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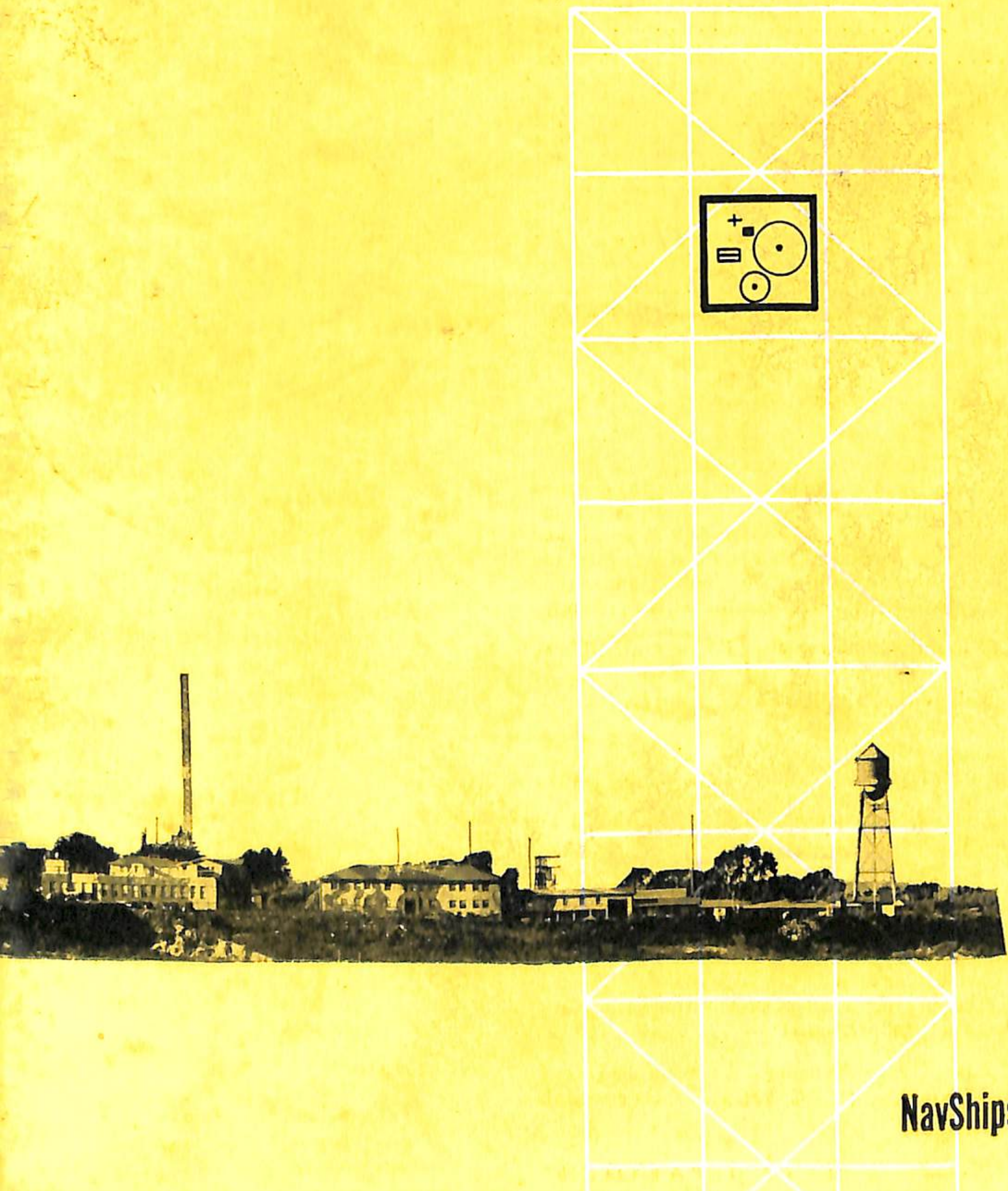
BUSHIPS Electron



US NAVY ELECTRONICS LABORATORY
SAN DIEGO CALIFORNIA

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CONFIDENTIAL

BUSHIPS Electron

A MONTHLY MAGAZINE FOR
ELECTRONICS TECHNICIANS

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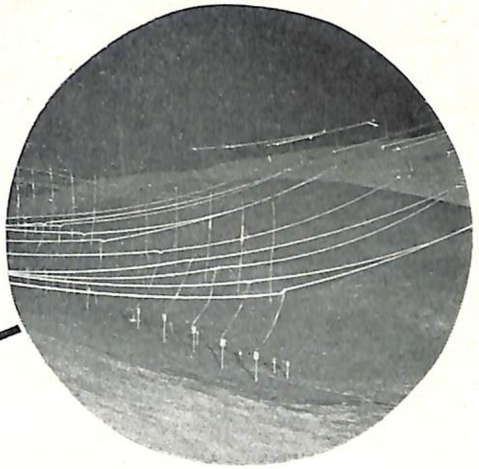
THE HUMAN FACTOR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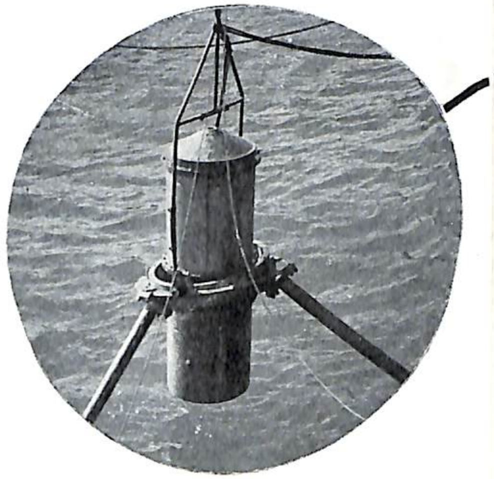
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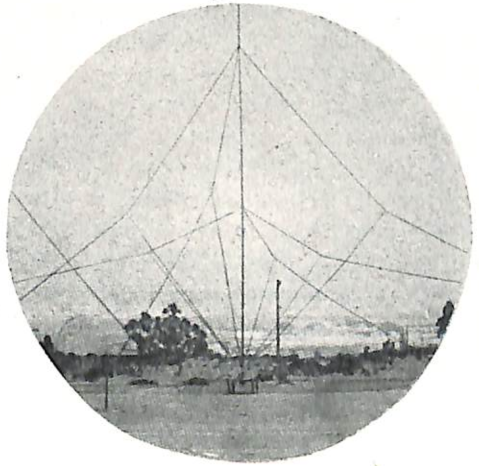

RADIO

THE U.S. NAVY ELECTRONICS LABORATORY

The fullest possible use must be made of the best electronic devices, equipments, and techniques that can be provided by modern science to make the U. S. Fleet superior to the fleet of any possible enemy nation. It is the primary mission of the U. S. Navy Electronics Laboratory to provide the Fleet with such devices, equipments and techniques. This mission is accomplished under general program guidance of the Chief of the Bureau of Ships, and under a broad policy that requires a two-way flow of information between the Bureau and the Laboratory on the one hand and the Laboratory and the Fleet on the other. Thus the Laboratory personnel are in an excellent position to understand the immediate problems confronting the Fleet while at the same time remaining aware of general program requirements as formulated by the Bureau and the Chief of Naval Operations.

Close contact with the Fleet is favored by the Laboratory's San Diego location. Much of the Pacific Fleet is based at San Diego, so that work in direct support of the Fleet is greatly facilitated. Location also favors work at sea in the Laboratory submarine and surface ships, which have been specially equipped for research and development investigations. An equable climate and the proximity of a wide range of oceanographic conditions contribute to efficient laboratory operations at sea. Investigations at sea are not, however, limited to the waters off southern California. Laboratory personnel have carried out tests and special investigations throughout the Pacific area—from the Antarctic to the Arctic; from the Marianas to Mexico.

Very broadly, the research and development program of the Laboratory embraces four principal fields: sonar, radio, radar, and the human factor in applied electronics. Both applied research and development work are carried out. The research and development program is administered by the Director, Captain Rawson Bennett II, and is under the immediate technical direction of the Superintending Scientist, Mr. Joseph P. Maxfield. The Research, Development, and Systems Engineering Divisions carry the bulk of the research and development work.

The U.S.S. WITEK and a hull-mounted HYDROPHONE used for special sonar studies.

In the performance of their work they are aided by a Consulting Staff headed by Dr. Alfred E. Focke and by supporting divisions that provide administrative, supply, technical, and information services.

Sonar Investigations

In the modern Navy, sonar is the most important single detection technique in pro- and anti-submarine warfare. There are two primary sonar detection methods. One consists of echo-ranging through the emission of sound waves that travel through the water, bounce off the target, and return after reflection to the detecting surface ship or submarine. The other consists of detecting the target ship through listening to sound emitted by the target.

