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AIRBORNE MEASUREMENTS OF THE THERMAL RADIATION FROM THE SCHNORKEL AND WAKE OF THE U.S.S. DOGFISH

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AIRBORNE MEASUREMENTS OF THE THERMAL RADIATION FROM THE SCHNORKEL AND WAKE OF THE U.S.S. DOGFISH

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November 22, 1948

Approved by:

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DEPARTMENT OF THE NAVY OFFICE OF NAVAL RESEARCH

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ABSTRACT

By employing special blimp-borne detection equipment, the thermal radiation from the schnorkel and wake of the submarine U.S.S. DOGFISH was successfully measured from the air under various conditions. Although limited by "optical" noise from the surface of the sea, the apparatus easily detected schnorkel signals which reached a maximum of 37 times noise at 500 feet and $4\frac{1}{2}$ times noise at 2000 feet altitude, and detected wake signals which varied from 12 to $1\frac{1}{2}$ times noise at altitudes of from 500 to 2000 feet and distances astern the target up to 3 miles. Sufficient data was obtained to permit the development of improved apparatus for future measurements.

PROBLEM STATUS

This report concludes work on the phase of the problem assigned by the Bureau of Ships correspondence. Work on other phases of the general problem of thermal detection is continuing.

AUTHORIZATION

NRL Problem N07-02R (BuShips Problem Request NP14/L8(277), 19 May 1946, modified by BuShips ltr C-S67-(12)-(1), Serial No. 947A-762, 18 May 1948).

AIRBORNE MEASUREMENTS OF THE THERMAL RADIATION FROM THE SCHNORKEL AND WAKE OF THE U.S.S. DOGFISH

INTRODUCTION

The possibility of detecting the approximate position of either a completely submerged or a schnorkelling submarine by use of an airborne thermal radiation detector had been indicated in the past (1,2)* but had never been successfully established by actual measurements. The only informative measurements which had been made previously had been carried out at sea level. (3,4,5,6,7) It was, therefore, the purpose of this work to provide suitable airborne equipment capable of measuring from the air the magnitude of the thermal radiation from: (a) the wake of a completely submerged submarine, (b) the wake of a submerged submarine employing its schnorkel, and (c) the schnorkel itself. Such measurements provide information pertinent to the development of suitable search gear and also indicate some of the latter's limitations.

The necessary equipment was assembled and installed in a U. S. Navy blimp by the Applied Optics Section, Optics Division of this Laboratory. One set of Mark VII equipment (8) was also installed by the Infrared Division of the Underwater Sound Laboratory to provide supplementary data. After several "shakedown" runs, flights were made over the New London - Block Island area using a schnorkel-equipped submarine as a target. While measurements were being made from the air, similar measurements were made at sea level from the decks of surface vessels by the Underwater Sound Laboratory.

This report covers the measurements made with the NRL equipment only. The results obtained with the Mark VII gear and with the equipment employed at sea level may be found in another report. (9)

EQUIPMENT

Available equipment proved inadequate for the task so a hybrid system was assembled (Figure 1).† It consists of an optical head and thermopile borrowed from the Navy's Passive Bearing Finder system, (10) an NRL-constructed amplifier and power supply, and an Esterline-Angus recorder.

The optical head consists of an f-0.7, 3-inch-diameter Maksutov optical system in the focal plane of which is mounted a General Motors Corporation thermopile. The thermopile is self-compensating in that it consists of two halves connected in electrical opposition thus permitting the observation of differences in incident radiation only. The dimensions of the thermopile are such as to describe an optical field-of-view, 1.0°-0.5°-1.0° wide by 3.0° high (Figure 2). By mechanically wobbling the system's spherical mirror, the field-of-view is caused to oscillate over a 1.5° arc at a 5-cps rate. Thus a

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* Numbers in parenthesis refer to references on page 35 of this report.

† All illustrations and tables appear at end of report.

point target, for example, which lies on the optic axis, is viewed first by the left half and then the right half of the thermopile, which, in turn, generates a 5-cps voltage. A small extended target, such as a schnorkel, which can be completely included in the field-of-view, produces the same effect. However, a greatly extended target, such as a submarine's wake, must consist of a large thermal gradient or of thermal discontinuities to be detected.

By means of the associated amplifier (Figures 3-6), the 5-cps signal from the thermopile is amplified, rectified, and presented as a d-c signal on an Esterline-Angus recorder. The input impedance of the amplifier is 5 ohms and matches that of the thermopile. The effective voltage amplification of the transformer is 150 times (turns ratio = 300) which, together with that of the electronic stages and recorder, yields an overall sensitivity of approximately 60 milliamperes per microvolt from a 5-ohm generator. Selectivity (Figure 7) is obtained by capacitive plate load shunting of the pentode stages and undercoupling between them. A peak frequency of approximately 7 cps with a bandwidth of 7 cps measured between the half-voltage points is achieved in this manner. The equivalent input noise level with the 5-ohm thermopile connected is 1×10^{-9} volts which amounts to 0.04 milliamperes at the recorder. Unfortunately most of this noise originates in the first vacuum tube (flicker effect) rather than in the thermopile itself. In other words, the inherent electrical noise of the amplifier does not permit satisfactory observation of the thermal agitation noise in the thermopile. To achieve linearity over a wide range of signal strengths (Figure 8), use is made of a 5-db-per-step attenuator which permits the observation of signals as great as 500 times the normal noise level.

The recorder is an Esterline-Angus, model AW, 1400 ohms, 0-1 milliampere unit. It has a relatively slow response which, unfortunately, limits the performance of the entire system. Because of this, a much faster panel-type meter, mounted on the amplifier chassis, is employed for monitoring purposes.

The power supply (Figures 9-11) provides power for both the amplifier and the mirror-wobbling motor in the optical head. Its wiring diagram is shown in Figure 12. A standard carbon-pile regulator is employed to permit operation from a 20 to 30-volt d-c line. Metering is provided for the input voltage, the mirror-wobbling motor voltage, the amplifier plate voltage, and the amplifier filament current.

Calibration of the entire system was carried out by having the optical head scan a 1/4-inch diameter, 100°C, black-body source situated in a uniform background at a distance of 50 focal lengths from the head. The effective aperture of the head was then reduced with external stops until a signal-to-noise ratio of unity was obtained at the recorder. The radiation at a known distance from the black-body source was then measured with a calibrated thermopile and galvanometer. Employing the inverse-square law, the flux density at the head was calculated. From this quantity the total flux entering the stopped-down optical head was calculated and the equivalent flux density for an unstopped aperture was determined. The value is 1.5×10^{-9} watts/cm^2 which is the E.N.I. (Equivalent Noise Input) of the entire system. In a similar manner the sensitivity of the system was found to be 27 milliamperes/microwatt/cm^2.

SHAKEDOWN TESTS

The entire system was installed in the K-65, a U. S. Navy blimp, at the Naval Air Station, Lakehurst, N. J. A section of the deck in the forward part of the ship was removed and the optical head which was mounted on a special frame was placed over the hole (Figure 13). Provisions were made to move the frame easily so that the optical field-of-view could wobble either along the length of the ship or athwartship. In addition, the optical head could be tilted in the direction of the wobble. The false bottom in the ship, however, restricted the angle of tilt to approximately 15° either side of the vertical.

A number of shakedown flights were made off the New Jersey shore prior to the scheduled submarine tests at New London. The wakes from passing freighters were used as targets. Since it was not the purpose of these runs to accumulate data but rather to get the "bugs" out of the apparatus, not much attention was paid to operational ranges. However, it was noted that radiation from wakes up to eight miles astern the freighters could be measured.

Three sources of trouble were encountered: moisture, vibration, and poorly regulated power.

Trouble with moisture had been anticipated. The low-signal-level, high impedance stages in the amplifier were carefully enclosed and kept dry with dessicants. However, trouble developed in the high-signal-level stages. There it was found that the moisture produced leakage paths between the plate load resistors and grid leak resistors which were mounted on the same bakelite strip. The net result was the appearance of positive d-c voltages on the grids of the tubes in question which altered the bias of these stages and reduced their amplification. The effect was a gradual one and was not noticed for a long time. At first it was thought that the failure to observe signals was due to an increase in the absorption of the radiation by the atmosphere, however absolute humidity readings indicated otherwise. A calibration of the system back at the base showed an overall reduction in the sensitivity of the system of from three to four times, enough to wipe out many of the signals. No trouble was experienced with the optical head. However, this does not rule out the possibility of having moisture condense on the optical corrector plate and thus reduce its transmission. The troubles encountered, present or future, clearly indicate the need for the extensive use of dessicants. More important, they indicate the need for a simple calibrating device which will show the condition of the system at all times.

The vibration problem is a fundamental one and plagues all thermal detectors. On board the K-65, the vibration was very severe particularly at engine speeds of less than 1200 rpm. The vibration produced two types of noise, that due to the motion of the low-impedance, low-signal-level input cable in the earth's magnetic field and that due to microphonics in the input transformer and first vacuum tube of the amplifier. No vibrational troubles were experienced with the thermopile mounted in the optical head. The cable trouble was overcome by employing a special short input lead consisting of 4 strands of #30 enameled wire tightly twisted with opposite strands connected in parallel (11) and electrostatically shielded with two layers of copper braid. Transformer microphonics can be reduced by proper design. Microphonics in vacuum tubes at low frequencies, however, has been the subject of many investigations for some time without significant results. For these particular tests, the amplifier was placed on 6 thicknesses of ordinary felt mattress (Figure 14). In spite of these precautions, the noise level of the system remained about two times higher than normal thus raising the E.N.I. to 3×10^{-9} watts/cm^2. Any practical blimp-borne search gear of this type will be even more severely limited in operation by vibration since a more practical method for mounting the equipment will have to be employed.

The power supply difficulties were the result of extensive swings in the blimp's 28-volt d-c supply which could not be handled by the carbon pile regulator and gas-tube regulators in the equipment's own power supply. As a result, it was necessary to employ a separate source of 28-volt power. It is quite evident that more extensive electronic voltage regulation is necessary for gear of this type.

TEST PROCEDURE

The formal tests, wherein the target was a submarine, took place in Block Island Sound during the week of 13 September 1948. The submarine U.S.S. DOGFISH made the necessary runs while being observed from sea level with thermal detection equipments mounted on board the surface ships, U.S.S. E-PCE(R)-852 and U.S.S. PC-564, and from the air with the NRL and Mark VII equipments installed in the airship, K-65.

Satisfactory operation was achieved according to a prearranged schedule while measurements were made on the schnorkel. However, strong off-course winds and very rough air made it impossible to follow the remainder of the schedule. Thus during the night of 13 September, only flights perpendicular to the submarine's wake were possible and during the night of the 14th, only "see-saw" flights along the wake were possible. In the first case it was necessary to have the optical head of the NRL equipment scan along the length of the blimp to permit the optical field-of-view to wobble across the wake at right angles. In the second case an athwartship scan was necessary to permit the optical field-of-view to wobble across the wake at right angles.

During many of the runs, the speed of the blimp across the wake was comparable to, or greater than, the scanning speed of the optical head. This resulted in either too short irradiation times for the thermopile or too short signal durations for the recorder. In a great many cases, for example, the monitoring meter indicated much larger signals than appeared on the recorder. Such recordings have been rejected. It is estimated that only one try in four was successful thus making the taking of data a hit-or-miss proposition Consequently, the data presented in this report is very "spotty."

It is clearly evident that the equipment employed in these tests is not suitable for general search application.

RESULTS OF SCHNORKEL MEASUREMENTS

Schnorkel measurements (Runs I-A and I-B) were made with the submarine submerged 60 feet resting on the bottom while charging batteries, first with both engines and then with one engine. Each engine is rated at 1500 horsepower and was run at 75% of full capacity. The resulting schnorkelling condition is shown in Figure 15. The exhaust pipe of the schnorkel is perforated at the end and is capped with a 3′ x 6′ plate to help reduce the surface bubble produced by the escaping exhaust. Nonetheless a large bubble was produced and temperature measurements showed that it was at least 1.9°C warmer than the surrounding water.

Although the intake pipe of the schnorkel was exposed above the surface of the water, it is believed that most of the radiation picked up by the airborne apparatus came from the bubble. The results of these measurements are tabulated chronologically in Tables I and II (all tables are at the end of this report). A typical recording is shown in Figure 16.

From Table I it is noted that the schnorkel bubble was slow (approx. 30 minutes) in reaching thermal equilibrium with two engines running, and from Table II it is noted that the bubble did not have an opportunity to reach equilibrium with one engine running.

The values shown in the two tables represent the radiation density from the entire schnorkel bubble measured with respect to an equal area of adjacent sea from an altitude of 500 feet. Since it was not the purpose of this test to determine threshold ranges, measurements at higher altitudes were not attempted. However, later in the tests during the wake measurements, the schnorkel was picked up easily from an altitude of 2000 feet (Measurement No. 93 of Table XIII). The radiation density at that altitude was 30.0×10^{-9} watts/cm^2.

The NRL equipment does not indicate whether a target is "hot or cold" with respect to its background. However, the Mark VII equipment does provide such an indication and it was noted that the schnorkel appeared warmer than an equal area of adjacent sea. The surface temperature measurements, of course, confirm this.

