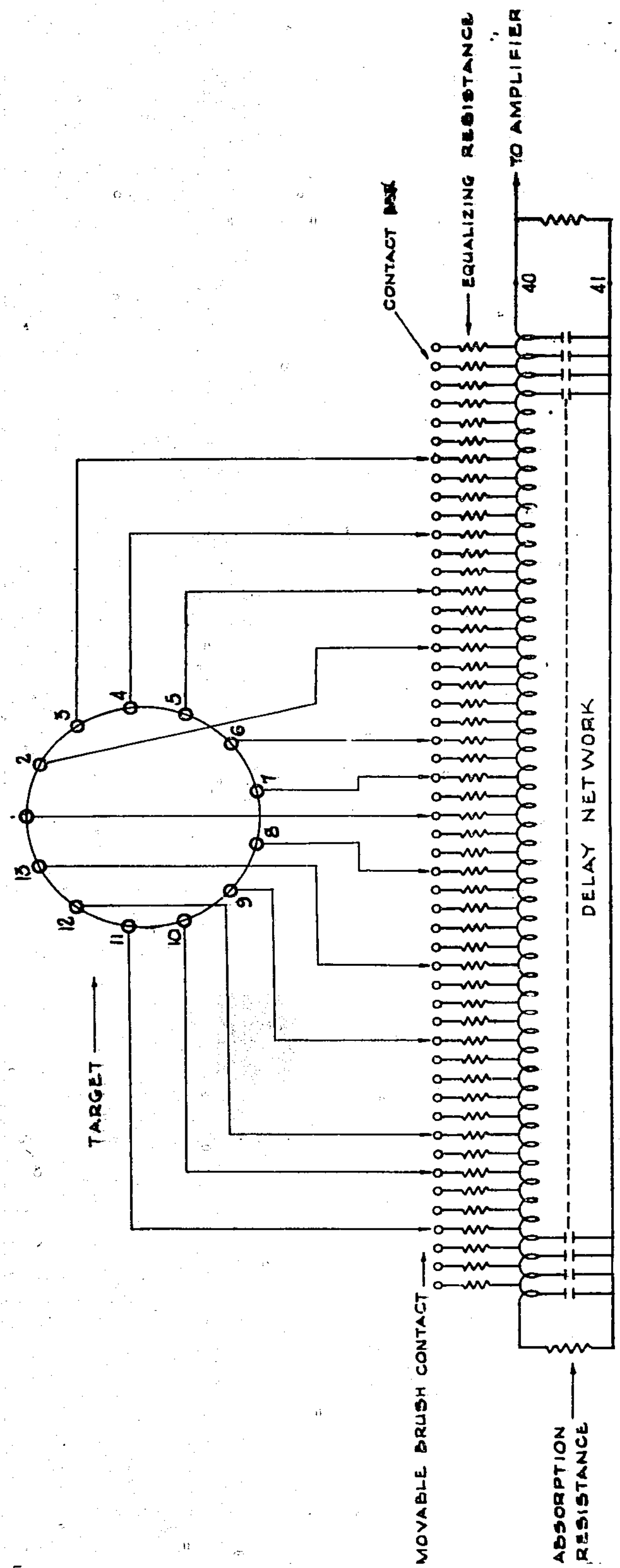


Figure 10
DELAY NETWORK OF TYPE 97 HYDROPHONE

determine the direction of the source.

The outline of the principle is shown in Figure 10.

As shown in the figure, when sound waves reach microphones 1, 2, 3 -----13 from some direction, the induced voltage of each microphone due to the sound wave, will be connected in parallel to the delay network. As shown in Figure 10, this contact point may be adjusted by relative rotation of the movable brush and contact bar. The arrangement of the movable brush must be exactly similar to the arrangement of the microphones. However, the scale is reduced. For the Type 97 hydrophone, the scale is 1 to 15. This collected and adjusted voltage flows out at 40 and 41 to the amplifier. The equalizing resistance, connected next to the contact bar, equalizes the induced voltage of each microphone which comes out at output terminals 40 and 41.

The connection of the element used in this type of delay network is shown in Figure 11.