Sonar investigations at NEL follow a broad program of research and development that provides for the study of both echo-ranging and listening methods and of a wide variety of equipments and systems. Current work with echo-ranging systems is divided between FM and pinging equipments. FM sonars emit sound energy continuously but at constantly varying frequency. During the time required for the sound to travel to the target and back, the frequency of the emitted signal has changed and become different from the frequency of the received echo. This frequency or pitch difference is used to determine the range to the target. Present investigations in FM sonar look toward the extension and modification of FM systems as an attack sonar. Some of the results may aid in the development of sonars that will be of maximum use for under-ice navigation.

In pinging sonar systems a rapid succession of pulses is emitted and in the brief intervals of silence in between, the returning echo which is the clue to the speed, direction, and location of the target is picked up by receiving hydrophones. Research studies presently being conducted at NEL look toward eventual development of a very short pulse, high power pinging sonar. These studies, which are being conducted along broad and comprehensive lines, have not yet yielded sufficient information to permit a definite forecast of results. It is possible, however, that shorter pulses and higher power may be the key to attainment of greater sonar ranges than are presently being achieved.

The effectiveness of all kinds of sonar systems is greatly influenced by the noise emitted by the ship or submarine on which the sonar gear is mounted. Effectiveness is also influenced, particularly in the case of listening systems, by the amount and kind of noise generated by the target ship or submarine. Therefore noise level studies are of great practical importance in all research and development work in the sonar field.

Representative of the studies in this field at NEL are the WITEK noise studies that are currently being undertaken. The WITEK is a 2100-ton 692 class long-hull destroyer which has been specially equipped as a sonar research ship. Over 100 hydrophones of several different kinds are mounted on her hull and she carries a wide variety of sonar systems. The sounds picked up by selected hydrophones of the various sonar systems are recorded automatically and synchronously in the master sonar control room—a recording method that permits detailed study of self noise. In the present tests the ship is run at a wide range of speeds under different conditions of state of the sea and with different auxiliaries operating. Through careful comparison of a large number of such tests it is possible to determine the various sources of self noise and to describe the noise characteristics of the screw, of various auxiliaries, and of other noise sources.

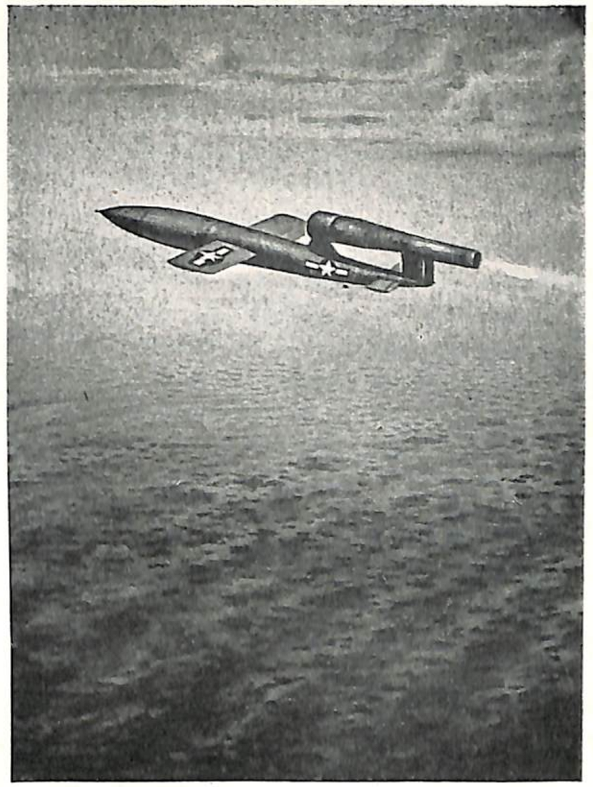
Actually, the noise level studies are but one portion of the comprehensive sonar investigations made aboard the WITEK. Studies have also been made of operator performance, and special listening tests of various kinds have been accomplished.

Radio and Radar Investigations

Radio and radar investigations at NEL are directed toward achievement of three broad fundamental goals: (1) developing special radars necessary to meet particular detection and tracking requirements; (2) obtaining reliable automatic communication, especially over long distances; and (3) developing efficient integrated radiating systems.

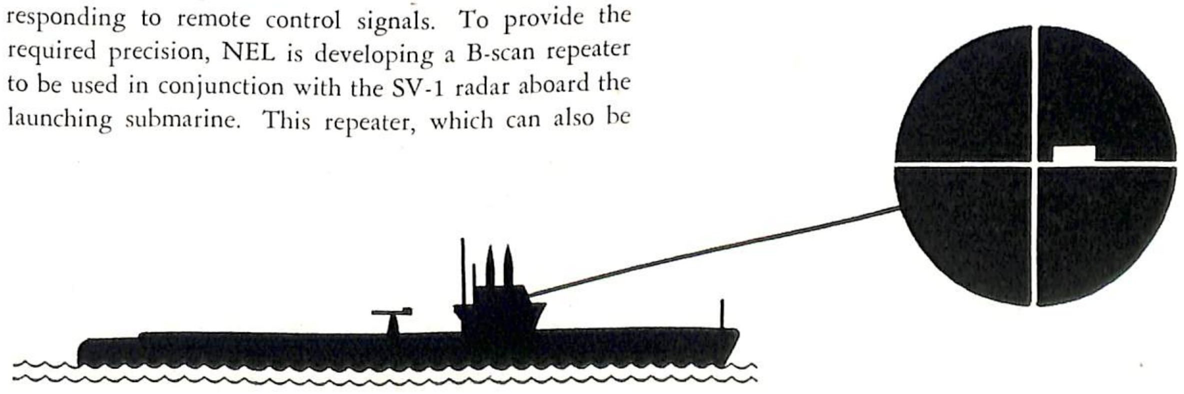
During the course of the war, vast improvements were made in radar equipments. Further improvements, many of them involving radical design changes, are still being made, both at NEL and elsewhere.

One of the most severe requirements that has recently been placed on radar equipments arises from the need for a detection and tracking system that can be used against guided missiles. NEL is assisting the forces afloat in solving one aspect of this problem: the modification of the radar used to track submarine-launched guided missiles which are currently being tested at Pt. Mugu, California. The immediate operational problem in the Pt. Mugu tests is to track the missiles with a high degree of precision so as to observe whether the "bird" is on the predetermined course and whether it is responding to remote control signals. To provide the required precision, NEL is developing a B-scan repeater to be used in conjunction with the SV-1 radar aboard the launching submarine. This repeater, which can also be used with other radar equipments, will have bearing stabilization and range circuits that will permit the missile to be tracked to within 100 yards at a distance of 20 miles, and within 400 yards at a distance of 80 miles.



Perhaps the chief limiting factor in the achievement of reliable automatic communication over long distances is the signal distortion that takes place along the transmission path. As described elsewhere in this issue, fundamental studies are currently being made of long-distance transmission through the ionosphere with the object of increasing the efficiency of such communication. At the same time, analagous studies are being made for short-distance radar transmission. These radar studies, described elsewhere in this issue, are particularly concerned with the influence of duct conditions on high-frequency radio transmission.

Reliable automatic communication requires not only efficient transmission but also effective transmitter cir-



cuits and radiating systems on the one hand and effective automatic receivers, converters, and teletypes. These aspects of the general communication problem are also being investigated at NEL.

One of the approaches being studied as a possible means of increasing communication speed is a method of high-speed keying at very low frequencies whereby the transmitter frequency is shifted very rapidly back and forth while at the same time the transmitting circuit is altered so that reasonably effective radiating performance is maintained on a continuous basis. If this method of frequency shift keying proves effective it will be possible to speed up communications by using one frequency to represent dots and the other frequency to represent dashes. In effect, continuous transmission will have been substituted for interrupted transmission.

In the present-day Navy the development of integrated radiating systems is of paramount importance. Shipboard antennas must provide for the sending and receiving of radio signals required for communication, navigation, detection, and identification. The design of antennas to carry this heavy load of traffic must be approached from an over-all integrated point of view if maximum all-around efficiency is to be achieved.

As reported at length in earlier issues of ELECTRON,[1] studies of integrated radiating systems at NEL are made in large part on a model basis. By the careful scaling of model ships of different types and classes and by a corresponding scaling of radio frequencies, it is possible to determine relatively rapidly the effects of antennas upon one another, the effect of placement and arrangement, the influence of ship superstructure upon the efficiency of antennas, and other interrelated effects. The model technique is checked against and supplemented by full-scale studies made aboard ship. Model techniques are also employed in the study of shore-based radiating systems.

The Human Factor in Applied Electronics

In the development of all electronic equipment there are two primary dangers. One is the possibility of developing an equipment that requires so much of the operator that he is unable to utilize fully the potentialities of the equipment and may even commit serious errors in operation. The second danger lies in the opposite direction—an equipment may not take full advantage of the capabilities of the operator and may therefore be unnecessarily crude and inaccurate in performance. For these two primary reasons any realistic program in electronics must consider the human factor. A properly designed equipment should make maximum use of operator capability while at the same time making allowance for such factors as fatigue, and the adverse effect of combat conditions and of noise and other distractions encountered under actual operating conditions aboard ship.

