UNDERWATER SOUND RANGING EQUIPMENT

INTRODUCTION

Previous to 1930 investigation of the employment of subaqueous sound for the location and tracking of ships and submarines was carried on jointly by the Coast Artillery and the Signal Corps at Fort H. G. Wright, New York. In July 1930, this activity was transferred to the Signal Corps Laboratories, Fort Monmouth, New Jersey. This transfer involved the moving of some considerable laboratory equipment and certain personnel.

In the developments carried on at Fort H. G. Wright and continued at the Signal Corps Laboratories, audio sound signals were converted into bearings by bringing the signals from two separate groups of receivers into phase, such phase equality being determined by the binaural sense. In the work at Fort H. G. Wright, the receivers were mounted on fixed underwater structures and electrical compensators in the shore station were used to produce phase equality by introducing time delays in the channel of leading phase. Very satisfactory results were obtained. However, the electrical equipment required in the shore station was complicated, expensive, and difficult to maintain.

The efforts of the Signal Corps Laboratories were directed first toward the design and construction of an underwater structure such that the receivers were housed in a horizontal beam which could be rotated about a vertical axis. Equality of phase in the two receiver channels was accomplished by an electro-mechanical means -- that is by rotating the receiver housing to a position such that the subaqueous sound signals arrived in phase. The binaural sense was employed to indicate the direction of rotation

required, and the instant phase equality was achieved. The development of a new type of underwater microphone was carried on at the same time.

The early work was carried on without military characteristics or assignment of nomenclature. The underwater structure referred to above was called the "Rotating Beam". One model of this is illustrated by the photograph of Inclosure #1. Starting from the bottom, this structure consists of:

a. A triangular steel base.

b. A water-tight caisson, mounted on the base, containing a direct current electric motor with a speed reduction gearing, a special potentiometer which serves as a sea end of azimuth indication equipment, and a system of collector rings. In the upper part of the caisson there was a shaft, supported by suitable bearings, the lower end of which was connected to the speed reduction unit and the upper end extended through a packing gland. Cable for supplying direct current power to the motor and another cable for transmission of the microphone signals and azimuth indications entered the caisson through a water-tight junction box at the lower end of the caisson.

c. A microphone housing mounted on top of the shaft referred to in third paragraph. This housing was a steel tube 10 inches in diameter and 42 feet long. This contained 30 Navy type SE-1612 Hydrophones (microphones). These were later replaced with moving coil microphones developed in the Signal Corps Laboratories.

d. A diving bell was fastened by a water-tight joint to the portion of the shaft protruded above the caisson. This protected the packing gland at the upper end of the caisson by trapping air as structure was lowered into the water.

The shore station consisted of two identical audio frequency amplifiers carefully matched as to gain and phase delay; and the shore end of the azimuth

indicating equipment which consisted of a panel containing on the front side an azimuth circle and on the back side a potentiometer identical with that in the rotating beam.

In the complete equipment there were two identical sound channels. The microphones in one end of the beam (say the right end) were connected through brushes and collector rings in the caisson to conductors in the signal cable, which in turn were connected with one amplifier in the shore station. The output of the amplifier was fed into the right receiver of a binaural headset. Likewise, the other sound channel started with the microphones in the left end of the beam and terminated in the left receiver of the binaural headset.

During the years 1931 to 1934, various modifications of the rotating beam were made and tested. The shore station was located in a Coast Guard Building at Sea Bright, New Jersey and the underwater equipment was planted about 1-1/2 miles out to sea. The last equipment installed at this location was completed 12 January 1934. This equipment was submitted to engineering test by personnel of the Signal Corps Laboratories and was also service tested by representatives of the Coast Artillery Board. The engineering and service tests occupied the entire calendar year of 1934.

The results of the engineering tests are given in SCL Engineering Report No. 432, dated 12 January 1935. The important results may be summarized as follows:

a. The range of the equipment in tracking the ships of from 3,000 to 8,000 tons, travelling at a speed of 10 to 17 knots, was between 20,000 to 55,000 yards in winter and 10,000 yards in summer. Trans-atlantic liners were tracked to 60,000 yards and sometimes more than 100,000 yards. In summer, the maximum range of this class of boat was approximately 15,000 yards.

b. When account is taken of corrections which may be applied to the indicated azimuth, the probable error of azimuth is .206°.