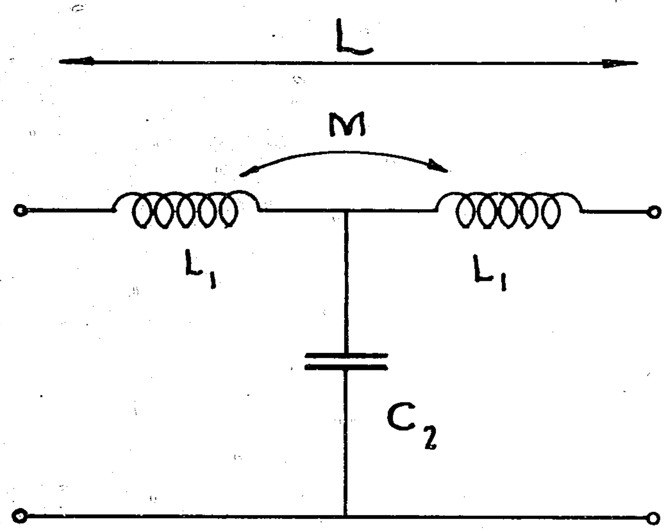


Figure 11

ONE ELEMENT OF THE DELAY NETWORK OF TYPE 97 HYDROPHONE

L = overall self-inductance M = mutual inductance between L_1
C_2 = capacity

In the Type 97 hydrophone:

C_2 = 0.02μf
M = 6.64 mH
Z_o = 2000 ohms (surge impedance)

t = 40 μ seconds per element
50 = number of elements
L = 80 mH

Total delay time = 40 μ sec x 50 = 2000 μ sec.

One element = 6 water cm, i.e, one element compensates for 6 cm underwater since 50 elements compensate for 3 m, the diameter of the hydrophone mount.

Figure 12 is the wiring diagram of the Type 97 hydrophone sonic bearing evaluator.

The sound pressure electric current from the microphones is first fed through the shore cable to the connection box, #1, and then enters the microphone transformer, #2.

Current from each of the 13 microphones passes through the hearing and testing switch, #3, then goes through slip ring, #4, to the microphone brush, #5.