The surface of the sea is not a smooth thermal surface. Each wavelet produces a small thermal disturbance which causes an otherwise "quiet" sea background to become "noisy." These thermal variations in the background manifest themselves at the optical head as "optical noise" (Figure 16) which was present during all of the measurements and determined the minimum target signals which could be detected. This noise added to the amplifier noise produced the total observed noise tabulated in Tables I and II. If it is assumed that the optical noise, N_O, is perfectly random, then it adds to the electrical noise, N_e, to produce the total noise, N_t, as follows: (12)

$$N_t = \sqrt{N_O^2 + N_e^2}\,.$$

As already stated, the electrical plus vibration noise, N_e, amounts to 3.0×10^{-9} watts/cm^2, hence the optical noise may be found using the expression

$$N_O = \sqrt{N_t^2 - (3.0 \times 10^{-9})^2 \text{ watts/cm}^2}\,.$$

The signals from the schnorkel were very large compared with the "optical noise." However, this may not always be the case. In the first place, the sea was relatively calm during these tests, with 1- to 5-foot waves. A choppier sea will produce more "optical noise." In the second place, redesign of the schnorkel to include water jacket cooling of the exhaust pipe and water spray cooling of the exhaust, such as carried out by the British, (13, 14, 15) will undoubtedly reduce the direct thermal output considerably. In the third place, the column of turbulent water which rises as the result of the forced exhaust process can undoubtedly be reduced in size thus reducing the portion of warmed water which becomes exposed at the surface of the sea. Thus a considerable reduction in target signal from improved schnorkels can be expected in the future whereas the "optical noise" may be greater.

The problem of schnorkel detection, therefore, will be one of detecting a small signal in a noisy optical background and will not be as simple as the numerical results of these measurements indicate.

RESULTS OF WAKE MEASUREMENTS - SUBMARINE SURFACED

At the conclusion of the schnorkel measurements, the submarine surfaced and proceeded to get into position for the succeeding trials. During this interval, unscheduled measurements of the radiation from the wake of the surfaced submarine were made. The results are tabulated in Table III. Also tabulated are the values of observed total noise. By way of comparison, it was also noted that the radiation from the wakes of the E-PCE(R)-852 and PC-564 which were travelling at the same speed and which were at the same distance from the points of measurement, were of the same magnitude.

[redacted]

While making these measurements, it was observed visually that a crosstide broke up the wake rather badly about $3\frac{1}{2}$ or 4 miles astern the submarine. This probably accounts for the fact that it was not possible, in these or later measurements, to observe the radiation from the wake at points greater than 6000 yards astern the target.

RESULTS OF WAKE MEASUREMENTS - SUBMARINE SUBMERGED

The first wake measurements, with the submarine submerged, (Run II-C) were made with the target at a depth of approximately 60 feet and travelling at 10 knots while employing its schnorkel. Attempts were made by the blimp to fly parallel to the wake at an altitude of 500 feet so that the thermal radiation distribution along the wake could be determined. However, because of off-course winds and rough air as explained previously, this was not possible. The results of the few good measurements which were obtained are tabulated in Table IV. The values of total noise are also tabulated.

A second similar run was made but with the submarine operating on batteries (Run II-D) at a speed of 8 knots. The schnorkel was retracted and the periscope was up. The results are tabulated in Table V.

Because of the failure of the blimp to maneuver properly, the remaining portions of the test are identical to the above two runs with the exception of the altitude of the blimp and the speed of the submarine. These data and the explanatory remarks are tabulated in Tables VI through XIII.

Typical recordings of the wake signals are shown in Figures 17 and 18. Simultaneous measurements with the Mark VII equipment, although not too successful, showed that the wakes appeared "cold" with respect to the surrounding sea indicating that the submarine's screws had churned cold water to the surface. Contact temperature measurements of the water from aboard the submarine showed no difference between the sea temperature at the surface and that at a depth of 60 feet. Measurements made from aboard the PC-564 revealed a temperature difference of 1.5°C, however.

A comparison of the data obtained at an altitude of 500 feet (Tables I through VIII) with that obtained at altitudes of from 1000 to 2000 feet (Tables IX through XIII) shows that signals from the wake observed at the higher altitudes are greater than can be accounted for by the difference in values of atmospheric absorption. For example, reference to Table VI shows that the signals observed from a 500-foot altitude at a distance of from 200 to 350 yards astern the target average about 12.0×10^{-9} watts/cm^2, whereas reference to Table X shows that the signals observed from a 1000-foot altitude at a distance of from 200 to 400 yards astern the target average better than 42.0×10^{-9} watts/cm^2. The absolute humidities are 3.4 and 2.1 centimeters of precipitable water per sea mile, respectively, which correspond to a total water vapor content of 0.29 and 0.35 centimeters of precipitable water. Thus the total atmospheric absorption for the two path lengths is approximately the same. (16) This leaves the factor of $3\frac{1}{2}$ times still unaccounted for. An explanation can be found in the fact that the width of the wake varies from approximately 20 feet immediately astern the target to 150 feet 3 miles aft. At low altitudes, the projected field-of-view of the detector (Figure 2) is, in most cases, not as wide as the width of the wake. Thus the apparatus crudely measures the cross-sectional gradient of the wake. It was noted that, at such altitudes, the signals came from the two edges of the wake where gradients existed and that no signals were observed in the middle of the wake (Figure 17). At higher altitudes, a situation was approached wherein the radiation from an entire cross-sectional slice of the wake was compared with that from an equal area of adjacent sea. This produces a single large signal (Figure 18) which is independent

[redacted]

of the cross-sectional gradient of the wake. In other words, the signals obtained from entire cross-sectional slices of these wakes are greater than those obtained by measuring the cross-sectional gradients of the same slices. The cross-sectional radiation contour of the wake of the U.S.S. DOGFISH approaches that shown in Figure 19. Slightly different contours (Figures 20 and 21) were observed behind freighters during the "shakedown" runs. Contact temperature measurements, which have been made in the past, (17) indicate that still other contours may be expected. It is clearly evident from these measurements that the widths and separation of the two halves of the projected field-of-view should be at least as great as the maximum width of the wake, It is believed that the German's failure to observe this rule resulted in their unsuccessful attempts to detect wake radiation with a 0.35°- 0.12° - 0.35° wide by 1.4° high field-of-view from an altitude of 6000 feet. (18) Failure to do likewise in the current investigation has resulted in having a large part of the wake data tabulated in this report represent neither the total cross-sectional radiation of the wake nor its cross-sectional gradient. On the basis of the above reasoning, most of the tabulated values are too small, but are of the right order of magnitude, to represent total cross-sectional radiation.

Reference to the data in Table V and that in Table VI for points equally distant astern the target indicates that the magnitudes of wake radiation are the same for a schnorkelling and nonschnorkelling submarine if both are travelling at approximately the same speed and the same depth. A comparison of the data in Tables XI and XII shows that the magnitude of wake radiation decreases with decreasing target speed. No measurements were made to substantiate the belief that the wake radiation decreases with increasing target depth. However, if the temperature gradient of the water is not too great, it seems reasonable to assume, that as the target submerges, less churned water reaches the surface and hence the total radiated output from the raised water is less.

All of the data seems to indicate that the magnitude of the wake radiation decreases very slowly with increasing distance astern the target. There is also reason to believe that the wake does not develop fully immediately astern the target but at some distant point and that the radiation decreases from this point on. The data neither substantiate nor disprove this belief.

OPTICAL NOISE LIMITATIONS

There are two major sources of optical noise in the thermal background provided by the sea. (19) The first is caused by the waves and has already been mentioned. The second arises as the result of scanning the surface of the sea at varying oblique angles.

The magnitude of the optical noise generated by the waves under a given set of conditions is determined by the size of the optical field-of-view projected upon the surface of the water. If the noise is perfectly random, its magnitude is directly proportional to the square root of this projected area. The relationship holds whether the thermal element, which describes the field-of-view, is compensated or not. An experimental comparison may be made with the data found in Tables X and XI. The average value of the total noise as viewed from an altitude of 1000 feet is 8.1×10^{-9} watts/cm^2 and that viewed from an altitude of 1500 feet is 9.3×10^{-9} watts/cm^2. The corresponding values of optical noise are 7.5×10^{-9} and 8.8×10^{-9} watts/cm^2. The measurements involved were taken within an hour of each other, hence the condition of sea can be assumed identical in both cases. The absolute humidity was the same in both cases, 2.1 centimeters of precipitable water per sea mile. Thus the absorption in the 1000-foot path is due to 0.35 centimeters of water and that in the 1500-foot path is due to 0.53 centimeters of water. The corresponding values of total transmission are approximately equal, (20) hence the optical noise at the higher altitude increased by a factor of 1.2. But the projected field-of-view increased by a factor of $(1.5)^2$ and hence the noise should have increased by a factor of 1.5. The agreement is fair. The discrepancy lies in the fact that not enough waves are included in the field-of-view of the instrument to make a statistical analysis valid.

The problem of scanning the thermal surface of the sea has been treated in another NRL report. (21) It was hoped that by installing the NRL optical head in the blimp in a manner to view the surface of the sea at right angles, the slow ± 15-degree side-to-side scan would not introduce a similar problem. It did not. However, during the night of 14 February, the blimp developed a severe 3-second roll which caused the optical head to sweep across the sea in a 60-degree arc. The result was that a sinusoidal-like signal was developed as shown in Figure 22.

Following the reasoning of NRL Report H-2506, the origin of the sinusoidal-like signals can be deduced as follows: Over the range of angles under consideration, the angular distribution of the self-radiation from the surface of the sea closely obeys Lambert's cosine law. However, the size of the field-of-view of the detector projected upon the surface of the water varies in exactly the inverse manner. Hence the self-radiation from the sea, which this detector picked up, did not vary with the angle at which it viewed the surface. Thus these sinusoidal-like signals are not due to self-radiation from the surface of the sea. On the other hand, the reflectivity of the sea, while small, is fairly constant over this range of angles. This permits the thermal radiation from the sky, where a definite thermal gradient exists, to be reflected from the sea's surface without distortion (except for the local chopping effects of the waves). Hence as the optical head swung across the sea, it picked up varying amounts of reflected sky radiation which resulted in the signals of Figure 22.

This clearly indicates that, in addition to a symmetrical scan about a vertical axis, practical airborne search gear must incorporate two degrees of stabilization.

GENERAL CONCLUSIONS

The following conclusions can be drawn from the data concerning the thermal radiation from the schnorkel of the U.S.S. DOGFISH:

(a) Most of the thermal radiation observed from the air is generated by the heated water bubble created by the escaping exhaust gases.

(b) There is a considerable amount of thermal inertia associated with the generation of schnorkel radiation.

(c) The maximum observed radiation relative to that of the water from the schnorkel working under 75% of full load is greater than 112×10^{-9} watts/cm^2 (37 times noise) at an altitude of 500 feet. (A schnorkel signal corresponding to 30.0×10^{-9} watts/cm^2 ($4\frac{1}{2}$ times noise) was observed from an altitude of 2000 feet).

(d) The data on the schnorkel working under 38% of full load are incomplete and only show that the radiated output is less than that under 75%-of-full-load conditions.

(e) The schnorkel bubble appeared "warm" with respect to the adjacent sea.

(f) Smaller radiated outputs may be expected if the size of the schnorkel bubble is reduced and if water-jacket cooling of the exhaust pipe and water-spray cooling of the exhaust gases are employed.

The following conclusions can be drawn from the data on wakes obtained under the conditions of this test:

(a) There is no noticeable difference in radiated output from the wake generated by a schnorkelling submarine and that generated by a nonschnorkelling submarine travelling at the same depth and speed.

(b) The magnitude of the thermal radiation from the wake decreases with decreasing target speed.

(c) The magnitude of the thermal radiation from the wake decreases slowly with increasing distance along the wake.

(d) The radiation from the wake, with respect to the adjacent surface of the sea, at altitudes of from 500 feet to 2000 feet, and at distances along the wake up to 3 miles astern the target, varied from 10^{-7} watts/cm^2 (12 times noise) to 10^{-8} watts/cm^2 ($1\frac{1}{2}$ times noise).

(e) The wakes appeared "cold" with respect to the surrounding sea.

(f) The magnitude of the radiation from the wake is determined by the condition of the wake which in turn is determined by the state of the sea.

The following conclusions can be made with regard to the "optical" noise limitations:

(a) "Optical" noise is of two major types; that produced by waves creating thermal disturbances on the surface of the sea, and that resulting from rapid changes in angle at which the thermal pickup device views the radiation reflected from the sea.

(b) The "optical" noise created by waves will always be present and will always determine the ultimate signal-to-noise ratio of any airborne thermal detector employed against submarines. Its magnitude can be reduced by reducing the area of the projected field-of-view of the detector.

(c) The "optical" noise resulting from viewing the sea at angles which vary rapidly with time can be reduced considerably by stabilizing the thermal search gear and by having it scan symmetrically about a vertical axis.

RECOMMENDATIONS

It is quite obvious that the detection equipment employed for the measurements made during this test is not suitable for either schnorkel or wake detection. Also, it is quite obvious that equipment, which is suitable for use against one, is not suitable for use against the other.