In the service test report, No. 993, dated 3 January 1935, by the Coast Artillery Board, it was recommended that the development of the rotating beam installation be continued for the purpose of increasing the accuracy in direction and that the Chief Signal Officer be requested to conduct preliminary surveys of water areas pertaining to designated Harbor Defenses to determine in each case if conditions are suitable for installation of underwater sound equipment.

DEVELOPMENT OF LOCATOR SET GR-5

In connection with the Project Program for FY 1937, the Signal Corps Laboratories received a directive from Chief Signal Officer to start the development of Subaqueous Sound Ranging Equipment for installation in the Harbor Defenses of Puget Sound. This equipment was assigned the following nomenclature "Hydracoustic Tracking Set GR-5." It consisted of two each Hydrophones M-159 (circumferentor), one Hydrophone Control Equipment IE-5 (two-position), and Cable WC-533. Later this terminology was changed to read as follows: Locator Set GR-5 consisting of two Direction Finders M-159, one Control Equipment IE-5, and Cable WC-533 (submarine).

The selection of Puget Sound as a location for testing a complete Locator Set GR-5 was governed by the following considerations:

a. Swift tidal currents and a large tidal range rendered standard submarine mining impossible.

b. Tests carried out by the Navy in the late summer of 1936 indicated that submarine detection equipment carried by patrol vessels at that time was not capable of detecting submarines attempting to enter Admiralty Inlet during flood tide.

c. Hence, it seemed desirable to test Locator Set GR-5 as a means of submarine detection.

There was some doubt as to whether the Signal Corps equipment would be capable of detecting submarines running submerged at low speeds at the required ranges. Hence, it was decided to add to the equipment already developed for binaural listening, a pulse echo-ranging system operating at 3,000 c.p.s.

The first direction finder which contained the additional echo-ranging equipment was completed and installed in Puget Sound in June 1938. The location selected for this installation was found to be unsuitable and the following spring the direction finder was moved to a new location. During the summer of 1939, another direction finder, less the echo-ranging equipment, and with a 50 ft. beam was completed and installed in Puget Sound. During this summer, extensive engineering tests were conducted by personnel of the Signal Corps Laboratories and representatives of the Coast Artillery. For these tests, two submarines were furnished by the Navy and were available for a period of two months. The results of this test may be summarized as follows:

a. The Echo-Ranging Equipment of Direction Finder M-159 was not adequate for detection of submarines running submerged at low speed.

b. The Direction Finder M-159 using binaural listening was successful in detecting submarines running submerged at low speed.

The report of service test recommended that echo-ranging devices separate from binaural listening equipment be developed for the detection of submarines. The first direction finder was modified to conform to the second direction finder designed for binaural listening only, and later was planted at a new location.

Standardization of Locator Set GR-5 was recommended by SCTC Meeting No. 184, 7 December 1940, and approved by the Adjutant General on 21 March 1941. The completed installation of Locator Set GR-5 in Harbor Defenses of Puget Sound was transferred to Commanding Officer, Harbor Defenses of Puget Sound in April 1941.

In February 1940, Signal Corps Laboratories were directed by Chief Signal Officer to procure a Locator Set GR-5 for Harbor Defenses of San Francisco. The delivery of this equipment was made during the summer of 1941 and installation was completed at the end of November 1941. After 7 December 1941, this locator set was manned and operated on a 24-hour basis.

SUPERSONIC ECHO-RANGING EQUIPMENT

A project for the development of shore controlled supersonic echo-ranging equipment was authorized by the Chief Signal Officer in the Project Program for FY 1941. After preliminary investigations were made by the Signal Corps Laboratories, a contract was consummated with the Submarine Signal Company, Boston, Massachusetts, for the construction of supersonic echo-ranging equipment. The equipment called for in the contract consisted of a sea unit, shore control equipment and cable for connecting the sea unit to the shore control equipment. The transceiver of the sea unit was essentially the same as the magnetostriction transceiver used by the Navy in ship-board installations. This was mounted upon a suitable steel tripod so the entire structure could be planted on sea bottom. This equipment was completed in the spring of 1942 and installation was completed in May of the same year. Due to the transfer of all underwater sound ranging projects to the Navy, no comprehensive range test for this equipment was made.