A program of psychological studies undertaken as a means of improving the actual performance of electronic equipments is being pursued at NEL. This program is designed to determine what performance can be expected under a wide variety of circumstances of both the trained and untrained operator. Studies are being made in aural and visual perception, manual dexterity, and mental coordinating ability. An example of the kind of work being performed is the current study of multiple-tone discrimination. Many sonar equipments depend for efficient use upon the ability of the operator to identify tones which are not quite masked by background noise. It was desired to determine whether improved operator performance might be obtained if the operator were required to identify not a single tone but two or more tones in combination. Experiments were designed to test and compare operator performance in tone discrimination. The results indicated that no appreciable improvement is obtained if it is required that multiple rather than single tones be identified by the operator.

Electronic Training Equipment

The training of Navy personnel in the operation of new electronic devices cannot wait until the equipment is installed aboard the ships of the Fleet. Trained operators must be available to man the gear as soon as the ships are so equipped. Electronic trainers permit effective, realistic training in advance of the installation of any gear aboard ship.

Representative of the trainers being developed at NEL is the QDA/OKA trainer. QDA is the Navy's designation for target-depth-determining sonar equipment. OKA is the resolving equipment which computes the horizontal range of the target, and provides the necessary inputs to the QDA for recording the depth of the target. The QDA/OKA trainer is designed to develop in sonar operators the complex motor, visual, and auditory skills required in operation of the shipboard gear.

The trainer consists of five operator's stations and a master problem-control station. All student equipment possesses the operating characteristics of actual equipment at sea and presents realistic sounds and recorder traces.

The tactical situations provided by the problem-generator unit of the trainer are produced by cam-driven components. The sound effects and the required electronic inputs from azimuth sonar equipment are simulated. The instructor is able to select one of three basic problems, to vary the submarine's speed and depth of bottom, to introduce the simulated sound effects of various evasive devices, and to observe the students' operations by means of monitoring indicators.

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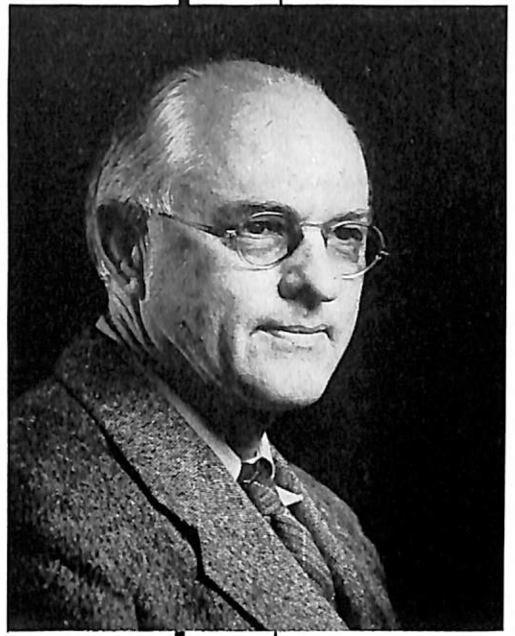
[1] ELECTRON, December 1947, January 1948, and February 1948.

SUPERINTENDING SCIENTIST



Joseph P. Maxfield, for 35 years a pioneer in the development of devices and techniques used in radio broadcasting, disc recording, and sound motion pictures, is the Superintending Scientist of the U. S. Navy Electronics Laboratory. In this position, he oversees the Laboratory's extensive program of research and development in the fields of radio, radar, and sonar.

Mr. Maxfield was graduated as a Bachelor of Science by the Massachusetts Institute of Technology in 1910. For four years thereafter, he taught electro-chemistry and physics at this educational center, then joined the staff of the engineering department of the Western Electric Company.

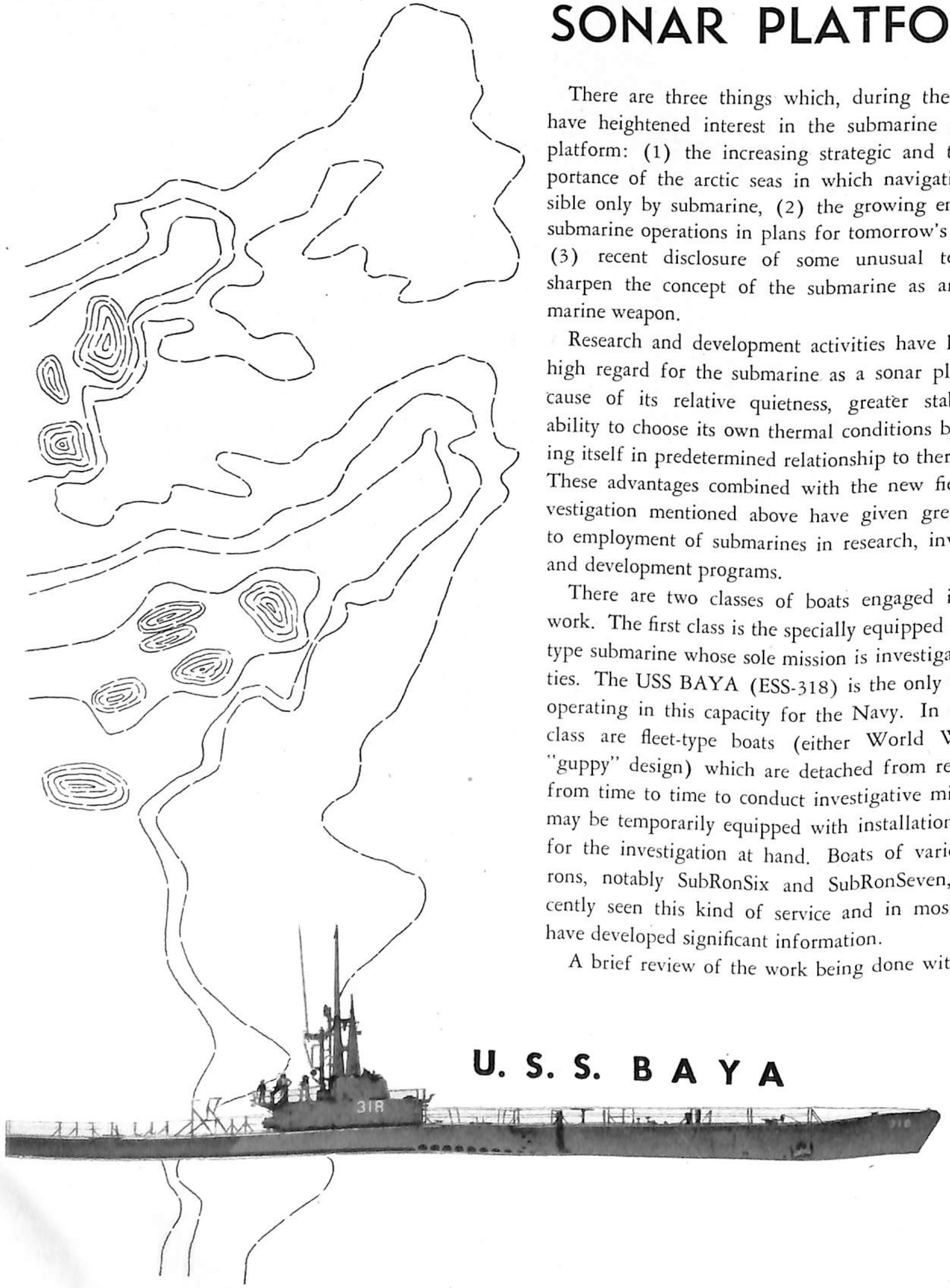
Mr. Maxfield's association with this organization, which in 1925 became the Bell Telephone Laboratories, was productive of several "firsts" in electrical sound recording and reproduction. His Maxfield transmitter, the double-button carbon microphone, was the standby of early broadcasters. He was the first to put into practice the idea of placing a microphone in the shadow of loudspeakers in public address installations. This technique, which makes it possible to reinforce the sound of a speaker's voice without interfering with his audio-visual relationship with his audience, was used first at the inauguration ceremonies for President Harding in 1921.

Mr. Maxfield first proposed the now generally accepted "live" method of sound pickup used in the broadcasting, recording, and motion picture industries. By recording the sounds of an orchestra together with some of the reverberation existing in the recording studio at the time of the performance, Maxfield demonstrated that it was possible to create for the ultimate listener an illusion of being present at the actual performance.

During World War I, Mr. Maxfield was active in investigations of the principles of acoustic ranging of aircraft and artillery. He continued acoustic ranging work in the second World War as Director of the Division of Physical War Research at Duke University under contract with the Office of Scientific Research and Development.