Until improvements are made in the exhaust structure of the schnorkel to reduce its radiated output, it does not appear worthwhile to continue radiation measurements on it. The relative radiated output is man-made, being the result of a given amount of heat dispersed in the water, and should be independent of weather conditions. Of course the signal-to-noise ratio observed at a given altitude should vary as a function of atmospheric transmission and of the condition of thermal background provided by the sea.

On the other hand, the values of wake radiation tabulated in this report are characteristic of the surface conditions and temperature gradients of the water in which the submarine made its runs. Since these conditions vary with weather and geographical location, the radiated output from the wake likewise varies. It appears reasonable to assume that some wakes may have less and others more output than the wakes encountered in this test.

It is therefore recommended that more suitable blimp-borne equipment be developed and that an extensive investigation of the thermal radiation properties of submarine wakes in various localities be undertaken.

It is also recommended that an investigation of the characteristics of the "optical" noise produced by waves be carried out for the purpose of reducing its limiting effects. Of immediate importance, is the determination of the empirical relationship between the magnitude of this "optical" noise and the size and configuration of the projected field-of-view of a thermal detector for use during day and night.

In connection with the development of the above equipment or any other airborne thermal detection equipment for use against submarines, it is recommended that an intensive program for the reduction of vibrational and microphonic noise in vacuum tubes at very low frequencies be pursued.

In addition, it is recommended that the capabilities of the magnetic-type of amplifier be thoroughly investigated for this application. This Laboratory has already initiated a similar investigation for a slightly different application.

DESIGN CONSIDERATIONS

As stated previously, an airborne thermal detector for use against submarine schnorkels is not suitable for use against submarine wakes and vice versa. The requirements placed on the two equipments are not compatible. Of couse, compromises can be made, but only at the expense of the operating characteristics of one or both of the detectors.

For example, a device to be employed against schnorkels should conform to the following general specifications:

(a) Employ a self-compensating thermal element to reduce "optical" noise. Compensations within ± 1% are possible.

(b) Have size of projected optical field-of-view as large, but not larger than, the area of the target. Increasing the projected field-of-view beyond that necessary to cover the target increases the "optical" noise without increasing the target signal and hence reduces the signal-to-noise ratio.

(c) Be stabilized for roll, pitch, and yaw to reduce the optical interference from sky radiation reflected from the surface of the sea. Stabilization errors should be as small as possible so as to put no restrictions on the size of the projected optical field-of-view.

(d) For the same reason, it should utilize a symmetrical scan about an axis perpendicular to the surface of the sea. A rapid scan in an arc athwartship (Figure 23) is one possibility.

(e) Have fixed altitude of operation so that the signal losses due to atmospheric absorption are tolerable. The absorption increases exponentially with altitude (for low altitudes where the water vapor distribution is constant) and is only partially offset by the slight increase in the sensitivity of the thermal element (due to decreasing size) which generates the fixed projected field-of-view. An altitude of approximately 2000 feet appears to be optimum for low signal loss and good lateral coverage of the target area (Figure 23). The associated optical path length of 3000 feet will provide a minimum total transmission of 25% for a clear atmosphere (with an absolute humidity of 5 cm of H_2O per sea mile) and 1% for a hazy or cloudy atmosphere (with the same absolute humidity but with a visibility of only 500 yards).(22) (These values are 17% and 0.034%, respectively, for a path length which is twice the above.)

(f) Utilize a fixed airship speed and have a fixed scanning arc so that there are no "holes" in area being covered. Thus, if the projected field-of-view is 10′-10′-10′ wide by 10′ long (0.19°-0.19°-$0.19^\circ \times 0.12^\circ$ for a 3000-ft path) to cover a 10-foot diameter schnorkel bubble, and the length of arc scanned is 5000 feet, then a thermal element with a 5-millisecond time constant will permit a $2\frac{1}{2}$-second scan in one direction. The airship's speed can, therefore, not exceed 10 feet per 5 seconds or 1.2 knots. (A multiple-element array with individual preamplifiers and electronic switching would permit elongating the field-of-view to permit greater airship speed without altering the signal-to-noise ratio.)

(g) Have sufficient sensitivity so that the noise level of the system is determined by "optical" noise rather than by the inherent electrical noise of the system. If this is to be the case when an atmospheric transmission of 1% exists, then the E.N.I. of the device should be 1/100th that of the NRL detector or approximately 10^{-11} watts/cm^2.

(h) Incorporate such features as an automatic calibrating device to permit overall performance checks of the detector while in flight, a highly regulated electronic power supply, and an adequate amount of dessicant.

On the other hand, a device for use against submarine wakes should conform to the following specifications:

(a) Employ self-compensating thermal element.

(b) Have a projected field-of-view whose width is exactly equal to the maximum width of the wake (Figure 24), approximately 300′-300′-300′ or 5.7°-5.7°-5.7° for a 3000-foot optical path. This match is important since the signal is the weakest where the wake is the widest. The length of the projected field-of-view does not appear to be critical. Reducing it, decreases the wake signal proportionally but this is offset by the decrease in "optical" noise and the increase in the sensitivity of the thermal element due to the decrease in its size (half-power law). A more exact relationship between the "optical" noise and the size of a projected field-of-view of this configuration must be found before any conclusions can be drawn regarding the proper length for the field-of-view. For the time being, it may be assumed that the length is 0.2° ($17\frac{1}{2}$ feet for a 3000-foot optical path) or slightly greater than the errors of a good stabilizer.

(c) Be stabilized for roll, pitch, and yaw.

(d) Employ a symmetrical scan about an axis perpendicular to the surface of the sea. A circular scan (Figure 24) appears to be the only type which permits the detector to cross a randomly orientated wake at or near right angles. Only those wakes, which are parallel or near parallel to the course of the airship and which lie at the edge of the scanned circle, will never be properly scanned. However, overlapping search patterns will take care of this.

(e) Have a fixed altitude of 2000 feet.

(f) Utilize a fixed airship speed which is slow enough to prevent holes in the area being covered. If a thermal element with a 5-millisecond time constant and a 300-foot wide projected field-of-view is employed, a complete scan around a 4800-foot diameter circle (Figure 24) can be made in 0.25 seconds. The airship's speed can, therefore, be not greater than the length of the field-of-view per 0.25 seconds or $17\frac{1}{2}$ feet per 0.25 seconds or 42 knots. (Since the wake is an elongated target, holes in search pattern can probably be tolerated which would permit a faster airship speed.)

(g) Have an E.N.I. of approximately 10^{-11} watts/cm^2.

(h) Incorporate such features as an automatic calibrating device to permit overall performance checks of the detector while in flight, a highly regulated electronic power supply, and an adequate amount of dessicant.

The differences between the two types of search equipments are quite evident from the above examples. However, they do have common drawbacks, namely slow search rates at a low altitude.

ACKNOWLEDGMENTS

The author wishes to express his appreciation for the cooperation extended the NRL group by the Experimental Group at Lakehurst and for the patience exhibited by the officers and crew of the K-65 during the 14-hour test flights. Mr. C. T. Jeffrey of this Laboratory is to be commended for his part in constructing, installing, and helping to operate the thermal detection gear.

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TABLE I

Date: Sept. 13, 1948
Run: I-A
Sub: Submerged 60 feet and anchored. Schnorkelling on two engines.
Blimp: Hovering at 500 feet altitude.
Sea: Calm. Few white caps. Strong tide.
Sky: Dusk. Moon not up.
Humidity: 73°/75°. 3.7 cm H_2O per sea mi.

Measurement Number	Schnorkel Signal Watts/cm^2	Total * Noise Watts/cm^2
1	28.2×10^{-9}	6.8×10^{-9}
2	35.3×10^{-9}	7.5×10^{-9}
3	27.0×10^{-9}	9.7×10^{-9}
4	37.5×10^{-9}	8.3×10^{-9}
5	30.0×10^{-9}	4.5×10^{-9}
6	$\gg 37.5 \times 10^{-9}$	5.3×10^{-9}
7	$\gg 112.0 \times 10^{-9}$	3.0×10^{-9}
8	75.0×10^{-9}	4.3×10^{-9}

*Amplifier noise + optical noise.

TABLE II

Date: Sept. 13, 1948
Run: I-B
Sub: Submerged 60 feet and anchored. Schnorkelling on one engine.
Blimp: Hovering at 500 feet altitude.
Sea: Calm. Few white caps. Strong tide.
Sky: Dusk. Moon not up.
Humidity: 73°/75°. 3.7 cm H_2O per sea mi.

Measurement Number	Schnorkel Signal Watts/cm^2	Total * Noise Watts/cm^2
9	35.5×10^{-9}	7.2×10^{-9}
10	97.5×10^{-9}	6.8×10^{-9}
11	79.5×10^{-9}	9.5×10^{-9}

*Amplifier noise + optical noise.

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TABLE III

Date: Sept. 13, 1948
Run: (Not Scheduled)
Sub: On surface getting into position for next run.
Speed - 8 knots.
Blimp: Altitude - 500 ft. Flying along wake.
Sea: Calm. Few white caps. Strong tide.
Sky: Twilight. Moon just coming up.
Humidity: $73^0/75^0$. 3.7 cm H_2O per sea mi.

Measurement Number	Astern Yards	Wake Signal Watts/cm²	Total * Noise Watts/cm²
12	0	$\gg 75.0 \times 10^{-9}$	9.0×10^{-9}
13	100	$> 37.5 \times 10^{-9}$	9.0×10^{-9}
14	200	$> 37.5 \times 10^{-9}$	9.0×10^{-9}
15	300	26.2×10^{-9}	9.0×10^{-9}
16	500	41.3×10^{-9}	4.9×10^{-9}
17	600	51.4×10^{-9}	4.9×10^{-9}
18	1500	38.0×10^{-9}	3.6×10^{-9}
19	1000	52.2×10^{-9}	5.9×10^{-9}
20	2000	100.0×10^{-9}	5.9×10^{-9}
21	0	$> 105.0 \times 10^{-9}$	6.0×10^{-9}

*Amplifier noise + optical noise.

TABLE IV

Date: Sept. 13, 1948
Run: II-C
Sub: Submerged. Schnorkelling.
Speed - 10 knots.
Blimp: Altitude - 500 ft. Attempting to fly along wake.
Sea: Calm. Few white caps. Strong tide.
Sky: Dark. Moon path 40^0 to wake.
Humidity: $73^0/75^0$. 3.7 cm H_2O per sea mi.

Measurement Number	Astern Yards	Wake Signal Watts/cm²	Total * Noise Watts/cm²
22	2000	13.1×10^{-9}	6.8×10^{-9}
23	1000	12.0×10^{-9}	6.8×10^{-9}
24	2000	15.0×10^{-9}	6.8×10^{-9}

*Amplifier noise + optical noise.

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TABLE V

Date: Sept. 13, 1948
Run: II-D
Sub: Submerged. Not schnorkelling. Periscope up. Speed - 8 knots.
Blimp: Altitude - 500 ft. Flying perpendicular to wake.
Sea: Calm. Few white caps. Gentle ground swell. Strong tide.
Sky: Dark. Moon path 45° to wake.
Humidity: 73°/75°. 3.7 cm H_2O per sea mi.

Measurement Number	Astern Yards	Wake Signal Watts/cm²	Total * Noise Watts/cm²
25	10	9.7×10^{-9}	4.5×10^{-9}
26	5	12.7×10^{-9}	5.3×10^{-9}
27	50	15.8×10^{-9}	4.5×10^{-9}
28	20	10.9×10^{-9}	3.8×10^{-9}
29	30	11.6×10^{-9}	4.5×10^{-9}

*Amplifier noise + optical noise.

TABLE VI

Date: Sept. 13, 1948
Run: II-E
Sub: Submerged. Schnorkelling. Speed - 11 knots.
Blimp: Altitude - 500 ft. Flying perpendicular to wake.
Sea: Calm. Few white caps. Gentle ground swell. Strong tide.
Sky: Dark. Moon path 40° to wake.
Humidity: 72°/73.5°. 3.4 cm H_2O per sea mi.

Measurement Number	Astern Yards	Wake Signal Watts/cm²	Total * Noise Watts/cm²
30	100	14.3×10^{-9}	4.1×10^{-9}
31	10	13.1×10^{-9}	4.1×10^{-9}
32	5	23.3×10^{-9}	5.3×10^{-9}
33	200	13.7×10^{-9}	6.4×10^{-9}
34	7	8.2×10^{-9}	4.9×10^{-9}
35	10	15.4×10^{-9}	4.9×10^{-9}
36	20	15.4×10^{-9}	5.3×10^{-9}
37	15	11.7×10^{-9}	4.9×10^{-9}
38	350	13.5×10^{-9}	6.0×10^{-9}
39	350	10.5×10^{-9}	4.5×10^{-9}
40	350	9.8×10^{-9}	5.3×10^{-9}

*Amplifier noise + optical noise.

TABLE VII

Date: Sept. 13, 1948
Run: II-F
Sub: Submerged. Not schnorkelling. Periscope up. Speed - 8 knots.
Blimp: Altitude - 500 ft. Flying perpendicular to wake.
Sea: Calm. Few white caps. Gentle ground swell. Strong tide.
Sky: Dark. Moon path 40° to wake.
Humidity: 72°/73.5°. 3.4 cm H_2O per sea mi.