TRANSFER OF UNDERWATER SOUND RANGING ACTIVITIES
TO THE NAVY

In report of action of Joint Army and Navy Board, file JB-303, serial 741, dated 3 February 1942, subject: "Responsibility for Fixed Underwater Listening Posts — Proposed Changes in Joint Action of the Army and Navy," it was recommended that "the Army will not provide and operate or maintain ——— a system of underwater listening posts." A copy of this report was forwarded to the Signal Corps Laboratories as inclosure to letter from the Chief Signal Officer, dated 3 March 1942, subject: "Responsibility for Fixed Underwater Listening Posts". In this letter, it is stated that the final plans for the transfer of the subaqueous project to the Navy will be arranged at a later date.

A conference was held at Signal Corps Laboratories 16 and 17 June 1942 to consider the procedure for transferring subaqueous sound ranging projects and equipments from the Signal Corps to the Navy. This conference was attended by representatives of the Navy Department, Office of the Chief Signal Officer, and Signal Corps General Development Laboratories. The recommendations of this conference were forwarded to the Chief Signal Officer by letter dated 18 June 1942, subject: "Transfer of Subaqueous Sound Ranging Projects and Equipment Pertaining thereto." In connection with the transfer, it was recommended at the request of the Navy, that the classification of all equipment and documents pertaining thereto be changed from "Secret" to "Confidential". The recommendation of this conference, including the matter of classification, was approved by 1st Indorsement, dated 25 June 1942, from the Chief Signal Officer to Director, Signal Corps General Development Laboratories.

ROTATING BEAM

Fig. 1.