Mr. Maxfield is a Fellow of the American Institute of Electrical Engineers, the American Physical Society, the Acoustic Society of America, and the Society of Motion Picture Engineers. He is a Senior Member of the Institute of Radio Engineers and a member of Sigma Xi. He has published many papers on the recording and reproduction of speech and music and on auditorium acoustics. He accepted appointment with the U. S. Navy Electronics Laboratory in September, 1948.

THE SUBMARINE
AS A
SONAR PLATFORM



U. S. S. BAYA

There are three things which, during the past year, have heightened interest in the submarine as a sonar platform: (1) the increasing strategic and tactical importance of the arctic seas in which navigation is possible only by submarine, (2) the growing emphasis on submarine operations in plans for tomorrow's Navy, and (3) recent disclosure of some unusual tests which sharpen the concept of the submarine as an anti-submarine weapon.

Research and development activities have long had a high regard for the submarine as a sonar platform because of its relative quietness, greater stability, and ability to choose its own thermal conditions by positioning itself in predetermined relationship to thermal layers. These advantages combined with the new fields of investigation mentioned above have given great impetus to employment of submarines in research, investigation, and development programs.

There are two classes of boats engaged in research work. The first class is the specially equipped laboratory-type submarine whose sole mission is investigative activities. The USS BAYA (ESS-318) is the only vessel now operating in this capacity for the Navy. In the second class are fleet-type boats (either World War II or "guppy" design) which are detached from regular duty from time to time to conduct investigative missions and may be temporarily equipped with installations required for the investigation at hand. Boats of various squadrons, notably SubRonSix and SubRonSeven, have recently seen this kind of service and in most instances have developed significant information.

A brief review of the work being done with specially equipped submarines will make possible a better understanding of the importance of the research projects they undertake and will show why the only boat now assigned to full-time experimental work, the BAYA, is already committed to established programs until the middle of 1950.

The Arctic Seas

The arctic sea investigation is a broad-gauge program involving oceanography, submarine operation, navigation, and tactics. The thermal layer effects encountered there are peculiar to the area and must be studied and charted to make operation in these seas practicable. This is of great importance because of the fact that the submarine is the only vessel capable of navigating these seas with any degree of freedom, and because even the submarine can navigate under ice only by means of sonar navigational aids. Anything which affects the propagation of sound, and certainly the oceanography and thermal structure of the waters in this area do affect sound propagation, must be carefully investigated to make possible the fullest use of the submarine in this new environment. Aside from tactical considerations, the physical characteristics of this area require that the submarine be used as an anti-submarine weapon, that all navigation, detection, and attack operations depend on sonar, and that the submarine (of necessity) be the platform for these sonar operations.

The BAYA is currently engaged in investigation of propagation conditions and in measurement of target strengths (as affected by propagation conditions) in these and other waters. In some of these measurements, the BAYA is itself serving as the target. To maintain control of the conditions under which these measurements are made the submarine is suspended from buoys at various predetermined depths. The boat has been equipped with hull-mounted hydrophones to measure the strength of the sound field at various points on the target (submarine) surface for comparison to the strengths of echoes as received by the echo-ranging ship. In addition to the target strength and propagation condition measurements, future investigations will include studies of thermal layers and thermal microstructure in the area as well as evaluation of various sonar equipments for navigation (under ice), detection, and attack.

The Submarine in Tomorrow's Navy

Current thinking along strategic and tactical lines is placing increasing emphasis on the submarine as an agency of tomorrow's warfare. It is hoped that the snorkel, atomic power, and advanced design (of which the "guppy" is the index of progress to date) will result in a high-speed true submarine. The true submarine would be capable of operating indefinitely below the surface of the sea, thus increasing the submariner's reliance on sonar for navigation, detection, attack, and communication.

The submariners and the various activities charged with advancing the submariner's art know what instrumentation is needed to meet these requirements, but if the development of the needed equipments is to proceed with reasonable dispatch, it is essential that submarine facilities be available for technical and tactical evaluation of the equipments as they are developed step by step. In this again, the BAYA attached to the U. S. Navy Electronics Laboratory since early 1948, has been of inestimable value.

In the few brief months during which this laboratory-type submarine has been available, investigations and evaluations have been conducted in programs on pulsed sonar; sonar navigation devices; self-noise and target-strength studies; on investigations of the physical characteristics of the sea as they affect sound propagation; and on FM attack sonars, to provide scan in elevation and azimuth, range rate and fire control information, and target tracking in range, in azimuth, and in elevation.

Because of the brief time the BAYA has been in service as a laboratory-type submarine, the investigations in the program cited above have been only of a very preliminary nature and much work of significance remains to be done in developing the needed equipments.

Anti-Submarine Submarine

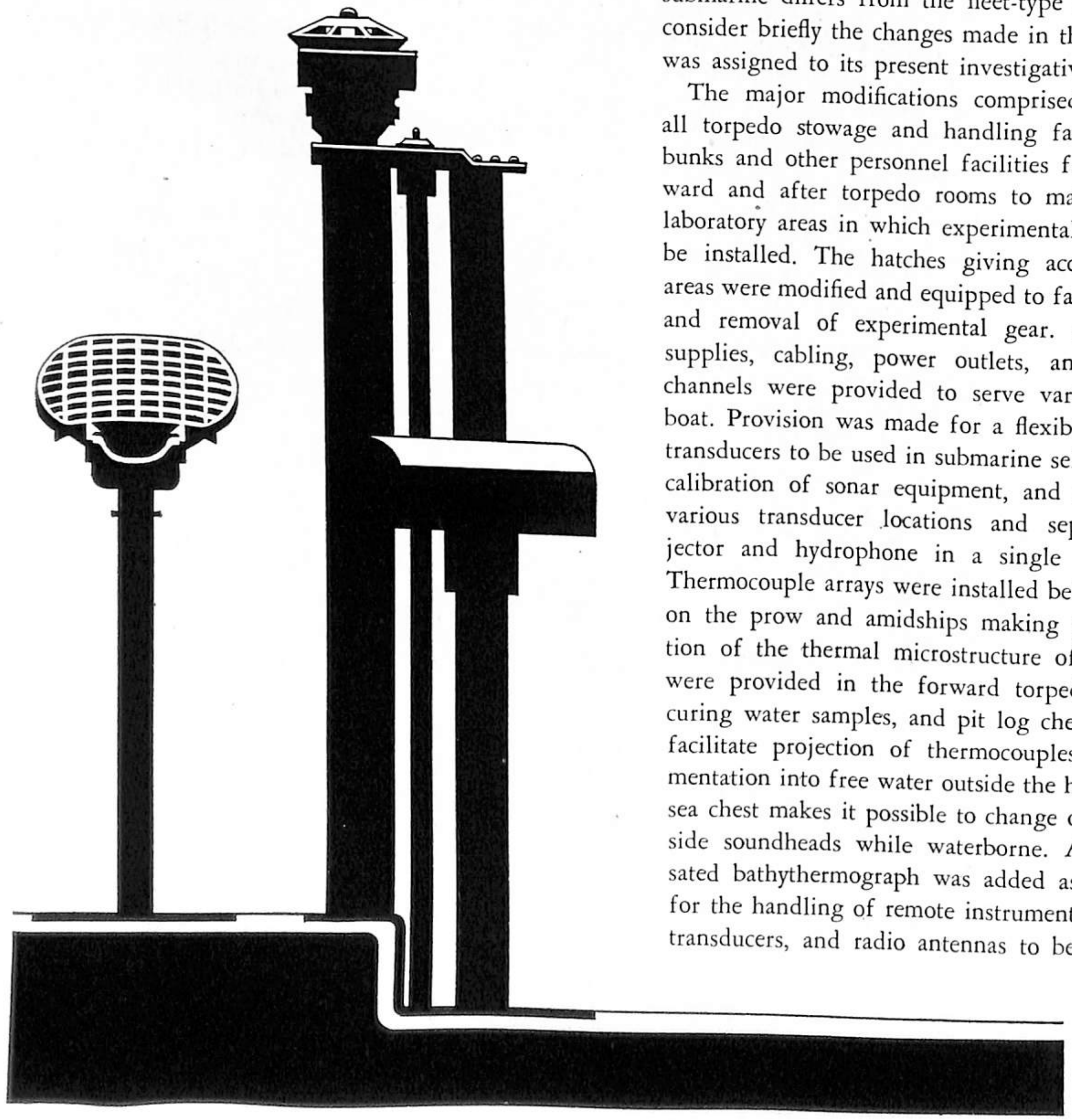
Tests conducted by SubRonSix during the past year revealed the submarine as a sonar platform "whose superiority over all others is far greater than had been supposed" in A/S operations of detection and attack.

Listening detection of snorkeling submarines at 37,000 yards and dependable ping returns from submarine targets at ranges above 5000 yards were reported. A submarine picket line was employed with five submerged "hovering" boats stationed 20 to 40 thousand yards apart to cover a line 100 miles in length.