Measurement Number	Astern Yards	Wake Signal Watts/cm²	Total * Noise Watts/cm²
41	100	9.8×10^{-9}	4.5×10^{-9}
42	700	7.5×10^{-9}	4.5×10^{-9}

*Amplifier noise + optical noise.

TABLE VIII

Date: Sept. 13, 1948
Run: II-G
Sub: Submerged. Schnorkelling. Speed - 11 knots.
Blimp: Altitude - 500 ft. Flying perpendicular to wake.
Sea: Calm. Few white caps. Gentle ground swell. Strong tide.
Sky: Dark. Moon path 40° to wake.
Humidity: 72°/73.5°. 3.4 cm H_2O per sea mi.

Measurement Number	Astern Yards	Wake Signal Watts/cm²	Total * Noise Watts/cm²
43	2500	7.5×10^{-9}	3.8×10^{-9}
44	800	10.1×10^{-9}	5.3×10^{-9}
45	4000	9.4×10^{-9}	6.0×10^{-9}
46	6000	10.5×10^{-9}	5.6×10^{-9}
47	4000	11.7×10^{-9}	7.5×10^{-9}

*Amplifier noise + optical noise.

TABLE IX

Date: Sept. 14, 1948
Run: II-C
Sub: Submerged. Schnorkelling. Speed - 11 knots.
Blimp: Altitude - 1000 ft. Flying along wake.
Sea: Calm. Few white caps. Mild ground swell. Strong tide.
Sky: Twilight. Moon just coming up.
Humidity: 59°/66°. 2.1 cm H_2O per sea mi.

Measurement Number	Astern Yards	Wake Signal Watts/cm^2	Total * Noise Watts/cm^2
48	100	23.2×10^{-9}	7.5×10^{-9}
49	1500	14.3×10^{-9}	7.5×10^{-9}
50	1500	20.3×10^{-9}	7.1×10^{-9}
51	1500	26.3×10^{-9}	6.8×10^{-9}
52	400	27.4×10^{-9}	6.8×10^{-9}

*Amplifier noise + optical noise.

TABLE X

Date: Sept. 14, 1948
Run: II-C
Sub: Submerged. Schnorkelling. Speed - 11 knots.
Blimp: Altitude - 1000 ft. Flying along wake.
Sea: Calm. Few white caps. Mild ground swell. Strong tide.
Sky: Dark. Moon path 40° to wake.
Humidity: 59°/66°. 2.1 cm H_2O per sea mi.

Measurement Number	Astern Yards	Wake Signal Watts/cm^2	Total * Noise Watts/cm^2
53	400	>> 38.0×10^{-9}	7.5×10^{-9}
54	1500	45.0×10^{-9}	6.4×10^{-9}
55	6000	27.8×10^{-9}	6.8×10^{-9}
56	400	28.5×10^{-9}	6.0×10^{-9}
57	200	37.5×10^{-9}	11.3×10^{-9}
58	1000	28.5×10^{-9}	9.4×10^{-9}
59	500	21.7×10^{-9}	6.4×10^{-9}
60	1000	31.6×10^{-9}	9.4×10^{-9}
61	1000	42.8×10^{-9}	9.4×10^{-9}
62	30	53.2×10^{-9}	7.1×10^{-9}
63	1000	46.0×10^{-9}	9.0×10^{-9}
64	200	64.0×10^{-9}	7.9×10^{-9}
65	20	119.0×10^{-9}	8.2×10^{-9}

*Amplifier noise + optical noise.

TABLE XI

Date:	Sept. 14, 1948
Run:	II-D
Sub:	Submerged. Not schnorkelling. Periscope up. Speed - 8 knots.
Blimp:	Altitude 1500 ft. Flying along wake.
Sea:	Calm. Few white caps. Mild ground swell. Strong tide.
Sky:	Dark. Moon path 40° to wake.
Humidity:	$59^{\circ}/66^{\circ}$. 2.1 cm H_2O per sea mi.

Measurement Number	Astern Yards	Wake Signal Watts/cm²	Total * Noise Watts/cm²
66	1500	45.2×10^{-9}	12.0×10^{-9}
67	200	45.7×10^{-9}	11.9×10^{-9}
68	100	54.4×10^{-9}	9.4×10^{-9}
69	300	77.2×10^{-9}	9.4×10^{-9}
70	1200	53.2×10^{-9}	9.4×10^{-9}
71	1000	30.9×10^{-9}	9.4×10^{-9}
72	400	57.3×10^{-9}	11.3×10^{-9}
73	100	112.0×10^{-9}	9.0×10^{-9}
74	50	108.0×10^{-9}	9.0×10^{-9}
75	2000	35.5×10^{-9}	7.5×10^{-9}
76	500	49.7×10^{-9}	5.9×10^{-9}
77	700	33.2×10^{-9}	12.0×10^{-9}
78	2000	34.4×10^{-9}	7.5×10^{-9}
79	1000	48.7×10^{-9}	7.1×10^{-9}

*Amplifier noise + optical noise.

TABLE XII

Date: Sept. 14, 1948
Run: II-D
Sub: Submerged. Not schnorkelling. Periscope up. Speed - 4 knots.
Blimp: Altitude 1500 ft. Flying along wake.
Sea: Calm. Few white caps. Mild ground swell. Strong tide.
Sky: Dark. Moon path 40° to wake.
Humidity: $57^\circ/64^\circ$. 1.9 cm H_2O per sea mi.

Measurement Number	Astern Yards	Wake Signal Watts/cm^2	Total * Noise Watts/cm^2
80	2000	21.2×10^{-9}	9.0×10^{-9}
81	20	18.4×10^{-9}	9.4×10^{-9}
82	2000	15.0×10^{-9}	9.0×10^{-9}
83	2000	13.1×10^{-9}	7.9×10^{-9}
84	2000	17.3×10^{-9}	8.2×10^{-9}
85	1000	25.1×10^{-9}	10.5×10^{-9}

*Amplifier noise + optical noise.

TABLE XIII

Date: Sept. 14, 1948
Run: II-C
Sub: Submerged. Schnorkelling. Speed - 10 knots.
Blimp: Altitude - 2000 ft. Flying along wake.
Sea: Calm. Few white caps. Mild ground swell. Strong tide.
Sky: Dark. Moon path 40° to wake.
Humidity: $55^\circ/61^\circ$. 1.8 cm H_2O per sea mi.

Measurement Number	Astern Yards	Wake Signal Watts/cm^2	Total * Noise Watts/cm^2
86	1000	11.9×10^{-9}	7.1×10^{-9}
87	200	28.5×10^{-9}	7.5×10^{-9}
88	35 (?)	115.0×10^{-9}	7.1×10^{-9}
89	700	51.0×10^{-9}	7.1×10^{-9}
90	700	33.2×10^{-9}	7.1×10^{-9}
91	500	43.3×10^{-9}	9.4×10^{-9}
92	200	23.6×10^{-9}	7.1×10^{-9}
93	0 (Schnorkel)	$\gg 30.0 \times 10^{-9}$	6.8×10^{-9}

*Amplifier noise + optical noise.

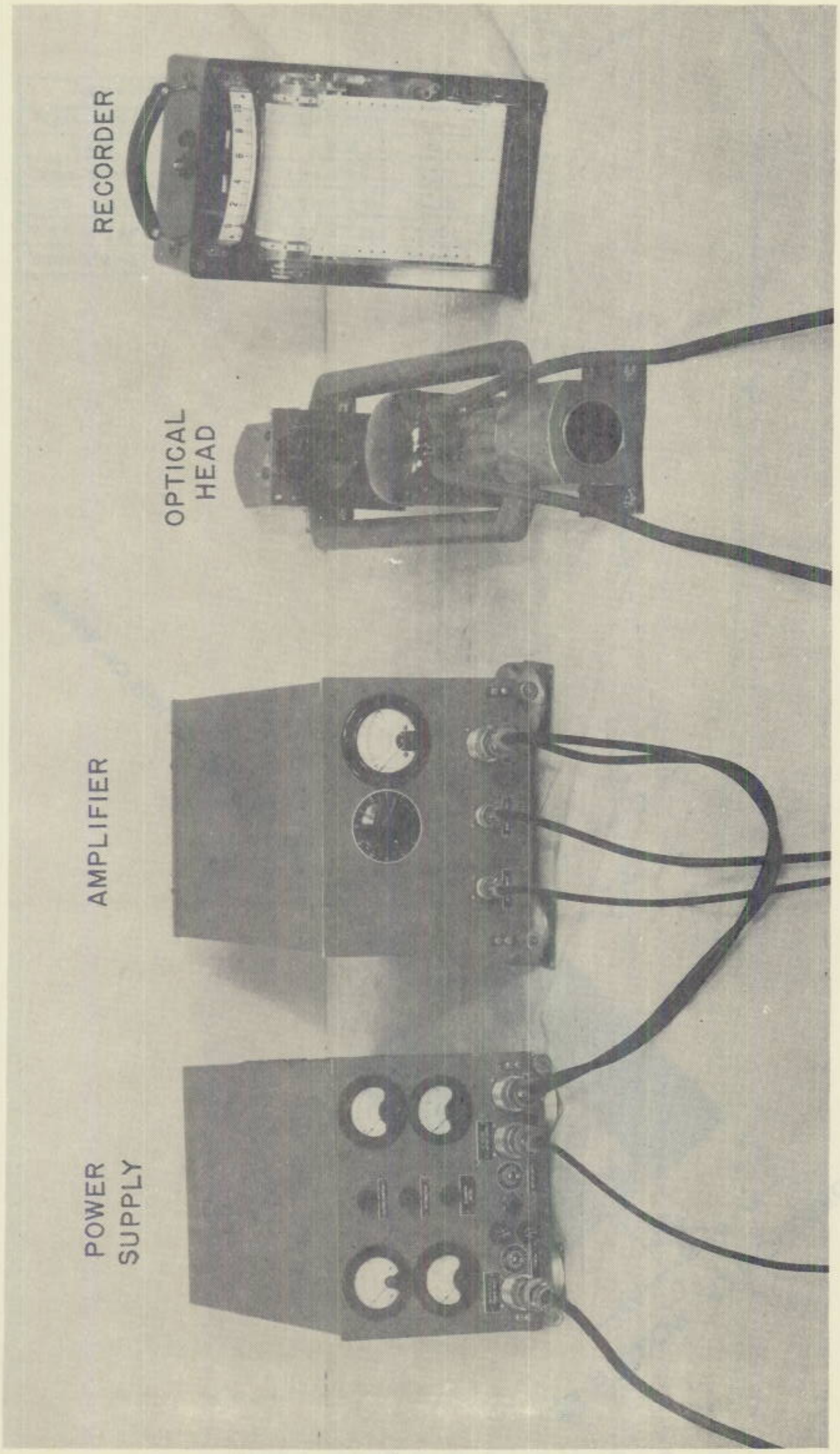
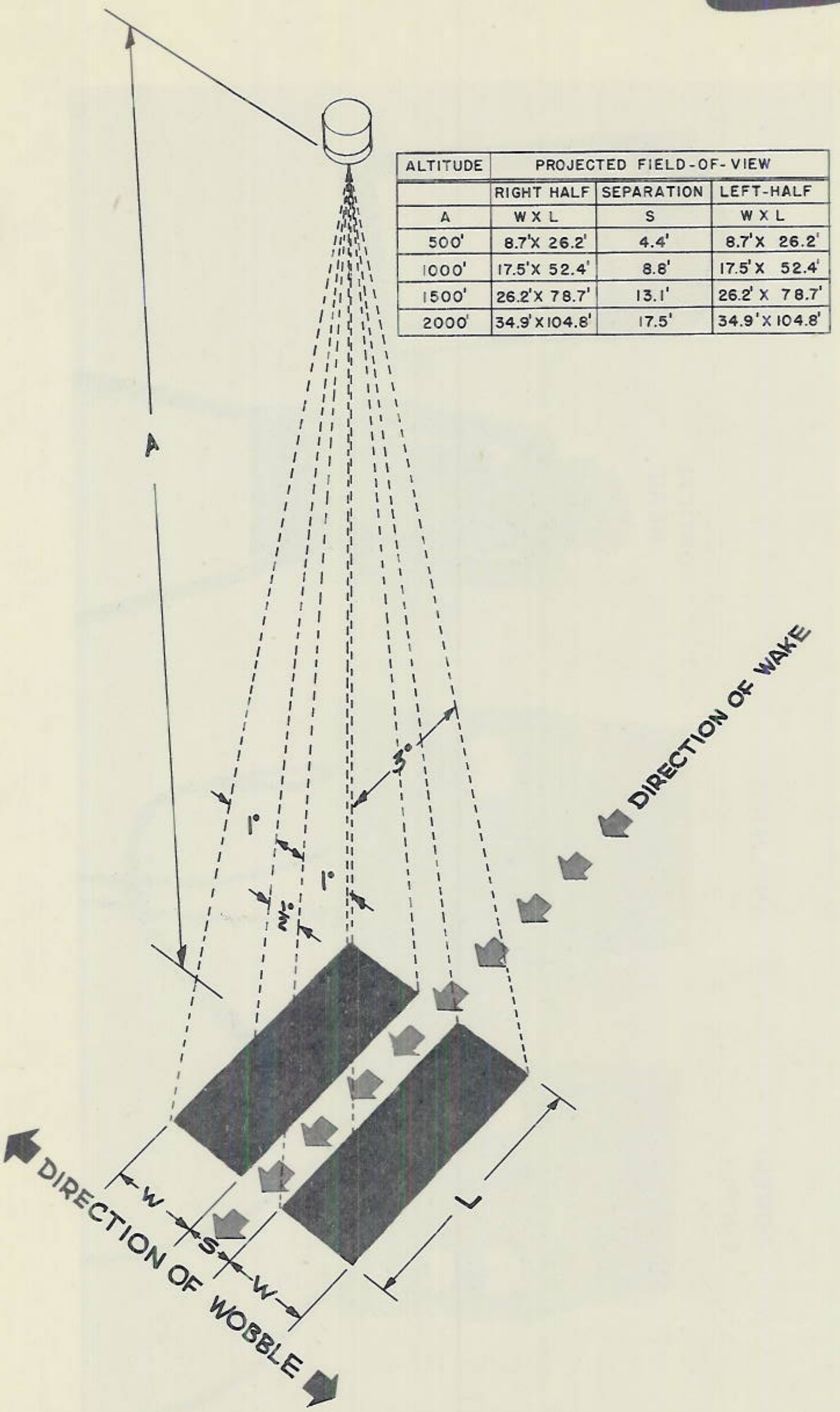