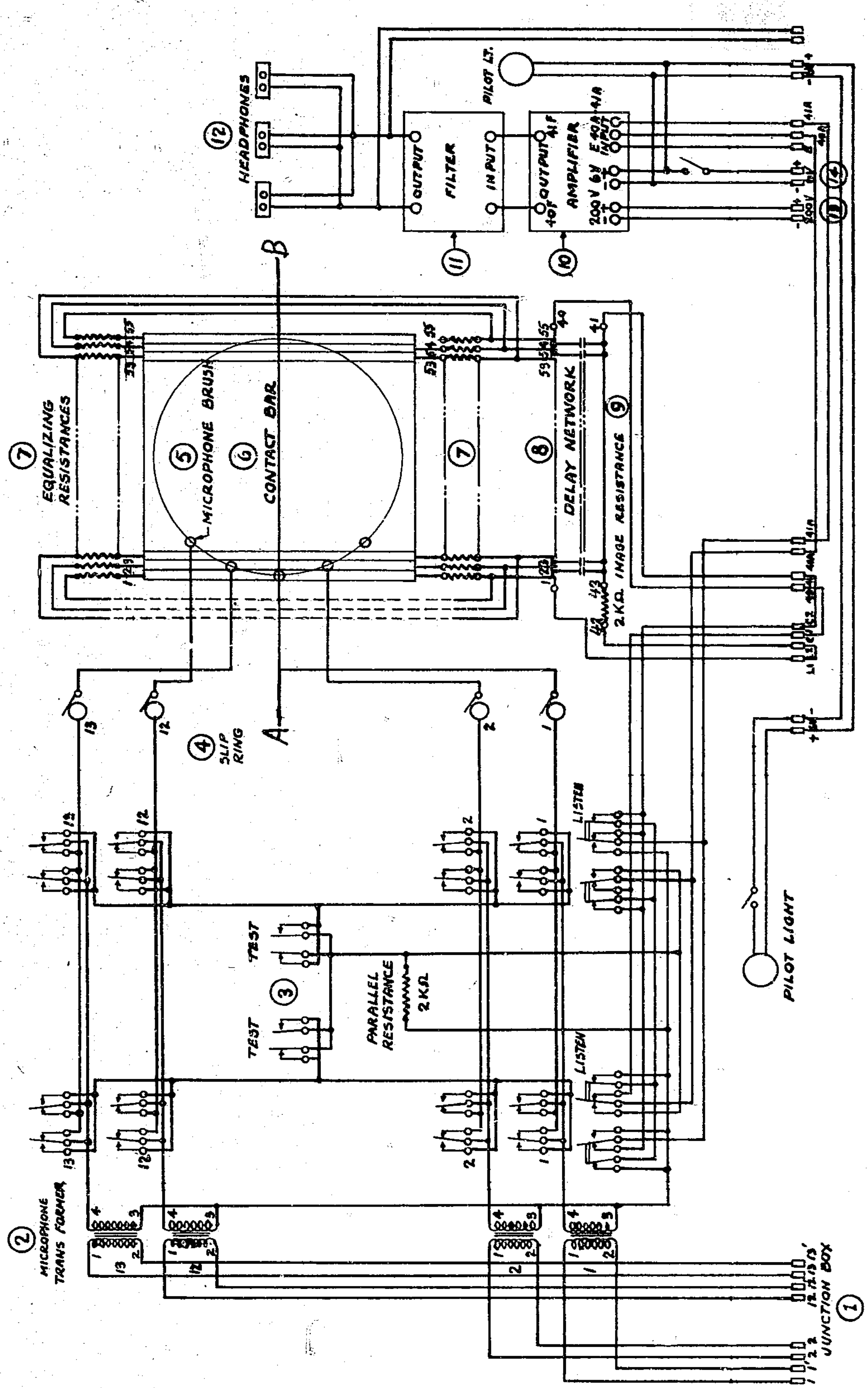
The vital part of the equipment begins here. It is necessary to arrange this brush in exactly the same form as the underwater microphones. In the Type 97, since the microphones are in a circle three meters in diameter, and the ratio is 1 to 15, the diameter of the arrangement of the screws of #5 is 300 cm x 1/15 = 20 cm.

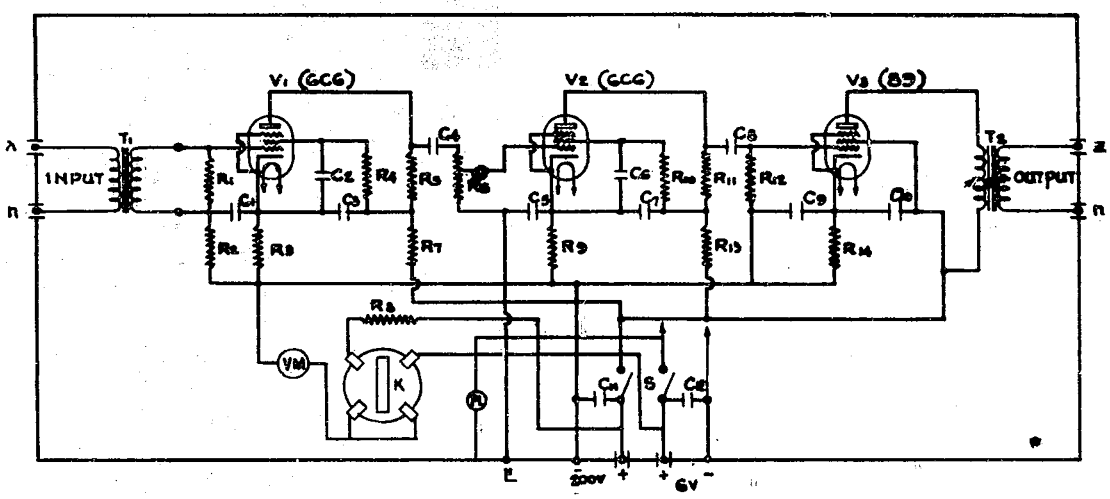
This brush, #5, can rotate freely on top of contact bar, #6, shown in Figure 12.