In these same exercises, "successful submarine A/S attacks were made using Mark 14 torpedoes" in which the killer submarine detects the target at long range and closes by alternately running-in and pausing to listen until a favorable solution and firing position has been reached.

The work undertaken by SubRonSix and similar investigations subsequently undertaken by SubRonSeven have immense tactical and operational significance. It should be noted, however, that most of this type of work reported to date has been conducted by fleet-type submarines and lacks much in scientific detail which would make the results applicable in a broader sense—detailed information which could be procured only were similar tests made using specially equipped laboratory-type boats.

SubRonSix exercises, for example, were conducted off Panama and Guantanamo. Lacking the special equipment for procuring detailed and exact information on sonar conditions existing at the time of the tests, it has been impossible to supply enough scientific data to permit proper evaluation of the tests in terms of other locations and sonar conditions. Hence, while the tests have served extremely well in pointing the way for further investigation and in spotlighting new possibilities of the submarine as a sonar platform, these same investigations could have been more fruitful and of wider immediate application had the investigating group included one or more properly instrumented laboratory-type boats.



The Laboratory-Type Submarine

To appreciate the manner in which the laboratory-type submarine differs from the fleet-type boat it is well to consider briefly the changes made in the BAYA when it was assigned to its present investigative mission.

The major modifications comprised the removal of all torpedo stowage and handling facilities as well as bunks and other personnel facilities from both the forward and after torpedo rooms to make space for two laboratory areas in which experimental equipment could be installed. The hatches giving access to these two areas were modified and equipped to facilitate the placing and removal of experimental gear. Additional power supplies, cabling, power outlets, and communication channels were provided to serve various parts of the boat. Provision was made for a flexible system of fixed transducers to be used in submarine self-noise studies, in calibration of sonar equipment, and in comparison of various transducer locations and separations of projector and hydrophone in a single sonar equipment. Thermocouple arrays were installed below the water line on the prow and amidships making possible investigation of the thermal microstructure of the sea. Fittings were provided in the forward torpedo room for procuring water samples, and pit log chests were added to facilitate projection of thermocouples or other instrumentation into free water outside the hull. An additional sea chest makes it possible to change one of the bottom-side soundheads while waterborne. A salinity-compensated bathythermograph was added as well as facilities for the handling of remote instrumentation: BT's, sonar transducers, and radio antennas to be lowered from or floated above the submarine at any desired operating level. Finally, all topside ordnance and other obstructions which might add to self noise or serve as ultra-short-range acoustic reflectors were removed and a three-inch ejection tube tending aft rather than athwartship was added.

In addition to the space and expanded research facilities provided by these changes, the laboratory-type submarine proves more economical in time, effort, and cost on research missions than does the fleet-type boat. This economy derives from two very simple and practical considerations:

(1) The fleet-type boat has no provision for comparative simultaneous tests of two or more equipments or components in the sense that these facilities are provided by a laboratory-type vessel. Hence, if comparative tests are even to be approximated, two submarines must be used rather than one, or a single submarine must repeat the operation using different gear. Such approximations at best are hardly comparative in the strict and scientific meaning of the term.

(2) The time and effort required for making temporary experimental installations for short trials aboard a fleet-type boat is excessive as compared to that required for similar installations aboard a submarine specially adapted for the purpose.

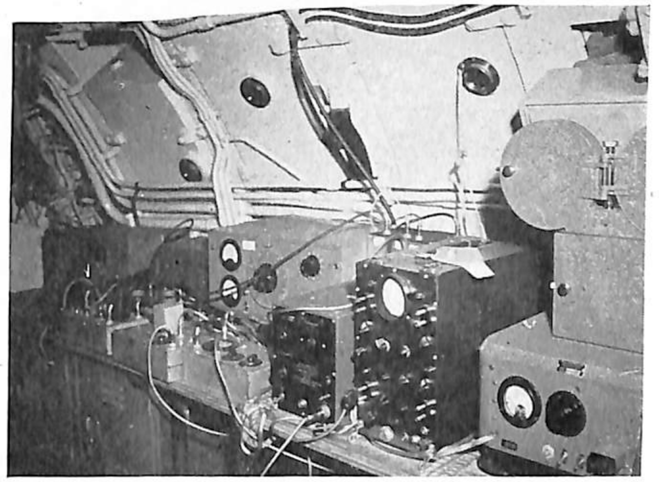
Based on the experience of the BAYA, there are a number of operational problems encountered in using a submarine as a laboratory ship which have not yet been solved.

The first of these operational problems is the matter of ship-to-ship and ship-to-shore communication. The most carefully planned schedule of operation is frequently subject to moment-to-moment change as the research problem unfolds. For example, the results of the first run on a target may give a clue to an unexpected anomaly which could be more fully examined by a change in one or more succeeding runs. As long as the submarine is operating on the surface, the communication of intelligence relative to changes in operating plans is no problem, but since most of the investigations are conducted with the submarine submerged the problem remains acute. The addition of underwater voice telephone equipment would improve the efficiency of the submarine as a laboratory vessel.

The second problem is one of submerged navigation. The nature of some of the investigations being conducted is such that a few yards difference in the distance from submarine to sonar target or control point is critical. This concept requires maintenance of an underwater position or following of an underwater course with an accuracy heretofore never considered, and currently achieved in practice only by fortuitous circumstance.

A third operational problem is that of accurate control of the submarine's vertical position in the ocean. The investigation of the sea's thermal microstructure, for example, requires keeping the boat at a given level in the ocean within a fraction of a foot. Present instrumentation does not register pressure differentials until a change of two or three feet in depth has already occurred and the submarine's 1200 tons are already in motion. A quick blowing or flooding of ballast, unless handled with consummate skill, results in the boat overshooting the desired depth. A more sensitive rapid-response element for measurement of pressure differentials appears to offer a solution to this problem, though at levels near the surface pressure differentials arising from wave action would complicate the situation. As the depth increased such an element would function more satisfactorily.

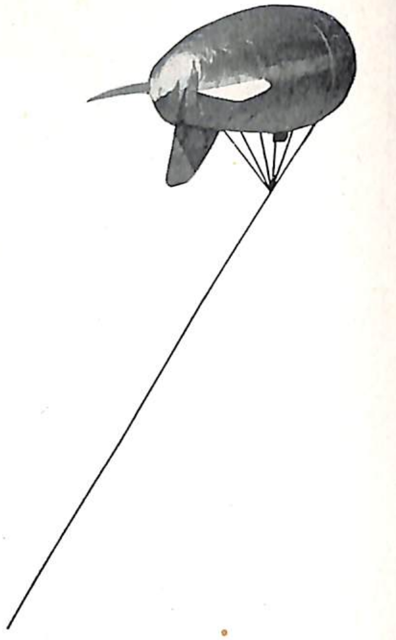
Handling of overside equipment, such as towed or buoyed targets, and handling of the submarine itself suspended from buoys are not yet sufficiently mechanized. Considerable time and physical wear and tear on personnel could be saved by proper mechanical facilities for these handling problems.



Conclusions

It seems well agreed that the current world-wide trend of submarine development demands intensified research in the field of subsurface warfare. Not only are present means of detecting and tracking a high-speed, deep-submergence submarine inadequate, but also the effective potential of such a submarine is limited by the capability of present sonar equipment.

Review of the investigations conducted in this field to date seems to indicate that the laboratory-type submarine with its special facilities and instrumentation is the most economical and quickest means of developing improved sonar techniques and equipments, and of achieving improved submarine operations based on greater knowledge of the seas in which the submarine must function.



RADIO WAVE PROPAGATION STUDIES

Since 1945, experimental investigations by the U. S. Navy Electronics Laboratory have been in progress on the relatively flat overland terrain in the Arizona desert as an important part of the problem to study the modification of the lower atmosphere and the effect of such modification on the propagation of high frequency radio waves. These studies may help to make it possible to choose an optimum frequency for a given meteorological situation. The propagation characteristics obtained will be useful in the study of radio wave propagation at sea and, possibly, in the forecasting of weather conditions.

Theory and Purpose

A so-called standard atmosphere is one in which the air nearest the ground is warmest, most humid, and most dense and in which the temperature, humidity, and pressure decrease regularly with altitude. When a radio wave moves through such an atmosphere, it is bent slightly downward so that energy is transmitted directly to a point somewhat beyond the geometric horizon. Under standard conditions, this point, known as the optical horizon, is the practical limit of radar and V-H-F coverage.

There are many parts of the earth, however, over which non-standard atmospheric conditions exist. Though both temperature and humidity may decrease with altitude, the rate of that decrease can frequently be irregular; temperature may even increase with altitude. These non-standard atmospheric conditions affect radar and V-H-F communication in ways which have never been adequately explained. Sometimes they result in great extensions of radar ranges: radars with normal ranges of 50 miles have obtained echoes from land 2000 miles away. At other times, however, radars may fail entirely to pick up targets clearly visible to the eye. It is with the view of explaining some of the effects of non-standard atmospheric conditions that NEL has been carrying on these investigations in the Arizona desert.