Fig. 1 - Complete Detection System



ALTITUDE	PROJECTED FIELD-OF-VIEW		
	RIGHT HALF	SEPARATION	LEFT-HALF
A	W X L	S	W X L
500'	8.7'X 26.2'	4.4'	8.7'X 26.2'
1000'	17.5'X 52.4'	8.8'	17.5'X 52.4'
1500'	26.2'X 78.7'	13.1'	26.2' X 78.7'
2000'	34.9'X104.8'	17.5'	34.9'X104.8'

Fig. 2 - Projected Optical Field-of-View

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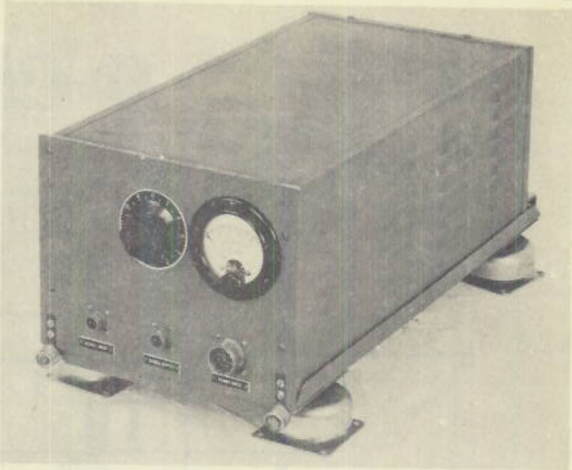

Fig. 3 - Amplifier, Front Exterior

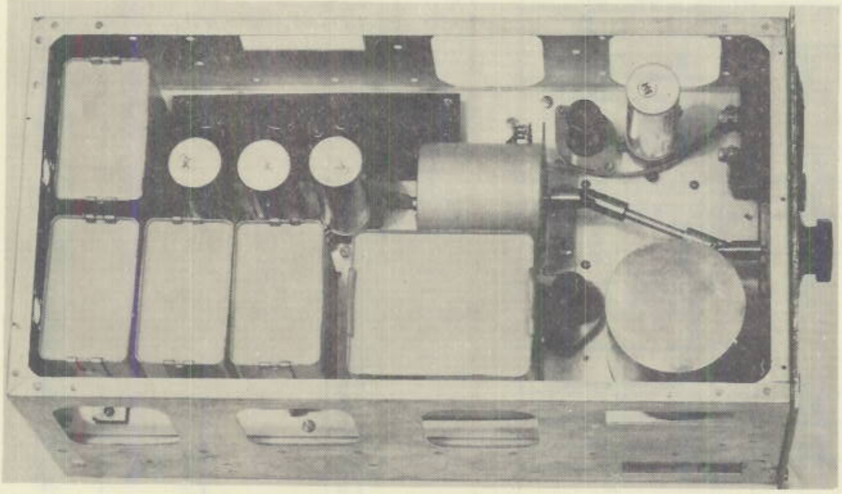

Fig. 4 - Amplifier, Top Interior

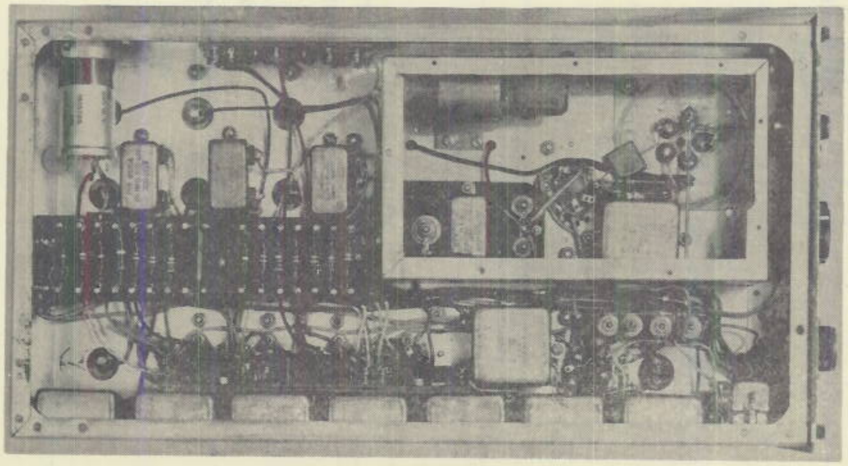

Fig. 5 - Amplifier, Bottom Interior

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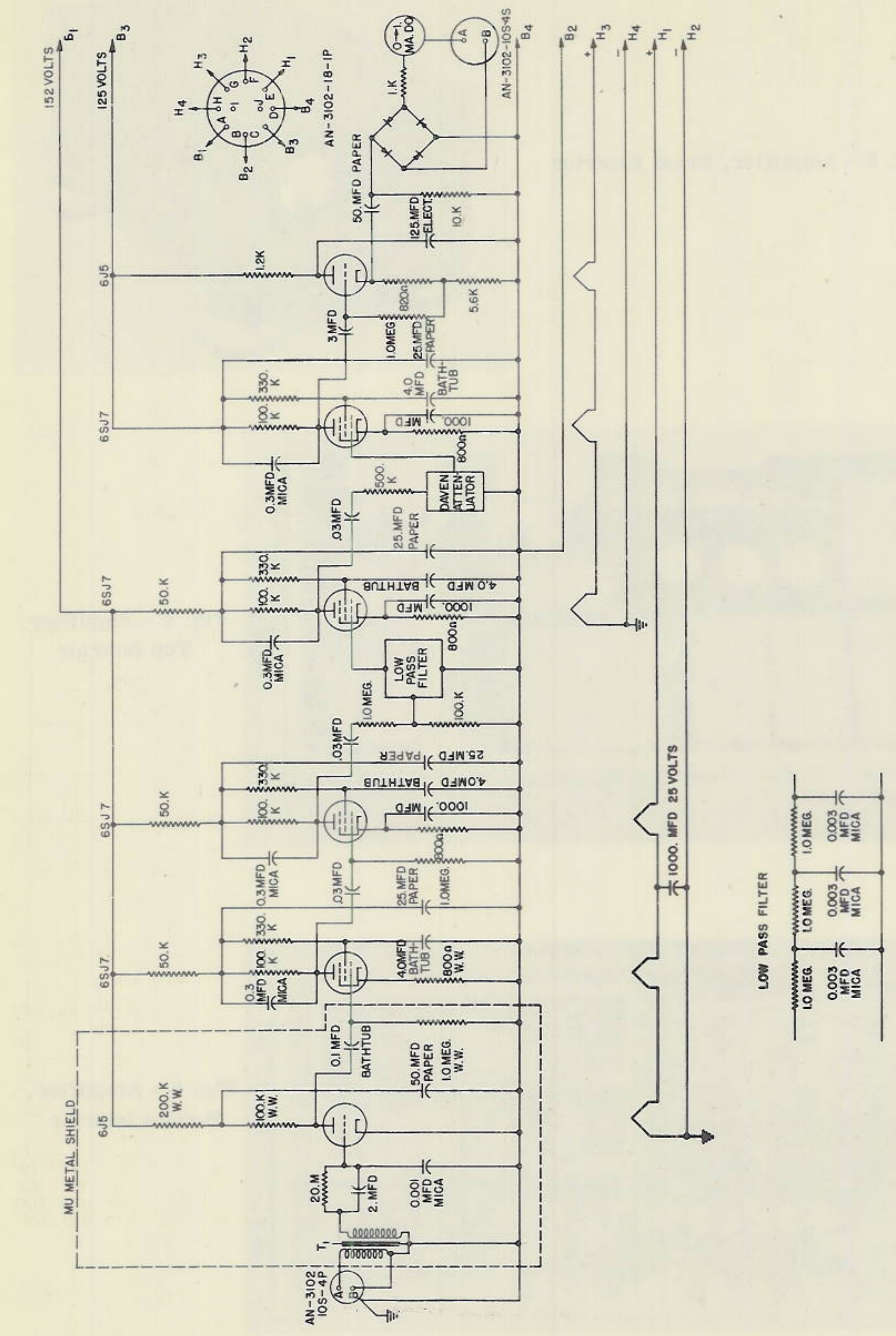

Fig. 6 - Amplifier Wiring Diagram

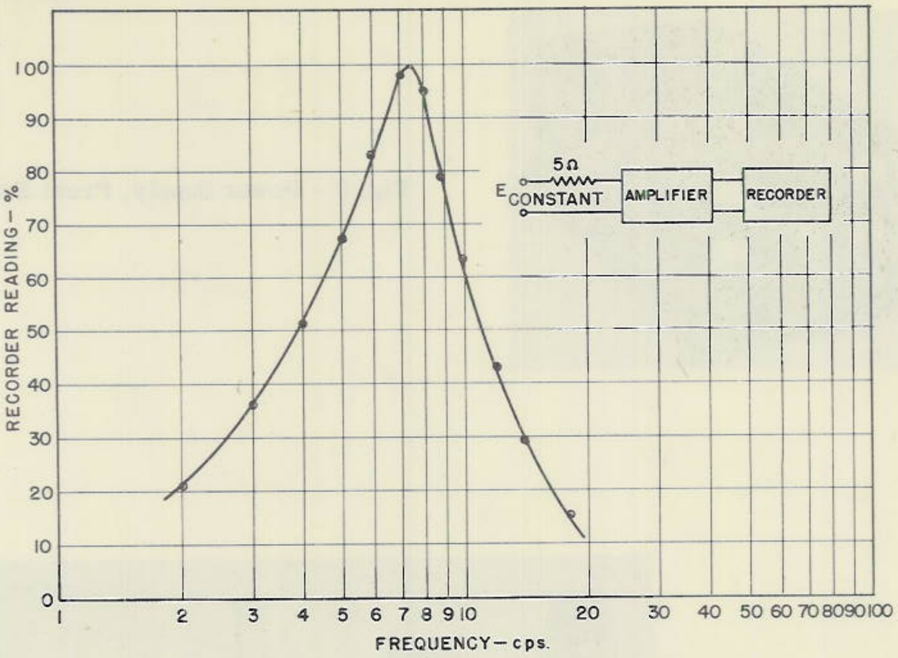

Fig. 7 - Amplifier Frequency Response

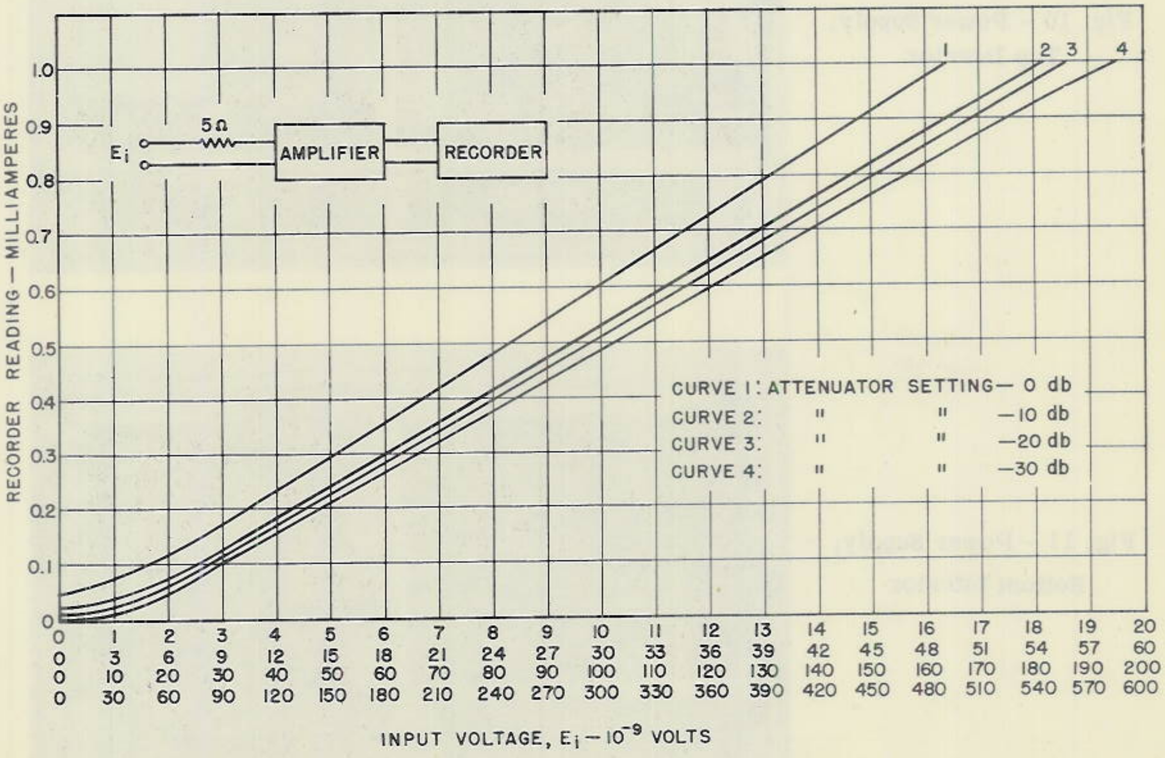

Fig. 8 - Amplifier Linearity

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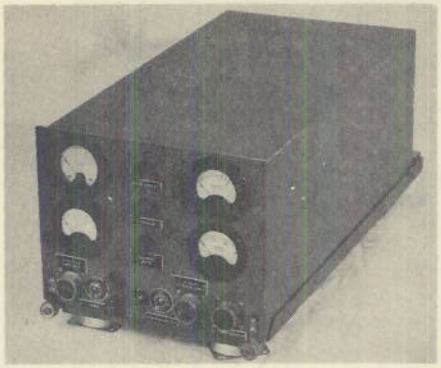