Incl 1

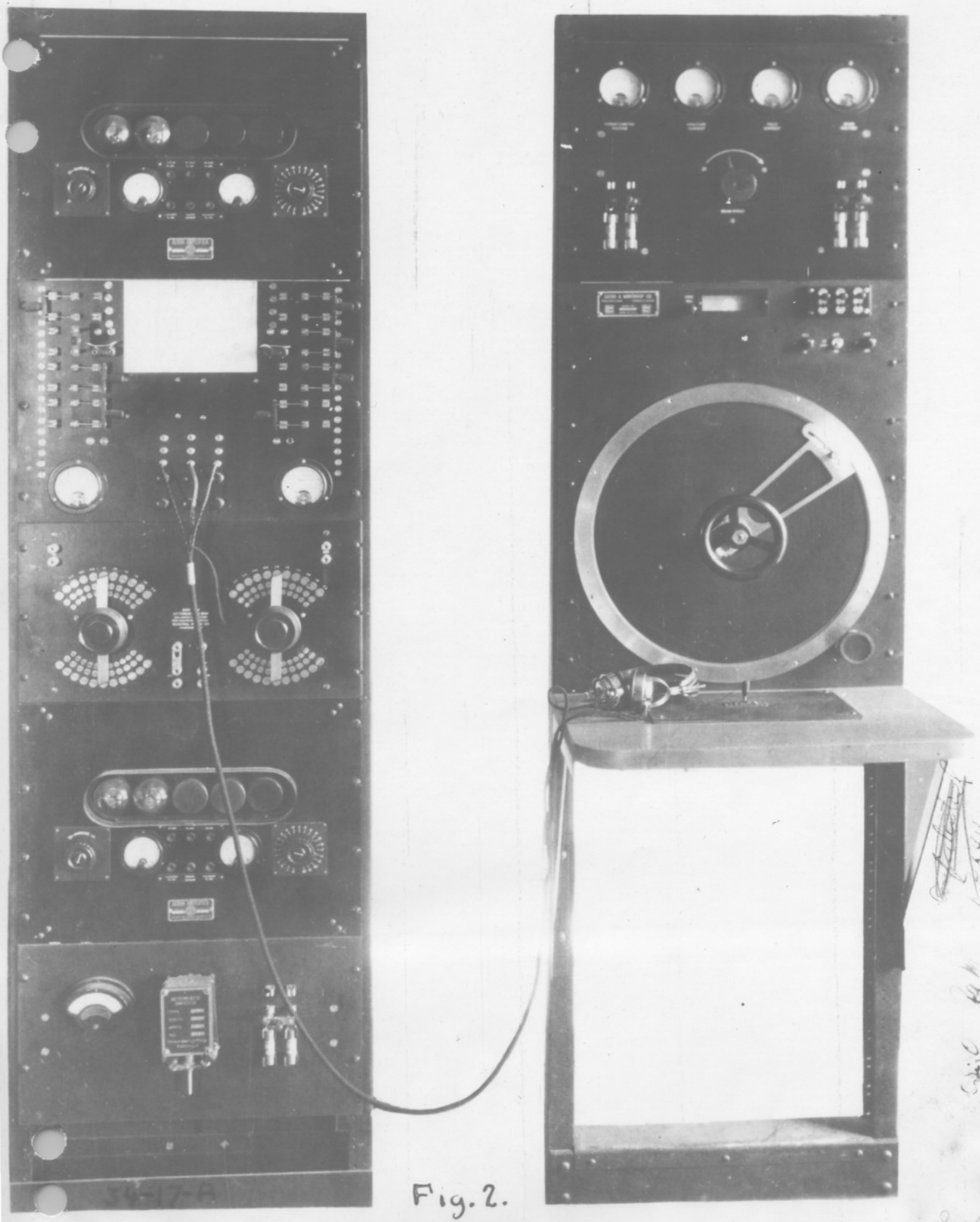
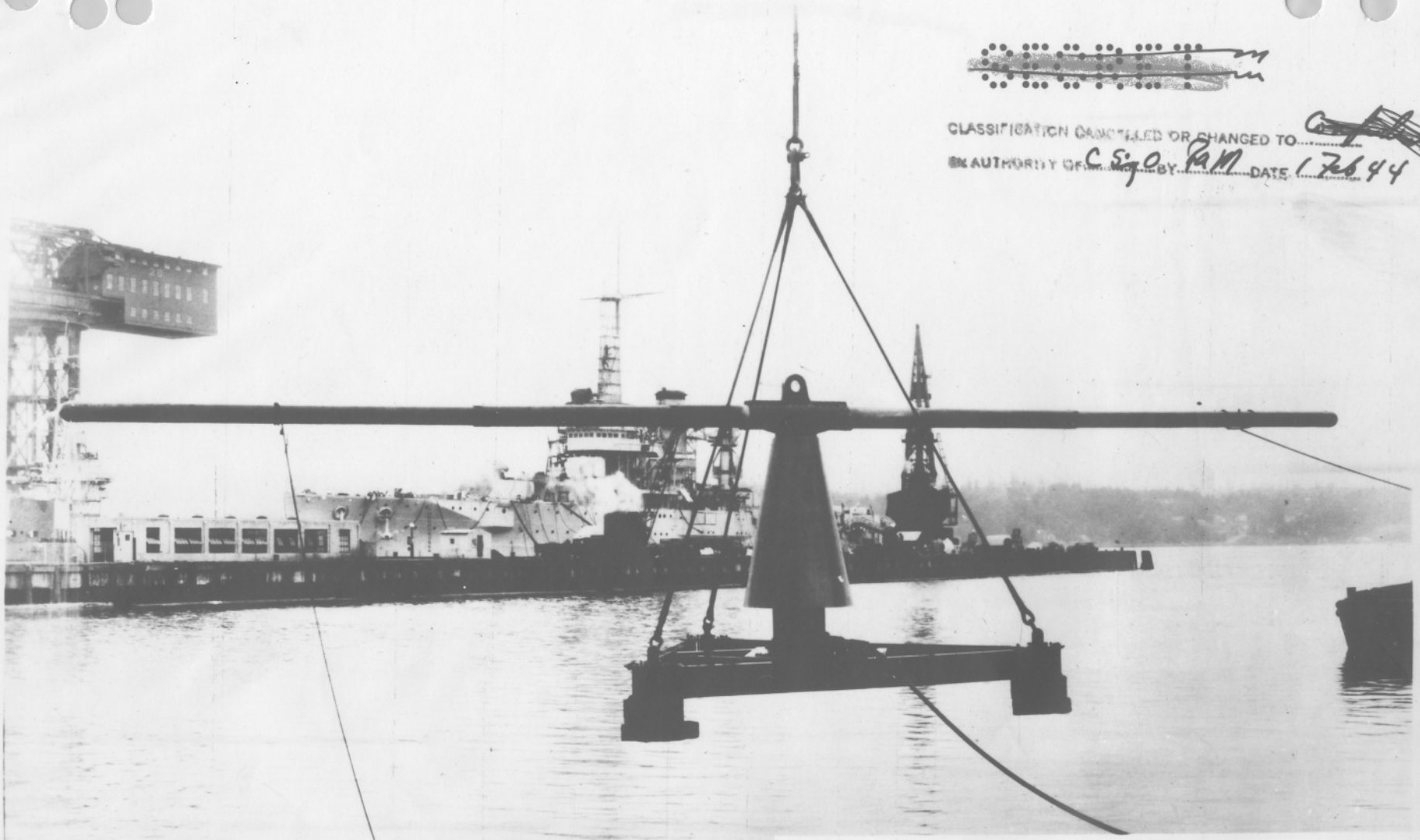


Fig. 2.