In the desert, the ground and the layers of air near the ground cool rapidly after sunset. Air from the similarly cooled surrounding slopes flows into the desert area and increases the vertical thickness of the layer of cold air immediately above the ground. Consequently, a surface-based temperature inversion occurs: "inversion" because the temperature does not decrease with altitude, but increases until it reaches a point of maximum temperature at some point well above the ground; "surface-based" because the temperature increase begins at the earth's surface. Because essentially the same meteorological situation takes place each night, the desert is an almost perfect natural laboratory for an exhaustive study of electromagnetic wave propagation under one kind of predictable, non-standard atmospheric condition.

Over ocean areas, one of the most common of the non-standard atmospheric conditions encountered is a low-lying moisture lapse caused by the rapid evaporation of water. Thus, a wind sweeping over the sea surface may pick up comparatively large quantities of moisture; at 50 or 100 feet, however, the moisture content of the air may drop suddenly. This sudden decrease is the moisture lapse. As a result of the moisture lapse, a medium for the propagation of radio waves is produced which is similar to that produced by temperature inversion over the desert. Both conditions produce a layer, or duct, of air characterized by marked contrast with the air layer directly above it. It makes comparatively little difference whether the layer is of moist air overlain by dry air, or of cold air overlain by warm air, since the manner in which the energy is propagated is primarily dependent upon the manner in which the velocity of electromagnetic waves changes with increasing altitude. This change is usually called the refractive index distribution.

Because the refractive index distribution over the desert is almost exactly the same as that frequently encountered over the ocean, this work in the desert can lead to a better understanding of radio wave propagation at sea. Desert experiments for this purpose have many advantages over experiments made at sea. The same meteorological condition occurs nightly, making possible the careful taking and checking of data and the repetition of experiments. Test equipment, such as towers, balloons, and trucks, is land-based, so that permanent and delicate recording apparatus can be installed at any convenient interval along the transmission path.

In this investigation by the Navy Electronics Laboratory of electromagnetic wave propagation under conditions of a very low-level temperature inversion, two problems were basic. First of all, the Laboratory set out to determine the possible differences between the effect of the earth surface and the sea surface on radio waves. Second, early experiments were carried out to measure the reflection coefficient of the ground for both vertically and horizontally polarized radiation. Rough determinations on these two problems showed that there was a

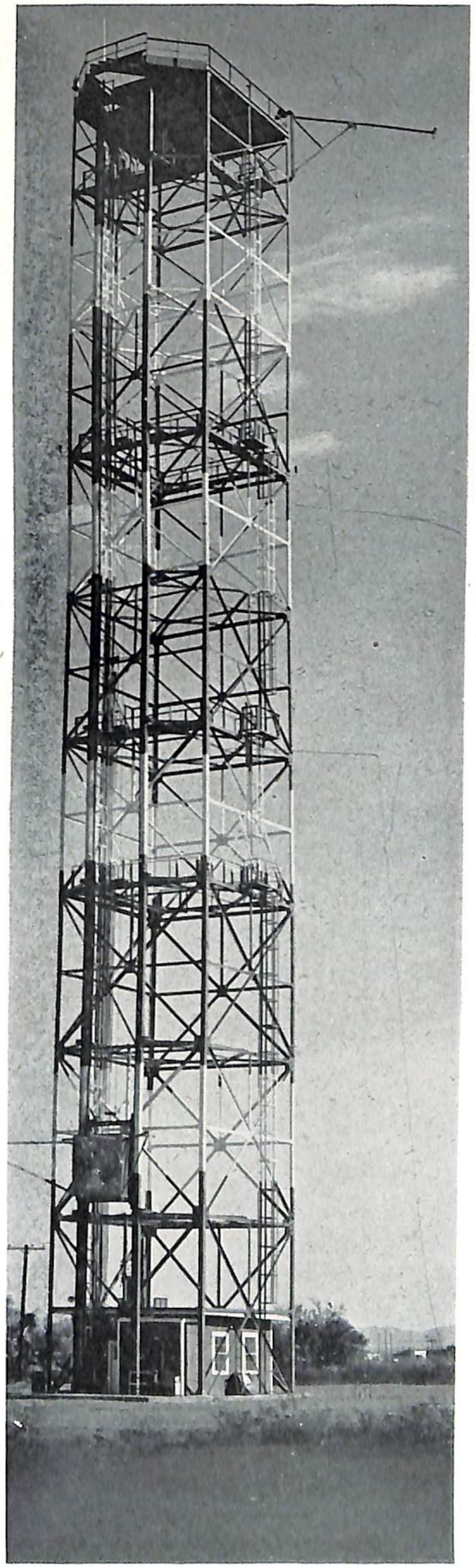


FIGURE 1. *A tower station showing hoist and elevator.*

great similarity in effect on radio waves between the earth and sea surface, and a reflection coefficient which approached unity for frequencies below 3,000 Mc.

With these basic premises established, the Laboratory set to work on the primary objective of correlating the non-standard field strength distributions with the non-standard refractive index distributions. Such a correlation should make it possible to establish the laws governing the propagation of high-frequency electromagnetic waves beyond the optical horizon. The formulation of such laws depended upon the solution of certain practical problems: (1) the experimental determination of an optimum frequency for a given refractive index distribution and (2) the experimental determination of optimum antenna heights for a given frequency and refractive index distribution.

Experimental Equipment and Procedure

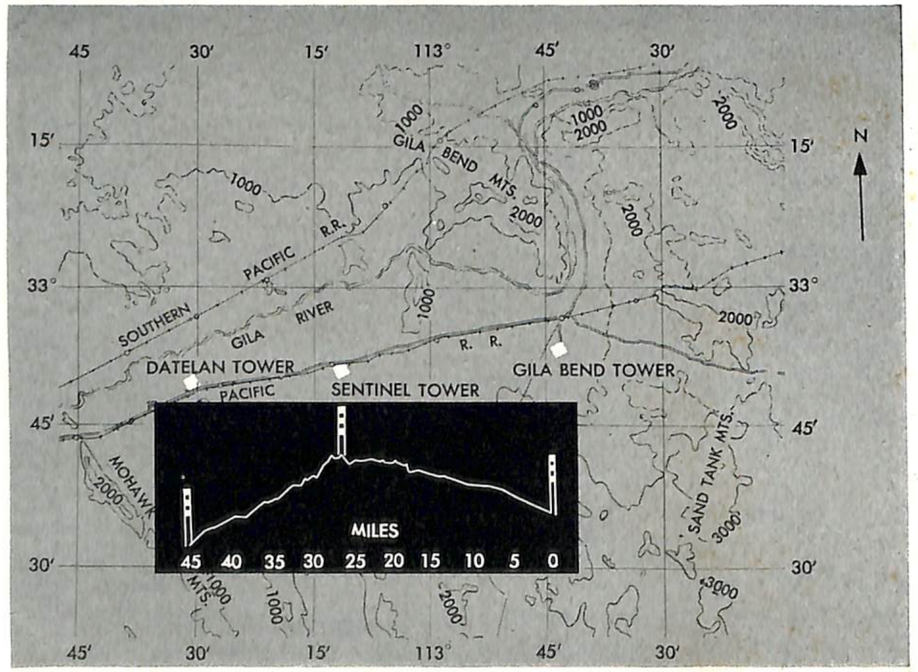
Three 200-foot towers, each supporting an outside elevator to carry radio equipment, and a small hoist to carry meteorological equipment (see figure 1), were set up on a straight line across the desert. The transmitting radio equipment was placed on the tower located near Gila Bend, Arizona. A short-path receiving station was located near Sentinel, Arizona, 26.7 miles from the transmitting station. A long-path receiving station was located near Datelan, Arizona, 46.3 miles from the transmitting station. (See figure 2 for the location of the towers.) The top of the short-path receiving station was so located that the top of the tower, but not the bottom, could be seen from the transmitting tower. The long-path receiving station was well below the optical horizon of the transmitting station.

The procedure involved the taking of field strength measurements at various transmitter and receiver heights while, at the same time, meteorological measurements were made. The readings from the towers were supplemented by meteorological and field strength measurements taken from an airplane which flew to heights of more than 8000 feet every morning and evening, by field strength measurements made from a truck and used to check the readings at the tower stations, and by captive balloons equipped with wired sondes used to give meteorological readings up to 1500 feet at three intermediate points along the transmission path.

In taking the field strength measurements, the transmitters, all mounted on the elevator of the Gila Bend tower, were operated at frequencies of 25, 63, 170, 520, 1000, 3300, 9375, and 24,000 Mc. These transmitters, the number of which varied from four to six, were operated simultaneously at different frequencies. The elevator was run to the top of the tower, or to any desired height, and kept there while the radio equipment on the two receiving towers moved up and down to measure field strength. In order to check the change of field strength with time, a receiver was left in one height position for several hours, or a night, to record the rapidity with which field strength changed. While the receiver was in this position, the transmitters moved up and down the Gila Bend tower. With a given refractive index distribution, measurements made in this way were used to point toward optimum antenna heights for the transmission of given frequencies.