Fig. 9 - Power Supply, Front Exterior

Fig. 10 - Power Supply, Top Interior

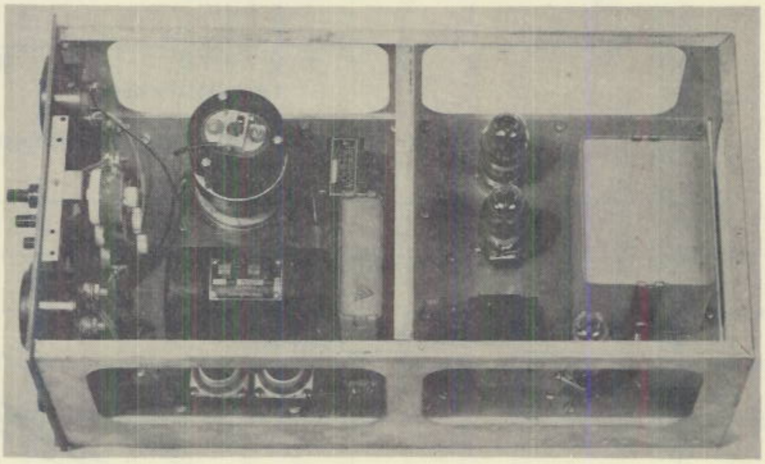
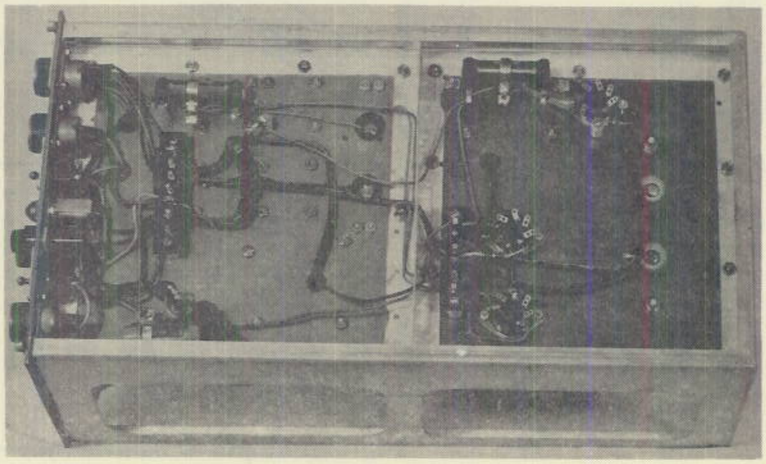


Fig. 11 - Power Supply, Bottom Interior



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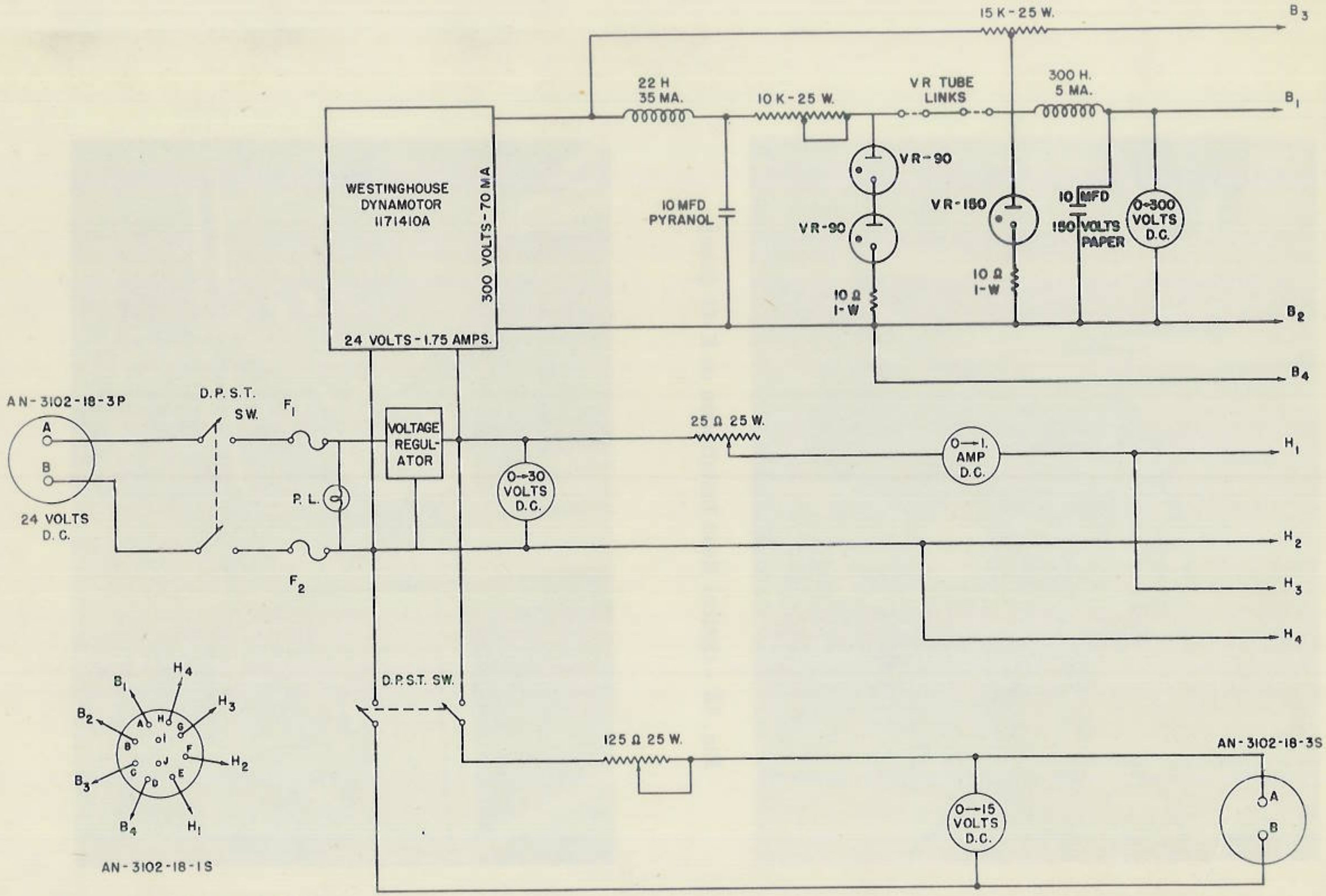

VOLTAGE REGULATOR - 21 TO 30 VOLTS
D.C. AT 5 AMPS.