SHORE CONTROL EQUIPMENT

[redacted]

CLASSIFICATION CANCELLED OR CHANGED TO ~~Confidential~~
BY AUTHORITY OF C Sig O BY RaM DATE 1 Feb 44



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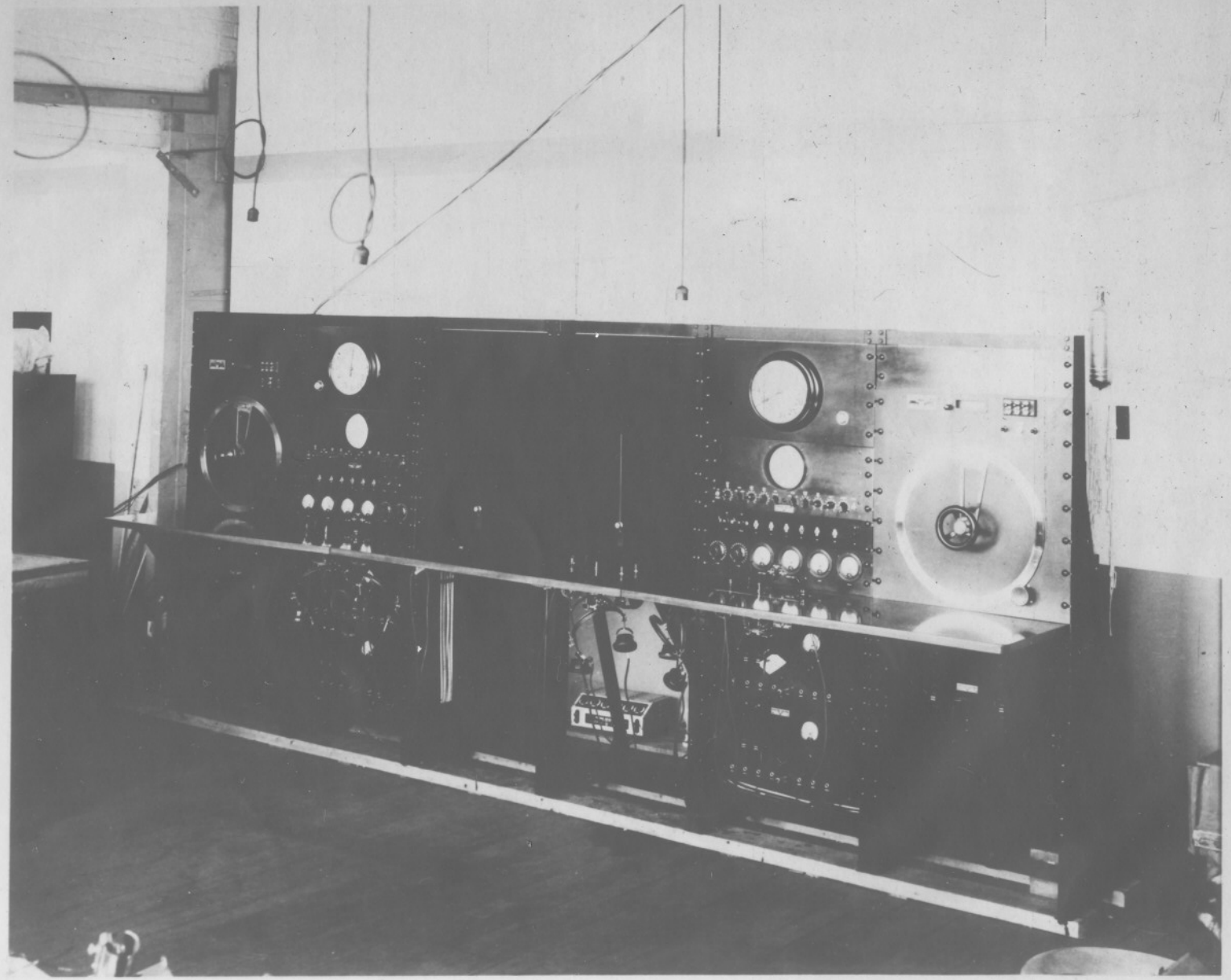
SIGNAL CORPS LABORATORIES, FORT MONMOUTH, N. J.