Contact bar, #6, is an extremely smooth, flat surface, composed of alternate parallel strips of conductors and insulators. The total number of strips of conducting material is 51. The interval between one conductor and the next is 200mm x 1/50 or 4mm. This interval must be made as accurate as possible.

It is important that contact brush, #6, and microphone brush, #5, establish perfect electrical contact. As #5 rotates, each brush from 1 to 13 moves from bar to bar. During this movement the electric current resistance must not change. If there is any change, static will result. There is a chance that two brushes may contact one bar. In this case the line and common return of the delay net will be connected by a very low resistance. To protect this connection, contact bar, #6, is divided into two parts, upper and lower, by line AB, and insulated. Next, each bar of contact bar, #6, is connected to equalizing resistance, #7, above and below the division. This equalizing resistance, #7, is connected to equalize the difference in loss for the various microphones in the delay network. The value of the resistance is small at the left-hand side of the figure and increases going to the right. The resistance has a minimum of 2000 ohms and a maximum of 11,500 ohms. The two pairs of equalizing resistance, upper and lower, are connected in parallel, and together are connected to delay network, #8. This network is a T-type net such as was shown earlier. The values of L, C and M are as already described. This is the Pierce net, discovered by Professor G. W. Pierce of Harvard University. By this delay network, #8, the underwater length of 3 meters will be divided by 50, giving 6 cm, therefore, the time lag can be accurately adjusted for this limit. In this delay network, #8, the phase is perfectly adjusted and superimposed for the direction of the sound source, and the current output at terminals 40 and 41.

In this case, the same current will flow out the opposite terminals, 42 and 43, where it is reflected back to 40 and 41. This phenomenon disturbs hearing, so that at terminals 42 and 43 the reflection must be prevented. To accomplish this, absorption resistance, #9, is connected between 42 and 43. The value of this resistance must be equal to the surge impedance of the delay network. In this case, the value used is 2000 ohms.


HEADPHONES
12
FILTER
OUTPUT
INPUT
11
AMPLIFIER
10
PILOT LT.
EQUALIZING RESISTANCES
7
MICROPHONE BRUSH
5
CONTACT BAR
6
DELAY NETWORK
8
2 KΩ IMAGE RESISTANCE
9
A
B
SLIP RING
4
TEST
3
PARALLEL RESISTANCE
2 KΩ
LISTEN
PILOT LIGHT
MICROPHONE TRANS FORMER
2
JUNCTION BOX
1



VM - Voltmeter
S - Switch
PL - Pilot light
K - 6 V, 200V Selector Switch

V_1 - 6C6
V_2 - 6C6
V_3 - 89
T_1 - Input Transformer
T_2 - Output Transformer
R_1 - 200 K ohms
R_2 - 1 K ohms
R_3 - 600 ohms
R_4 - 100 K ohms
R_5 - 30 K ohms
R_6 - Gain Control
R_7 - 10 K ohms
R_8 - Multiplier
R_9 - 600 ohms
R_{10} - 100 K ohms
R_{11} - 30 K ohms
R_{12} - 500 K ohms
R_{13} - 10 K ohms
R_{14} - 700 ohms
C_1, 2, 3, 5, 6, 7, 9, 10, 11, 12 - All equal to 2 microfarads
C_4, C_8 - 0.05 microfarads

Figure 13

WIRING DIAGRAM OF THE TYPE 97 HYDROPHONE AMPLIFIER

The current flows out terminals 40 and 41 and is amplified by amplifier, #10, and then filtered by electric filter, #11, and then is heard in the earphones, #12. To operate the amplifier, batteries, #13 and #14 in the battery room are used as a power source.

The front and side views of the bearing indicator are shown in Figure 14.

C. Efficiency

The range of the Type 97 hydrophone depends on the size, type and speed of the target, which in turn vary the sound intensity, tone (quality), and beat frequency of received signals. Also, the range depends on the turbulence of the water, extraneous noise, depth of the sea, and contour of the sea floor.