The meteorological data were gathered by raising the small hoists on the towers, stopping the instruments at 1, 5, 10, 20, 40, 70, 150, and 200 feet to measure temperature and humidity against time and altitude. The measurements made by the balloon sondes were taken at the same heights used by the tower meteorological equipment and then went on to 300, 400, 500, 750, 1000, and 1500 feet. The measurements taken from the airplane were used for heights above 1500 feet.

FIGURE 2. *Chart of the desert area. Insert shows the two transmission paths used.*



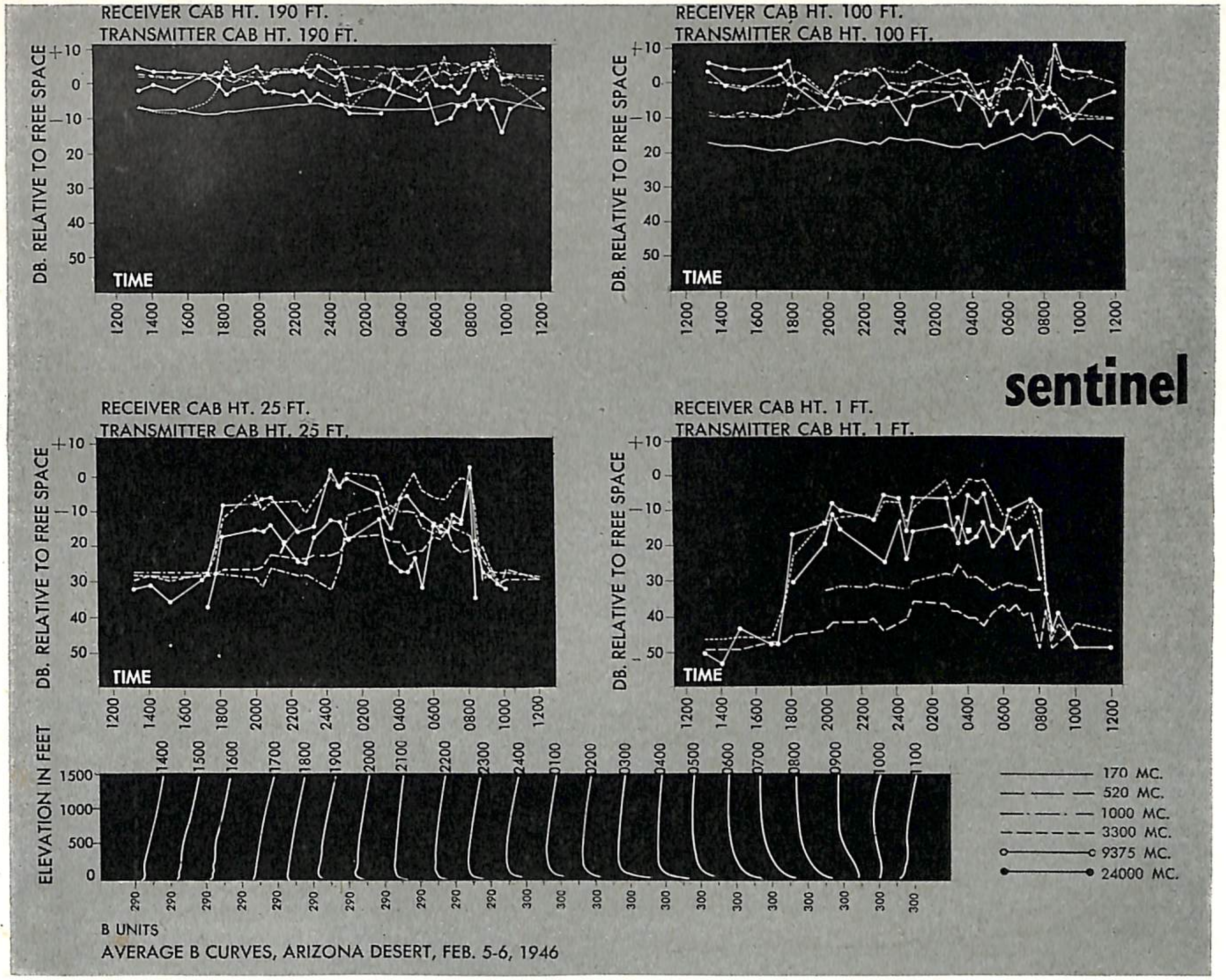


FIGURE 3. *Diurnal variations in field strength at the Sentinel station.*

The temperature measurements were made with two kinds of instruments: thermocouples and thermistors. A thermocouple (a combination of two unlike metals which shows a change in voltage for a corresponding change in temperature) was carried in each tower hoist and in the airplane. Recording on a tape, each thermocouple gave a continuous plot of temperature against time. A thermistor (a resistor whose resistance changes with very slight changes in temperature) was carried by each balloon and connected by a cable to an indicating ammeter on the ground.

The humidity measurements were also made with two kinds of instruments: automatic dew point recorders and hygrometric strips. A dew point recorder (an instrument which maintains an accurate record of the temperature at which the atmosphere gives up its moisture) was carried on each tower hoist. Since the automatic dew point recorders are expensive and delicate instruments, the captive balloons and the airplane carried hygrometric strips (small plastic plates covered with lithium chloride, a substance whose electrical resistance varies with changes in humidity). Although the measurements in this method are usually somewhat less accurate than those involving the automatic dew point recorder, carefully calibrated strips gave good results over the desert.

Results and Conclusions

The nocturnal radiation in the Arizona desert produces a layer or duct which has a marked effect on the propagation of short radio waves. The diurnal change of radio fields along the paths of 26.7 and 46.3 miles varies from a negligible value at 63 Mc. to about 50 decibels at microwave frequencies.

During the night at the higher frequencies, the shape of the height-gain curves is radically affected and changes rapidly with time as the lower atmosphere is modified by the cooling of the earth. The effect of the layer or duct on the shape of the height-gain curves for the 170, 520, and 1000 Mc. frequencies is not pronounced. In the daytime, the lower atmosphere is nearly standard, and the fields remain fairly constant.

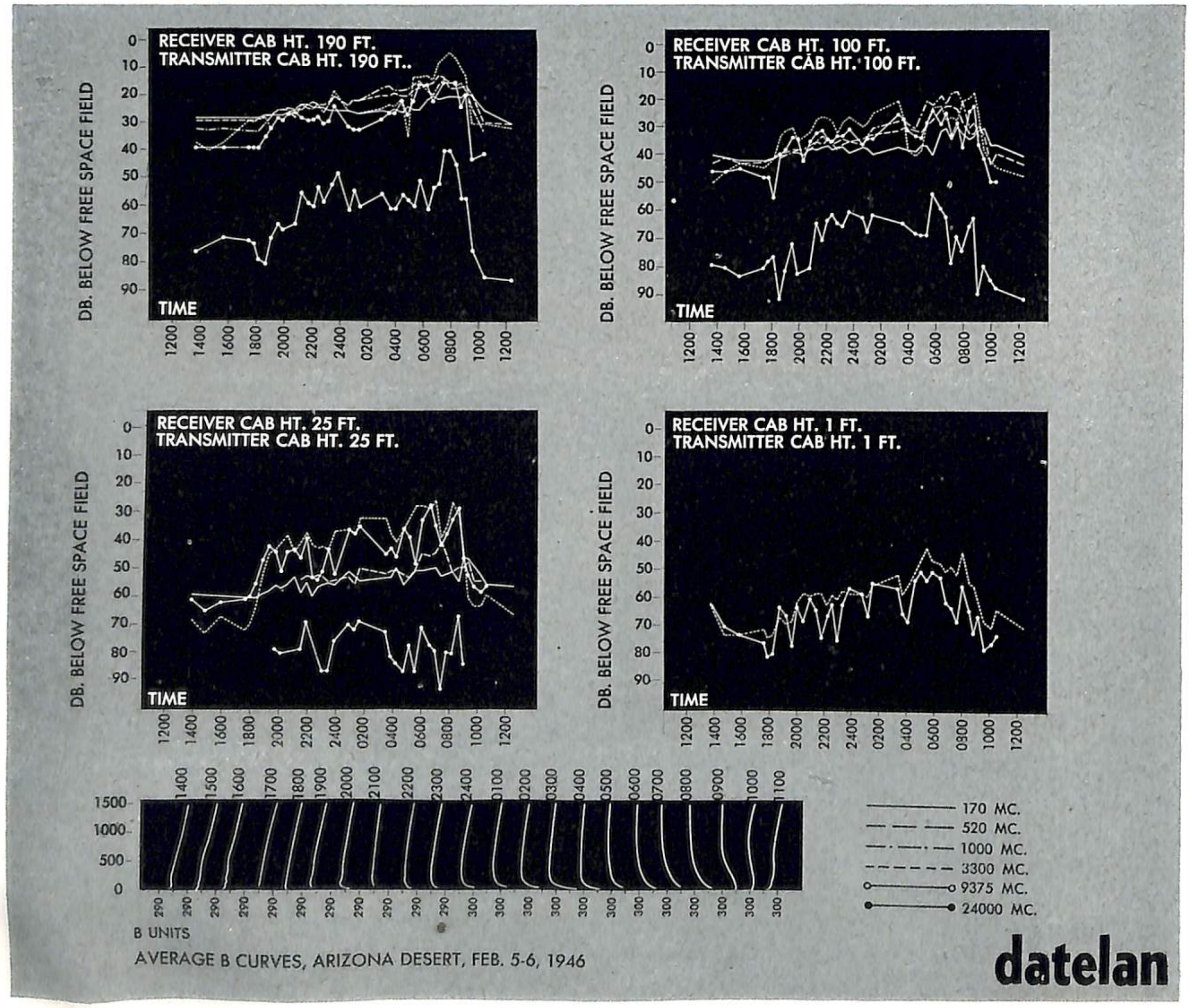
On the 26.7-mile path, the diurnal variation (figure 3) of signals is markedly different for the optical high terminals from that of signals for the non-optical low terminals. The fields for the high terminals vary less and, at the higher frequencies, may decrease rather than rise at night. The signals for the low terminals rise sharply at night for all frequencies with a much greater diurnal change than for the high terminals.