HYDROPHONE M-159-T2
AFTER SUBMERSION

Dwd 3



CONTROL EQUIPMENT IE-5

CONFIDENTIAL

Incl 4

ENGINEERING REPORTS ON UNDERWATER
SOUND RANGING EQUIPMENT.

1. SCL Engineering Report No. 30, dated 20 February 1932, subject: "Preliminary Study of a Proposed Subaqueous Sound Ranging Installation, Harbor Defense of Manilla and Subic Bays", by Lt. Bixby and Dr. H. A. Zahl.

2. SCL Engineering Report No. 69, dated 13 May 1932, subject: "Performance of Rotating Beam RB-1", by Dr. H. A. Zahl, (project 85-C).

3. SCL Engineering Report No. 116, dated 11 July 1932, subject: "Preliminary Study of the Factors in the Propagation of Underwater Sounds which affect Azimuth and Range in Subaqueous Sound Ranging", by M. J. E. Golay, (project 85b).

4. SCL Engineering Report No. 135, dated 26 August 1932, subject: "Subaqueous Rotating Beam RB-1", by Dr. H. A. Zahl, (project 85-C).

5. SCL Engineering Report No. 165, dated 17 October 1932, subject: "Supplementary Report on Subaqueous Rotating Beam Station RB-1", by Dr. H. A. Zahl, (project 85-C).

6. SCL Engineering Report No. 432, dated 12 January 1935, subject: "Engineering Tests of Sea Bright Hydracoustic Circumferentor", by Dr. H. A. Zahl and M. J. E. Golay, (project 85-C).

7. SCL Engineering Report No. 568, dated 13 March 1937, subject: "Hydracoustic Listening Tests on Submarine S-20", by M. J. E. Golay, (project 85).

8. Field Engineering Report No. 1, 8 May 1939, "Test and Overhaul of Hydrophone M-159-T3," by Master Sergeant Fred Timmerman.

9. Field Engineering Report No. 2, 14 October 1940, "Modification and Overhaul of Direction Finder M-159, Serial No. 2," by Captain Fred Timmerman, Signal Reserve.

10. Special Report on Locator Set GR-5, 22 September 1941, by Captain Fred Timmerman, Signal Corps.

11. Memorandum for File, S&L-524, dated 4 August 1942, subject: "Installation Report - Locator Set GR-9," by G. W. James.

12. SCGDL Engineering Report No. C-2, dated 22 August 1942, subject: "Ocean Temperatures Off New York Harbor, Narragansett Bay and Boston during March to June 1942 and their Relation to Underwater Sound Ranging," by Dr. Raymond B. Montgomery.

Incl. 5

[redacted]

MACHINE GUN LOCATOR.

A. Introduction.

1. In January 1940, the Chief Signal Officer, at the request of the Chief of Staff, set up a project for the development of a machine gun locator, which was assigned to the Signal Corps Laboratories, Fort Monmouth, by letter file OCSigO-111-FY-1941, dated September 24, 1940, from the Chief Signal Officer, subject: "Revised Expenditure Program FY-1941," to these Laboratories.

2. The following military characteristics were set up at the SCTC Meeting No. 182 on 1 October 1940, at which meeting the project was classified as "Secret:"

a. General: A portable, simple but accurate device for determining the location of a machine gun emplacement.

b. Light weight, rugged, portable.

c. Accuracy of $\pm 1^{\circ}$ at distances up to 1 mile.

d. Apparatus may be mechanical, electrical, or acoustical; mechanical or acoustical preferred.

e. Usable by personnel with no special training.

3. Nomenclature assignment "Sound Locating Set GR-6" was made by letter, file OCSigO-413.44(GR-6), from Chief Signal Officer, dated 5 December 1940, subject: "Sound Locating Set GR-6", to Director, Signal Corps Laboratories.

B. Preliminary Development.

1. The period from September 1940 to July 1942 was characterized by a comprehensive investigation of the suitability of simple binaural methods for this application, and an examination and test of equipment submitted by outside agencies.