The following ranges were obtained with Type 97 hydrophone:

Range (meters) Minimum	Maximum	Type Submarine (Submerged)	Speed (Knots)
0	1000	"RO" (500-1000 tons)	Under 3
2000	8000	"RO"	5
500	3000	"I" (over 1000 tons)	Under 3
5000	10000	"I"	5

It is very important to remember that the range varies greatly, depending on the speed of the target. Figure 15 shows the relation between sound intensity (in decibels) and speed of target (in knots).

As the graph shows, below three knots all submarines emit very little noise, so that their detection is extremely difficult. On the other hand, above three knots, noise increases rapidly with a corresponding increase in detection range. At this speed, not only the sound intensity but also the tone and heat frequency vary rapidly with the result that the signal can be clearly distinguished from background noises. It is believed that this sudden increase in noise is caused by propeller cavitation.

Every effort was made to detect submarines making less than three knots, but success was never achieved.

Background noises in the sea can be separated into two classes; general background noise, and special background noise.

General background noise is always present from about -5 db to -18 db. Its causes are not definitely known but are believed to be surface waves, shore waves, tidal currents, etc.

Special noise appears from time to time in certain localities. It is especially noticeable near harbors and presents a serious problem for harbor defense. See Figure 16, which shows the results of tests run at ENOURA Bay on 27 and 28 August 1944.

Special noise was so strong at BUNGO SUIDO that submarines could not be heard and harbor defense became a real problem at that point.

Fish noise was the principal cause of this undesirable condition and no means of eliminating it was found. The following species of fish are considered chiefly responsible: Grunt fishes (Sea-robin, toad-fish, etc), Squeteague and Maigre. (See NavTechJap Report, "Oceanography in Japan", Index No. X-40(N))

The contour of the sea floor definitely affects the hydrophone range. For example, see Figure 17.