Fig. 12 - Power Supply Wiring Diagram

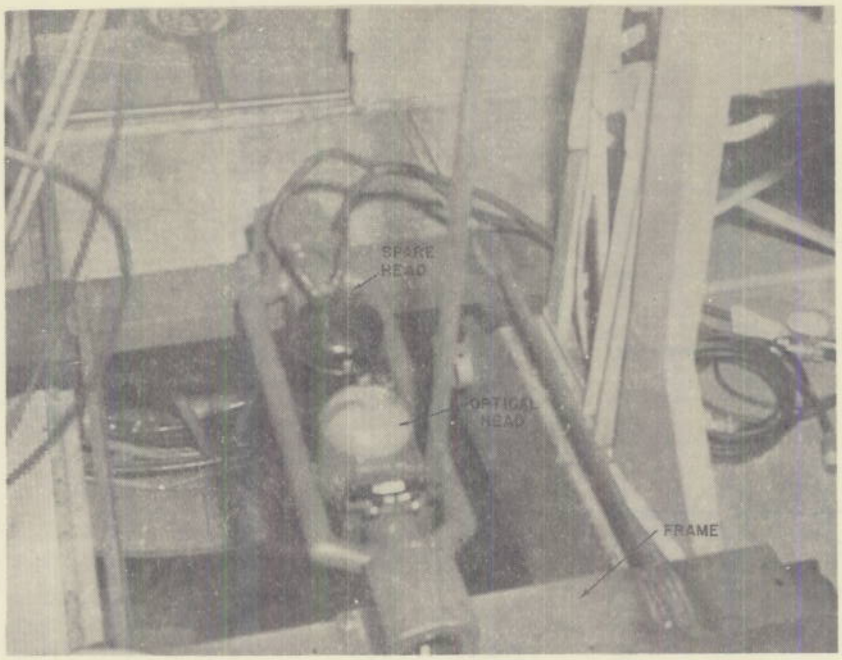

Fig. 13 - Optical Head Installation on K-65 Blimp

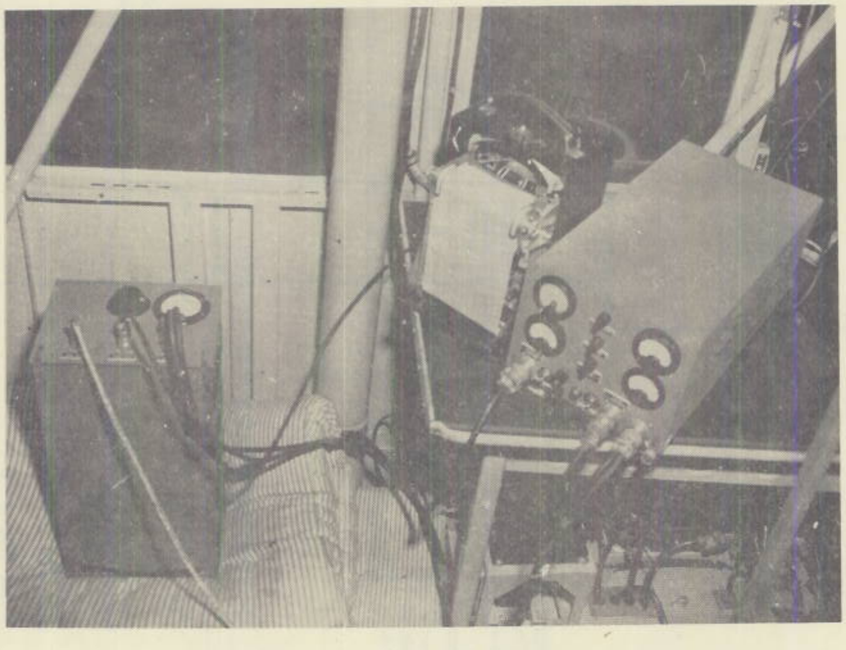

Fig. 14 - Amplifier Mounting on K-65 Blimp

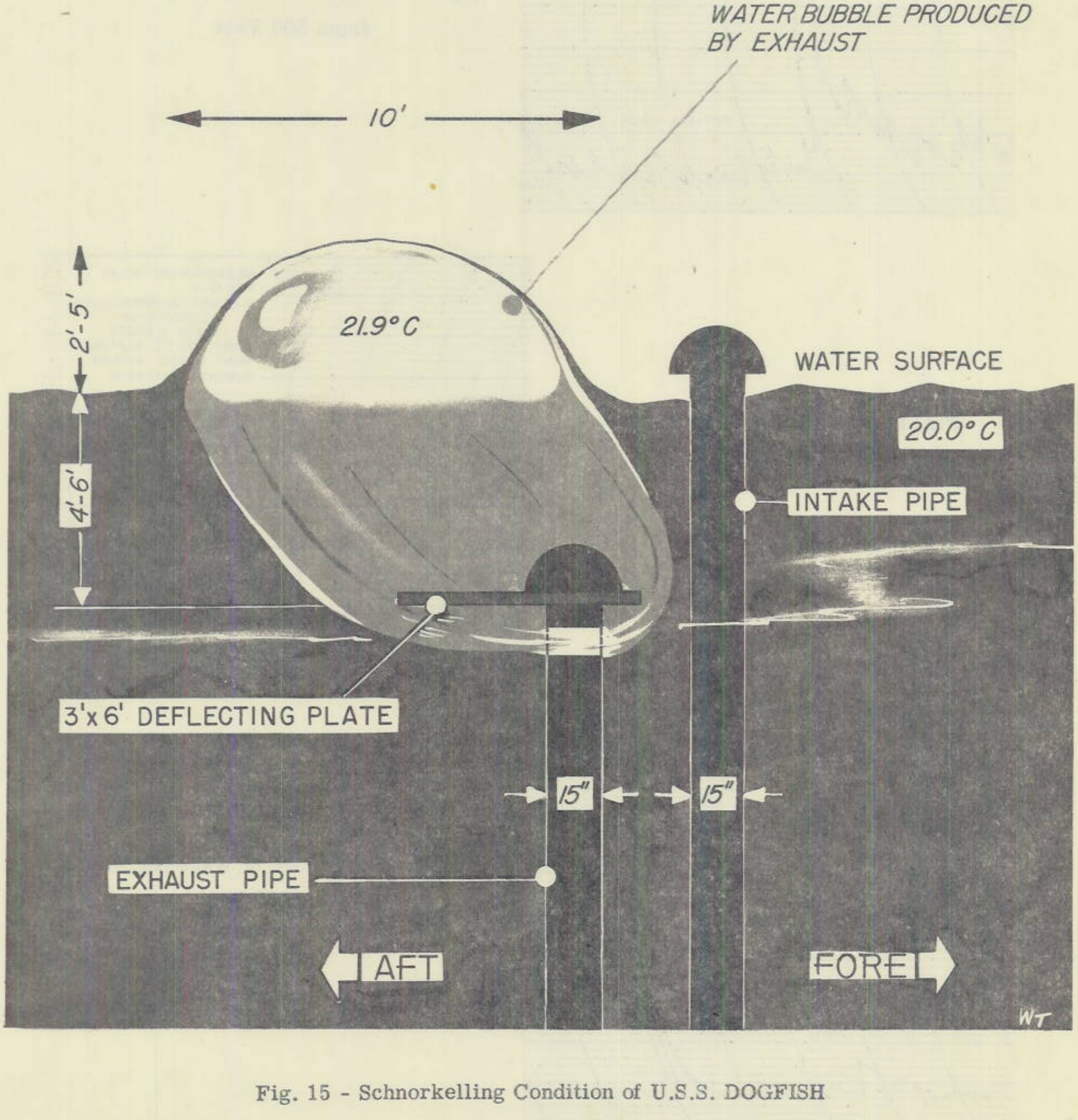

Fig. 15 - Schnorkelling Condition of U.S.S. DOGFISH

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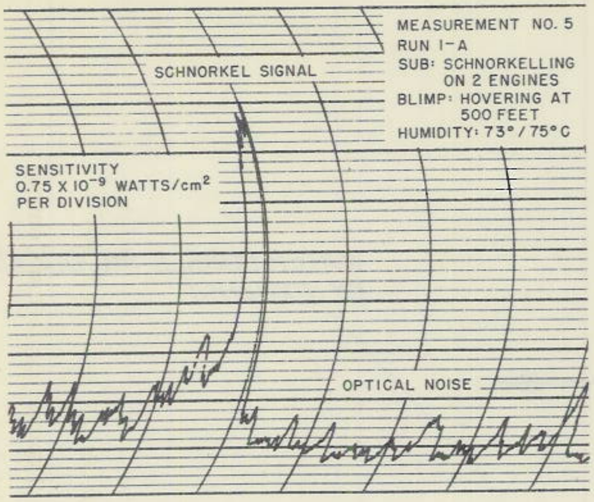

Fig. 16 - Record of Schnorkel Signal from 500 Feet

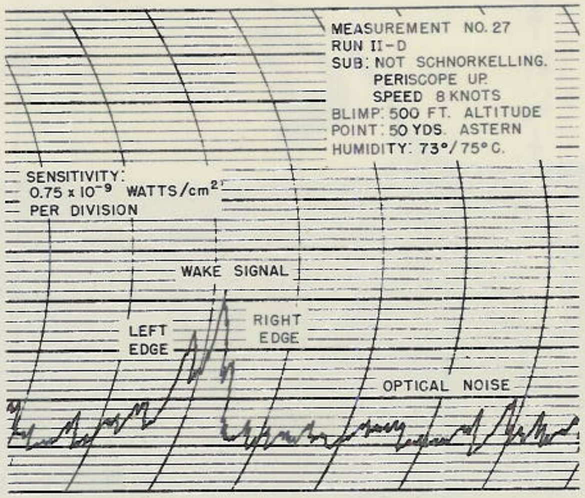

Fig. 17 - Record of Wake Signal from 500 Feet

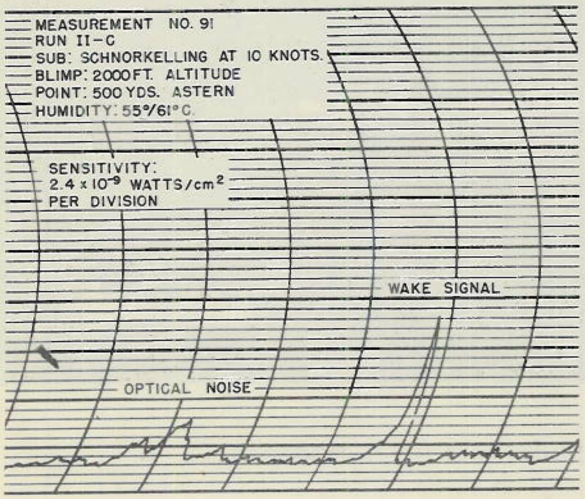

Fig. 18 - Record of Wake Signal from 2000 Feet

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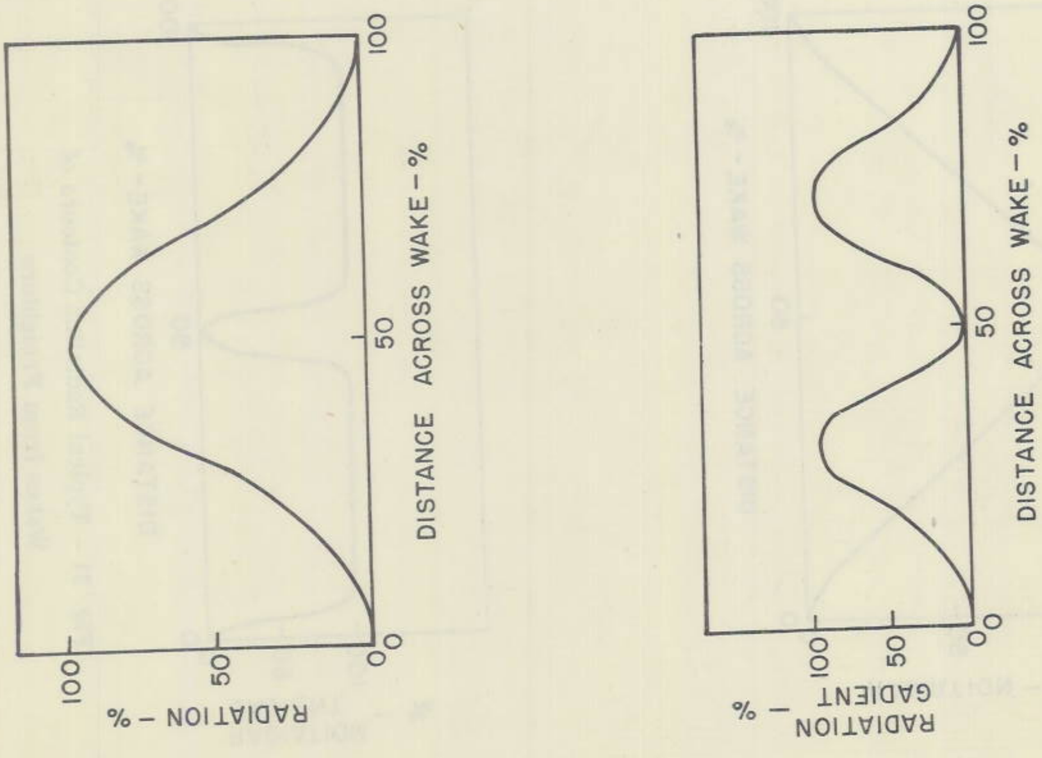