[redacted]

2. Binaural Methods. After considerable preliminary laboratory and field work, the suitability of the direct binaural method was subjected to a final testing at Fort Dix, New Jersey, during the period 29 June to 3 July 1942.

a. Purpose. The purpose of these tests was to determine the following:

(1) The effect of training and adaptability on the accuracy with which operators can determine a location.

(2) The relative effectiveness of the various binaural devices in locating a machine gun.

(3) The manner of firing most susceptible to location by binaural means, and the minimum number of rounds and duration of fire necessary to determine a location.

(4) The effectiveness of the various locators under quasi-tactical conditions, i.e., the ability to make a location and the accuracy that can be obtained when two or more guns are firing simultaneously from different locations.

(5) The general suitability of the binaural method to the problem of locating machine guns.

b. Equipment. The following types of binaural locators were tested:

(1) Rangertone Machine Gun Locator. This is a mechanical binaural device submitted by R. H. Ranger, Rangertone Inc., Newark, New Jersey, using gas filled sound-collecting chambers instead of horns. The gas used has a velocity of sound higher than the velocity of sound in air and the principle of operation is claimed to be similar to that of

a directional antenna array as used in radio reception. Inclosures 1 and 2, Photographs #SCGDL-818-S and #SCGDL-819-S, respectively show the test installation in a pit on the firing range.

(2) Conical Horn. This is a truncated cone having an opening six inches in diameter and length of approximately 18 inches. Inclosure 3, Photograph #SCGDL-820-S, shows the installation in a pit on the firing range.

(3) Insulated Conical Horn. This equipment has the horn suspended in the housing with sponge rubber to minimize the transmission of mechanical vibration. Insulation is provided to minimize the transmission of ambient noise through the walls. Inclosure 4, Photograph SCGDL-315-S, shows the instrument as normally set up. In these tests, the horns were mounted on the beam shown in Photograph #SCGDL-820-S in place of the conical horns.

(4) Exponential Horn. Each section of this binaural unit consists of eight small exponential horns folded and connected to a common throat. Inclosure 5, Photograph #SCGDL-310-S, shows an early assembly. In these tests the sections were mounted on the beam shown in Photograph #SCGDL-820-S in place of the conical horns.

c. Results and Conclusions:

(1) The Rangertone Locator failed to locate machine gun fire with acceptable accuracy.

(2) The results with other binaural locators were generally unsatisfactory and indicated that there was little choice

between instruments with respect to accuracy, ease of handling, etc. Also, using operators with special training produced results not very much improved over results obtained with average operators. The conclusion reached was that the application of binaural methods directly to the location of the source of a transient was impractical, and that a practical solution of this problem must incorporate means for selecting and "trapping" the transient and retaining it for a period long enough to extract the required information.

3. Outside Development:

a. Rangertone Machine Gun Locator (described in Paragraph 2b(1) above).

b. Rieber Machine Gun Locator. This locator was designed and built by Frank Rieber Inc., Los Angeles, California, and was submitted by the owner, Mr. Kelvin Smith. The locator was tested at Fort Benning, Georgia, 7-9 July 1941. This device records sound arrivals on a magnetic tape and determines the azimuth of arrival to a co-linear array of microphones by the in-phase addition of recorded pulses. Inclosures 6 and 7, Photographs #SCGSA-1763-S and #SCGSA-1764-S, respectively, show the complete experimental equipment and some details of the recording device. The equipment failed in this testing because of the inability to distinguish between pertinent muzzle blast recording and extraneous recordings produced by ballistic, ambient noise and reflections. No further testing or development was recommended.

C. Current Development.

1. Triangle Method. The proposed design is a reduction of the instrumentation of the triangle method of sound ranging to meet the requirements of the new application. In this method, sound arrivals are detected by three microphones placed in a small triangular array, recording is on magnetic tape, and scanning to determine relative differences in the time of arrival at the microphones is accomplished electronically by means of a small cathode ray oscilloscope or aurally by binaural playback of the recorded signals using matched headphones. The following types were developed:

a. GR-6-T1 Visual Scanning Locator. Design and construction of this locator was accomplished under contract by the Western Electric Company, New York. This locator services two triangular arrays on a known base line and determines two azimuths, the intersection of which gives a location of the sound source. The scanned image shows the character of the sound pulse recorded. Views of this equipment are shown in Inclosures 8, 9, 10 and 11, Photographs #SCCSA-1760-S, #SCCSA-1761-S, #SCCSA-1762-S, and #SCCSA-1759-S, respectively.