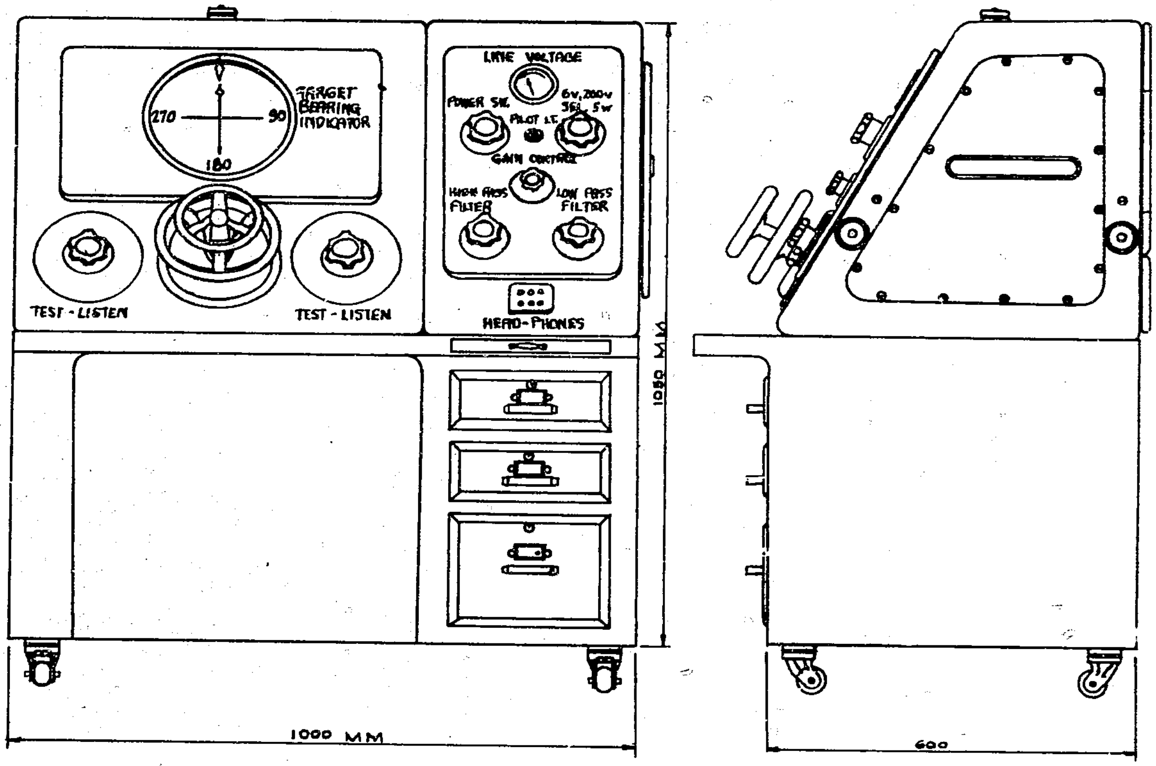


Figure 14

FRONT AND SIDE VIEWS OF THE TYPE 97 HYDROPHONE SONIC BEARING EVALUATOR

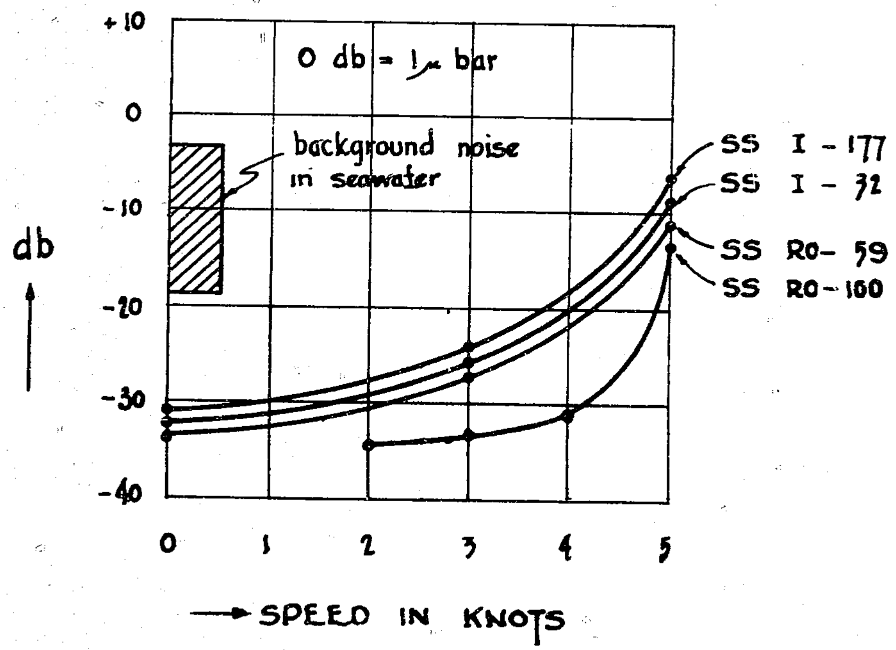


Figure 15

GRAPH SHOWING RELATION BETWEEN SOUND INTENSITY AND SPEED OF TARGET

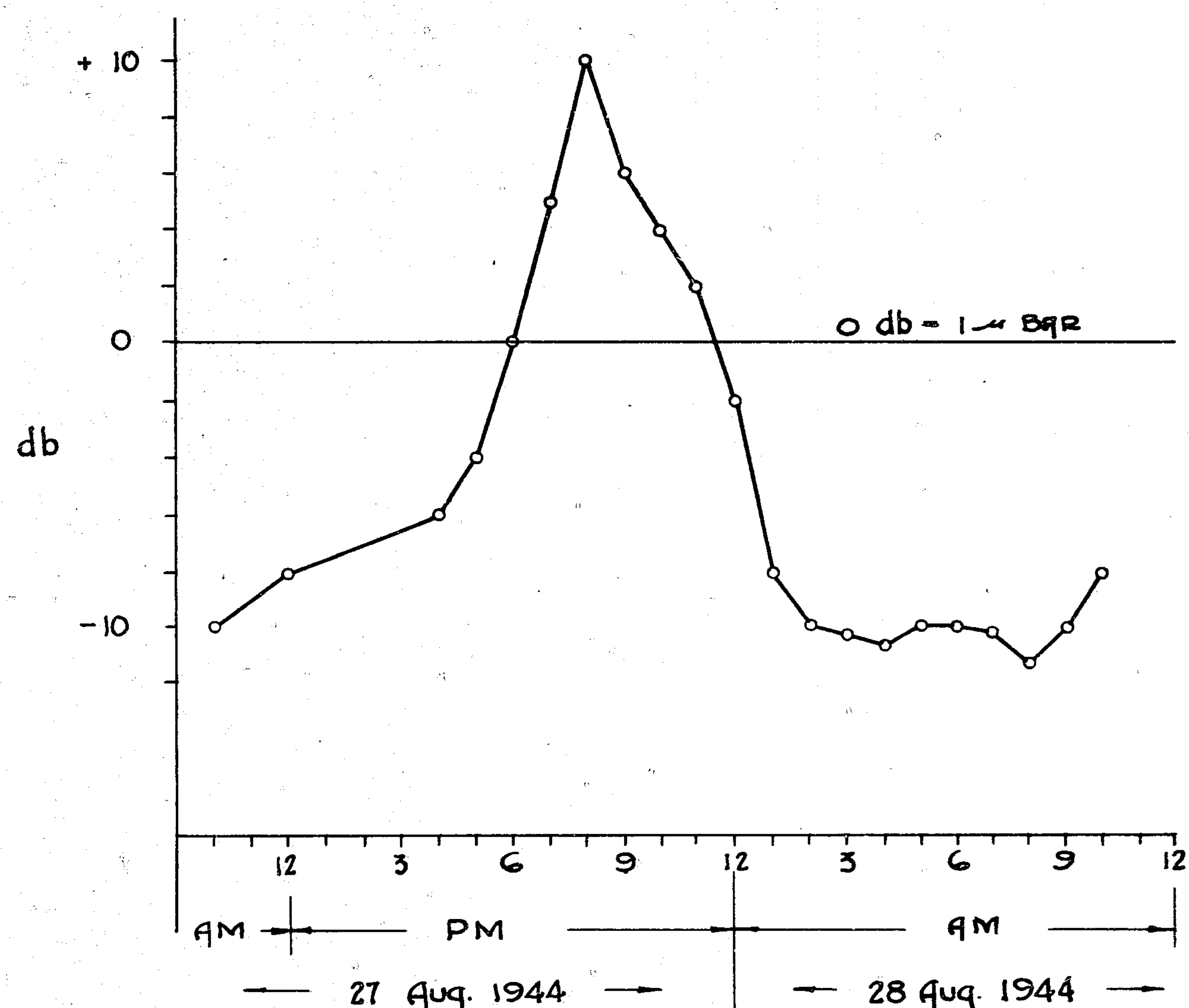


Figure 16

GRAPH SHOWING RELATION BETWEEN SPECIAL BACKGROUND NOISE (FISH NOISE, ETC.) AND THE TIME OF DAY

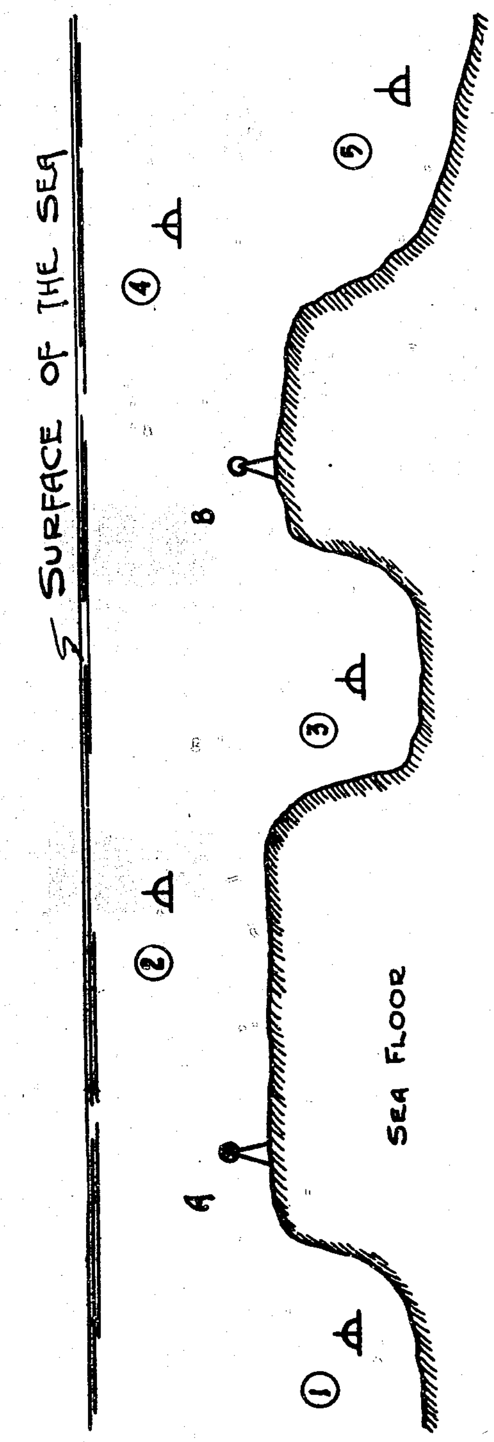


Figure 17
DIAGRAM SHOWING THE EFFECT OF THE CONTOUR OF THE SEA FLOOR ON HYDROPHONE RANGE

When hydrophones are at positions A and B, optimum conditions exist for detection of submarines at 2 and 4 while just the opposite is true for 1, 3 and 5. Therefore, the form of the sea bottom must be carefully studied before laying hydrophones.

The subaqueous condition of the sea markedly affects the transmission of sound in the supersonic range, however, the effect on reception by the Type 97 hydrophone is slight since it operates in the audio range from 500 to 2500 cycles per second.