Fig. 19 - Approximate Radiation Contours of Wake of U.S.S. DOGFISH

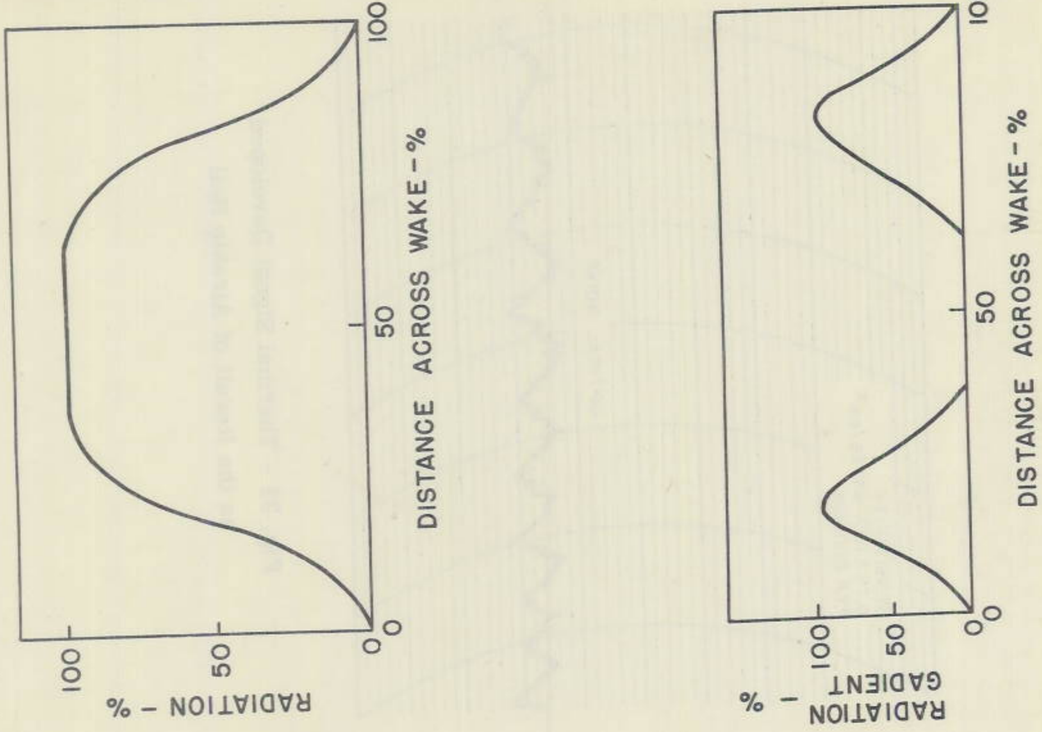

Fig. 20 - Typical Radiation Contours of Wakes from Freighters

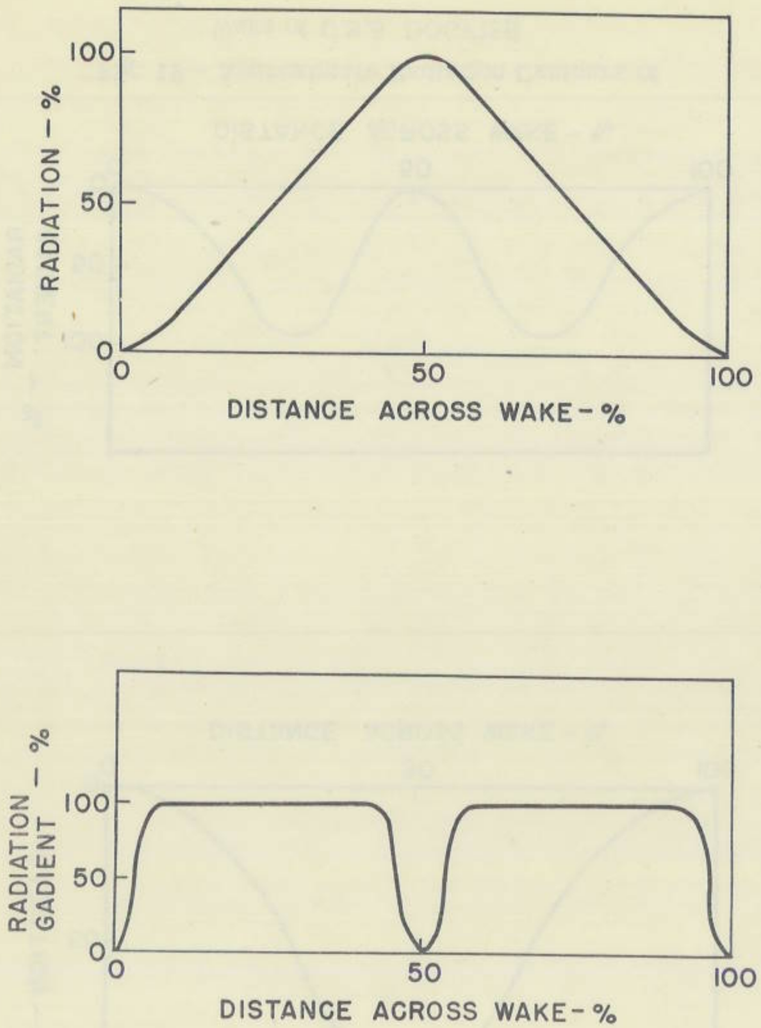

Fig. 21 - Typical Radiation Contours of Wakes from Freighters

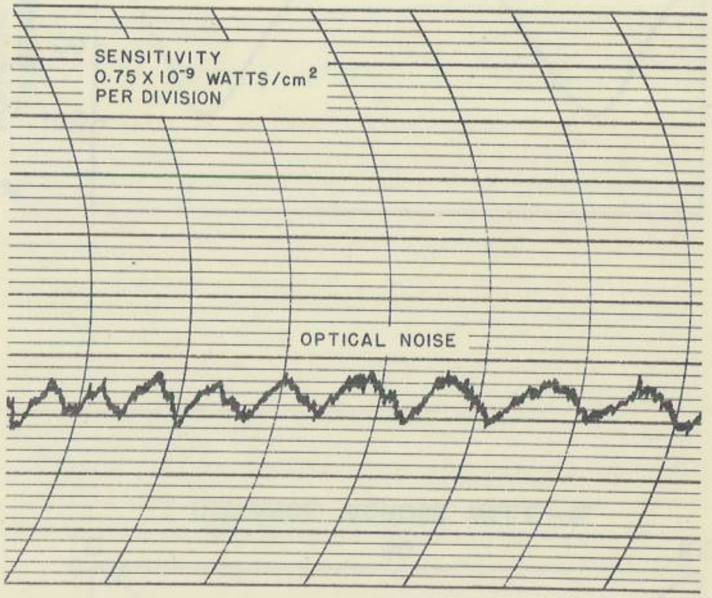

Fig. 22 - Thermal Signal Developed as the Result of Airship Roll

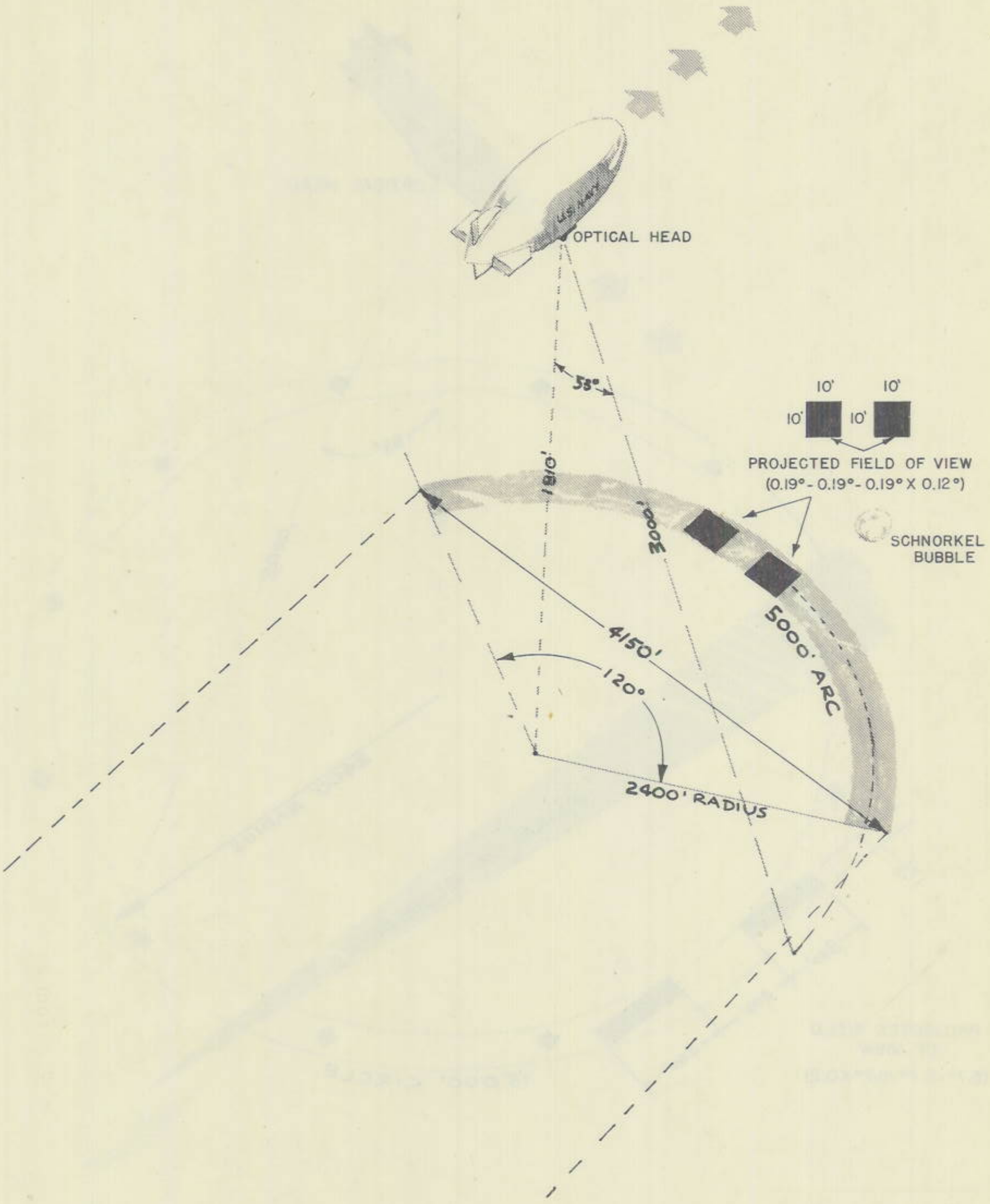

Fig. 23 - Suggested Method of Searching for a Schnorkel Bubble

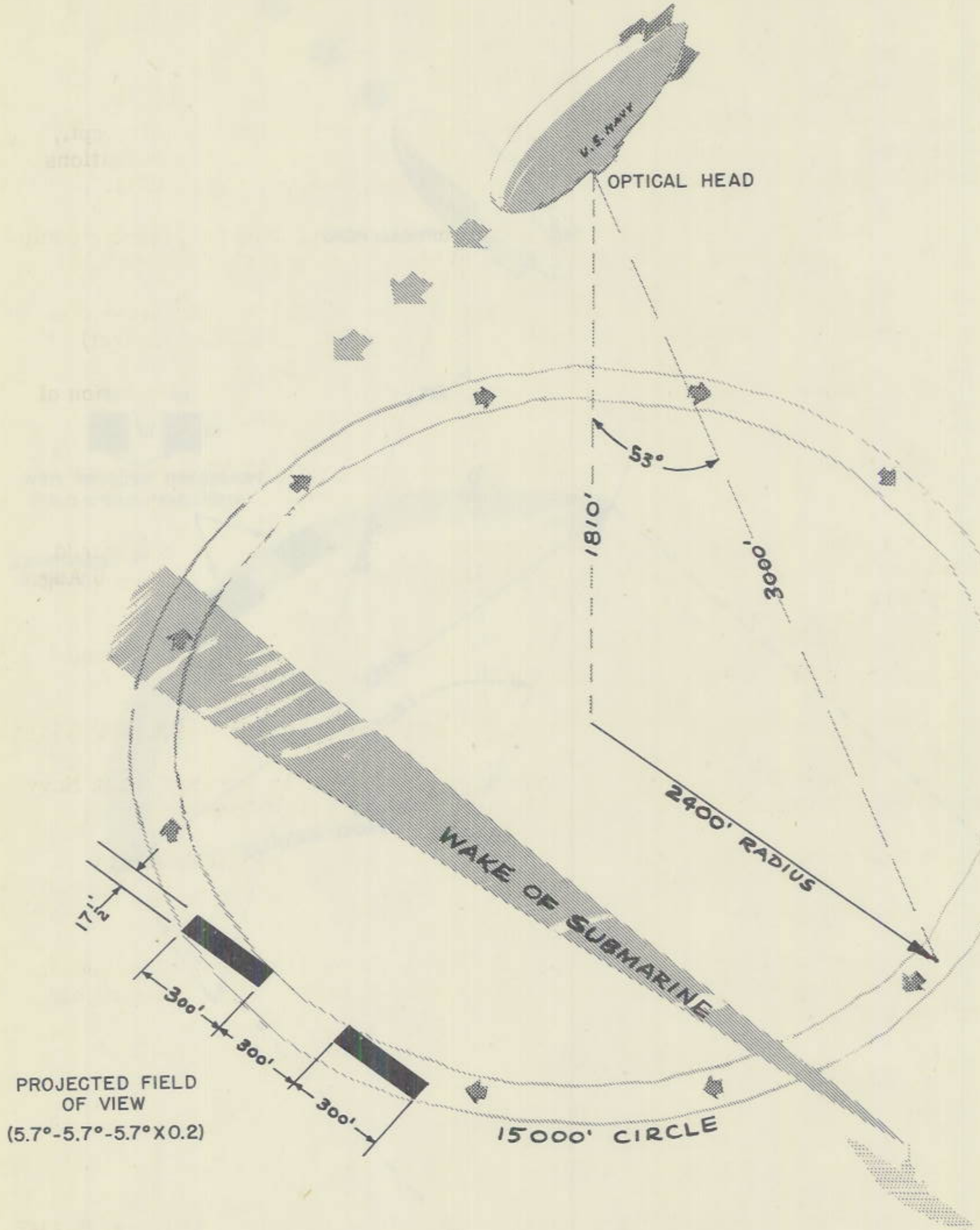

Fig. 24 - Suggested Method of Searching for a Submarine's Wake

REFERENCES

(1) High Frequency Research Institute (Travemünde, Germany) preliminary rpt., "Untersuchungen mit dem Wärmepeilgerät von Zeiss vom Flugzeug aus (Investigations with the Zeiss Heat Detection Equipment from an Aircraft)" issued 25 Sept. 1944.

(2) Preliminary report - Evaluation flight test of AN/ASQ-5 (XN) heat homing equipment, Naval Air Development Station, Report No. R-0198, 15 Oct. 1947. (Confidential)

(3) Great Britain Admiralty Research Laboratory Report R.2/E. 570, Detection of Schnorkel Exhausts by Non-Selective Thermal Receivers, 20 April 1945. (Secret)

(4) Great Britain Admiralty Research Laboratory Report R.3/E.570, Detection of Schnorkel Exhausts by Lead Sulphide Cells, 31 August 1945. (Secret)

(5) Great Britain Admiralty Research Laboratory Report R.4/E.570, Detection of German Schnorkel Exhausts by Thermal Radiation, 11 November 1945. (Secret)

(6) J. A. Sanderson, C. P. Butler, G. L. Harvey, J. A. Çurcio, Report on Infrared Radiation from Schnorkel Exhaust, U.S.S. Irex (SS482), NRL ltr. rpt. 600-272/47, 6 Aug. 1947. (Confidential)

(7) R. W. Mitchell, Schnorkel Detection Sea Tests, U. S. Navy Underwater Sound Laboratory rpt. No. 86, 22 Sept. 1947. (Confidential)

(8) BuOrd Instruction Book for Test Units, Mark 7, Mod 1, Mod 2, Mod 3, NOrd-7315.

(9) G. L. Harvey, The Detection of Schnorkelling Submarines by Infrared, U. S. Navy Underwater Sound Laboratory rpt. (D138C) (P-10.3) 30 Sept. 1948. (Confidential)

(10) BuShips conf. Instruction Manual for Passive Bearing Finder, NObs-21176.

(11) Method developed by Infrared Div., USNUSL.

(12) The conversion from radiated power falling on a thermopile to output voltage is a linear one, hence the noise amplitude after conversion can be expressed in terms of irradiating power density.

(13) British Report A.R.L./R.2/E.570, loc. cit.

(14) British Report A.R.L./R.3/E.570, loc. cit.

(15) British Report A.R.L./R.4/E.570, loc. cit.

(16) E. O. Hulburt, Atmospheric Transmission of Infrared Radiation, NRL rpt. H-2348 22 July 1944. (Secret)

(17) D. H. Garber, E. W. Smith, and J. Cryden, Investigation of Thermal Wake Detection of Schnorkelling U-Boats, U. S. Navy Electronics Laboratory rpt. S-23, Dec. 1945.

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REFERENCES (Cont.)

(18) High Frequency Research Institute (Travemünde, Germany) preliminary rpt., loc. cit.

(19) A third source of noise is that due to the random variation in sky radiation which is reflected from the surface of the sea. There is reason to believe that this noise is relatively small particularly for angles of incidence between 45 and 0 degrees.

(20) E. O. Hulburt, loc. cit.

(21) W. R. Holm, Thermal Signals Due to the Reflections of Sky Radiation by the Sea, NRL rpt. H-2506 20 April 1945. (Restricted)

(22) E. O. Hulburt, loc. cit.

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