b. GR-6-T2. Employs same basic method as the GR-6-T1, furnishes similar data, but the design of equipment is quite different. This locator was designed and built under contract by the Rieber Research Laboratory, Inc., New York.

c. GR-6-T3 Aural and Visual Scanning Locator. Recording is made on magnetic tape and scanning can be accomplished by visual methods, or aurally by binaural methods or by both methods simultaneously. This equipment was designed and built under contract by the Western Electric Company, New York. This particular design resulted from the experience gained in the Laboratory and the field with the GR-6-T1 and is the type chosen for limited procurement as indicated in Paragraph 4c below.

d. GR-6-T5 Single Station Position Locator. With this equipment the location of a sound source is determined from a single array. Location of the gun is determined from a measurement of the azimuth of the muzzle blast, the azimuth of the ballistic wave, and the time interval between the arrival of the ballistic and muzzle blast. While no special equipment has so far been built for this particular method, limited field testing of the method using the GR-6-T1 shows promising results.

2. Other types.

a. GR-6-T4 Binaural Direction Indicator. A rather simple device in which arrivals are recorded on magnetic tape, scanning accomplished by binaural listening to the recorded sounds, and the azimuth of sound arrival determined by the method successive approximations.

b. GR-6-T6 Instantaneous Visual Locator. A locator using two pressure-gradient microphones so arranged at one position that the direction of arrival of an incident sound wave is instantly indicated by deflection of the beam of an associated cathode ray tube.

3. Results of Testing. Development of the models described above was actively prosecuted from January 1942 to November 1943, at which time a comprehensive field test was arranged for the purpose of selecting a type for limited procurement for extended service testing. These field tests were conducted at the Tobyhanna Military Reservation, Tobyhanna, Pennsylvania, from 12 November to 3 December 1943. Representatives of Army Ground Forces, Army Service Forces, Field Artillery Board, British and Australian Liaison, Western Electric Company, Bell Telephone Laboratories Inc., and SCOSA witnessed the tests and attended the ensuing conference. All existing models

of the Sound Locating Set GR-6 were tested. Machine guns of .30 and .50 calibre were fired at ranges from 300 to 2200 yards. The instruments were set up in partially-cleared, in wooded, and in obstructed areas. The intervening terrain to the gun positions was invariably wooded and hilly. The conditions in general were a fair simulation of average tactical conditions. The more important results are presented below.

a. Sound Locator Set GR-6-T1.

(1) On days of average weather conditions, records taken during daylight show mean deviations in azimuth of the order of $\pm 1^{\circ}$ with about 90% of the readings falling within a total spread of 4°.

(2) At night, the mean deviation in azimuth is about 1/3 less in magnitude.

(3) The mean deviation in azimuth increased only slightly with range.

(4) The optimum size of the microphone array is 15 feet on the side, based on considerations of all factors.

b. Sound Locating Set GR-6-T3. Results obtained with this equipment agreed with those described above for the GR-6-T1 model, except the deviations in azimuth were about 25% smaller.

c. Sound Locating Set GR-6-T6.

(1) The limited amount of testing done with this instrument indicates an accuracy comparable with that of the other types whenever arrivals are definitely indicated.

4. Conclusions. At the conference held on 29 November 1943, the following action was recommended and concurred in by those present:

a. The present models of Sound Locating Set GR-6-T1 to be modified for use as training equipment if such a training aid should prove necessary.

b. The four recording units (comprising two complete Sound Locator Sets GR-6-T3) on order with the Western Electric Company be submitted for service test to the Infantry Board.

c. Action be initiated immediately for the procurement of 100 complete Sound Locator Sets GR-6-T3 for extended service testing.

d. Work on Sound Locating Sets GR-6-T4 be discontinued as this device appeared least promising of the sets demonstrated.

e. Development be continued on Sound Locator Set GR-6-T6.

D. Present Status

1. Two complete Sound Locator Sets GR-6-T3, being procured from Western Electric Company, are scheduled for delivery on 15 February 1944.

2. Procurement of 100 complete Sound Locator Sets GR-6-T3 for extended service test has been initiated.

11 Incls.-
(Listed on following page)