The major maintenance problems included: water leaking into the microphones, wear of the microphone brush, and breakdown of insulation, amplifier tubes, and power supplies.

Quite often, water leaked into the microphones over a long period of time, corroding the metal and causing the rubber packing to deteriorate.

The contact between the contact bar and the microphone brush often failed. The contact bar is very difficult to change, therefore, it was made of hard metal, usually nickel, and polished with oil once a week to prevent corrosion. The brush was tested occasionally and changed, if necessary. Sometimes the brush spring failed.

An insulation test was made daily on the microphones with a 500 volt megger and if the reading fell below one megohm it was considered unsatisfactory. However, it was so much trouble to change all the microphones that this would not be done unless three or more were unsatisfactory. Sometimes the shore cable shorted at the point of contact with the land, due to the waves beating the cable on the rocks, especially during typhoons. Moisture often caused a breakdown of insulation of the condensers in the delay network. All current conducting parts were insulation tested with a 500 volt megger and changed for values below one megohm.

The amplifier tube was checked occasionally, and changed if bad.

The voltage of the power source batteries was carefully checked. Sometimes the internal resistance became great, due to careless handling.

ENCLOSURE (A)

LIST OF DOCUMENTS FORWARDED TO THE WASHINGTON DOCUMENT CENTER

NavTechJap No.	Title	ATIS No.
ND 50-5400	Japanese Hydrographic Office Bulletin No. 14, dated 6 October 1945.	3279
ND 21-6262	Type 97 Hydrophone (Manufacturer's Blueprints).	3443
ND 21-6263	Type 97 Hydrophone (Manufacturer's Blueprints).	3444
ND 21-4583	Type 92 Controlled Mine.	3140
ND 21-4584	Type 92 Controlled Mine and Type 97 Hydrophone.	3140

ENCLOSURE (B)

LIST OF EQUIPMENT FORWARDED TO THE NAVAL RESEARCH LABORATORY, ANACOSTIA, DC.

NavTechJap No.	Title
JE 10-6053	Type 2 Model 1 Magnetic Loop Detector.
JE 10-6052	Type 2 Model 4 Magnetic Loop Detector.
JE 10-6054	Type 97 Model 2 Hydrophone.
JE 10-6061	Hydrophone Head For Use With Type 92 Mine.
JE 10-6010	Type 3 Mark 1 Model 3 Radar.
JE 10-6020	Type 3 Model 3 Echo-Ranging Equipment.