On the 46.3-mile path, the maximum diurnal change (figure 4) occurs at 3300 Mc., with less change at 9375 and 24,000 Mc. The explanation for this unexpected result lies in the fact that, when conditions are nearly standard in the daytime, the fields for 9375 and 24,000 Mc. do not drop to the expected values. Apparently, some mechanism other than refraction or diffraction, such as atmospheric scattering, is needed to explain these high daytime fields at higher frequencies on the long transmission path.

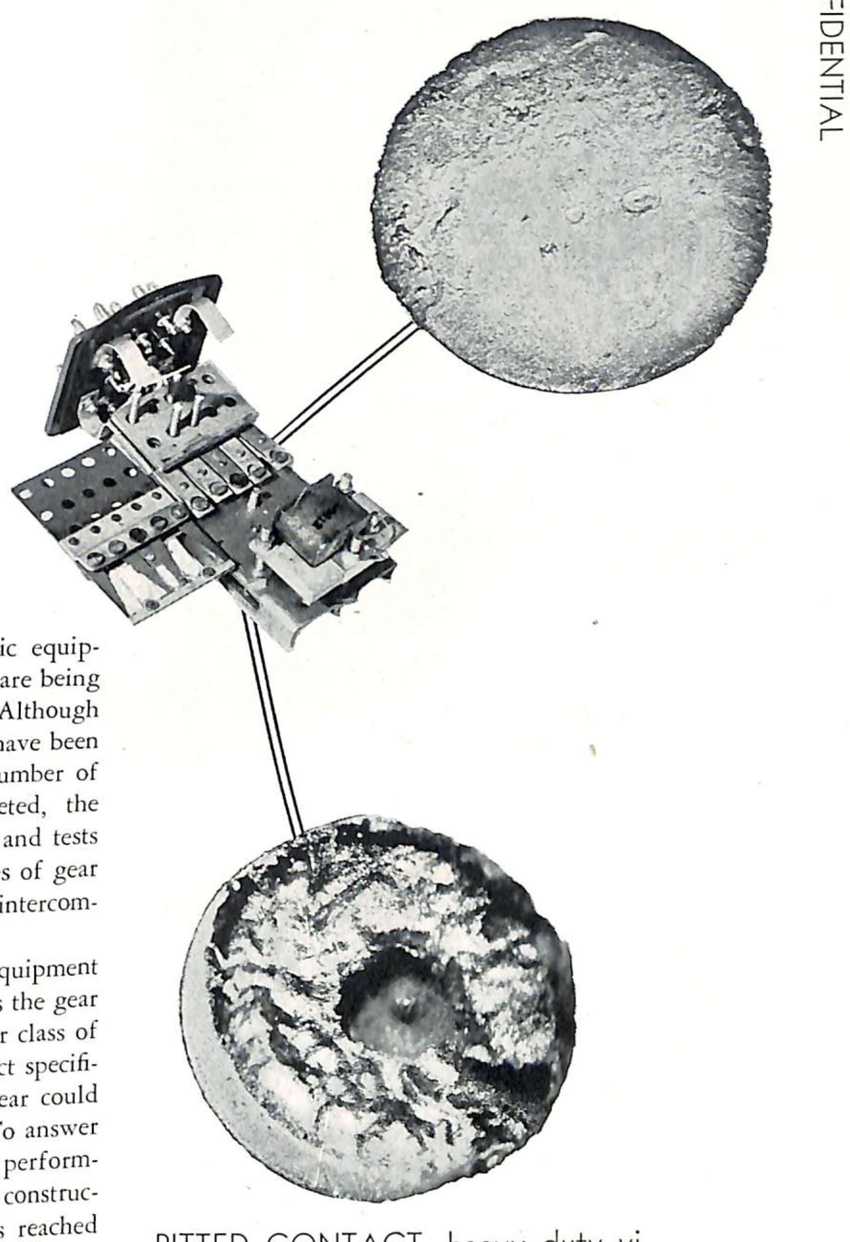
Although a distinct correspondence was noted between the formation and breaking up of the temperature inversion and the diurnal variation of field strengths, a detailed one-to-one correlation is not apparent.

The objective of increasing knowledge in the subject of radio and radio wave propagation is, as in any science, limited by the restrictions of theory and the impracticality of making actual measurements under all possible conditions. The objectives of the NEL desert experiments constitute an example of an attempt to modify theory from the results of certain critical measurements. On the basis of the measurements of this continuing study, it is possible to predict radio field strengths for certain specific refractive index distributions. With continued success of these studies by the U. S. Navy Electronics Laboratory, the results may well provide an aid to Fleet communications in estimating the transmission distances being achieved at a definite time and in predicting the transmission distances to be achieved within an interval of several hours.

FIGURE 4. *Diurnal variations in field strength at the Datelan station.*



TYPE TESTING ELECTRONIC EQUIPMENT

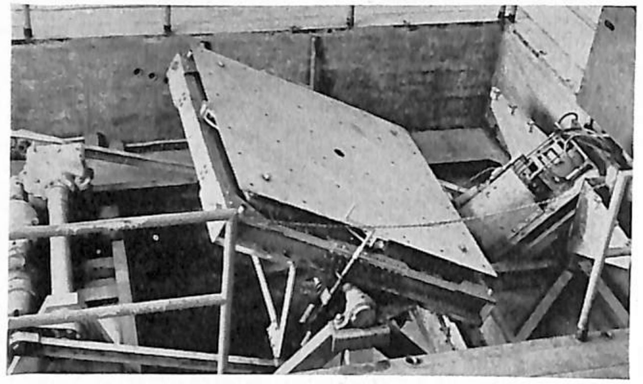


PITTED CONTACT, heavy duty vibrator. This is typical of the kind of defect uncovered in type tests of electronic gear.

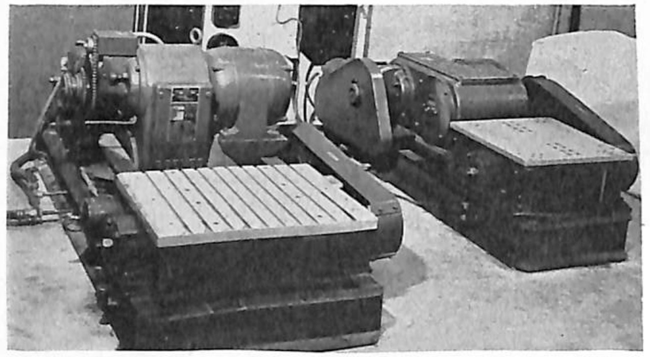
Complete facilities for type-testing electronic equipment manufactured for the United States Navy are being established at the Navy Electronics Laboratory. Although not all the apparatus and machines to be used have been installed, tests have already been made on a number of different types of equipment. When completed, the facilities will make possible all the inspections and tests necessary to a complete evaluation of prototypes of gear intended for use in radio, radar, sonar, and intercommunication systems.

Fundamentally, type-testing of electronic equipment consists of answering three questions: (1) Does the gear meet the general specifications for the particular class of equipment? (2) Does the gear meet the contract specifications? (3) Is there any way in which the gear could be modified to provide improved operation? To answer these questions, the electrical and mechanical performance of the submitted model is studied, its constructional features are assayed, and a conclusion is reached both on the suitability of the model to the purpose for which it was designed and on its suitability as a production standard.

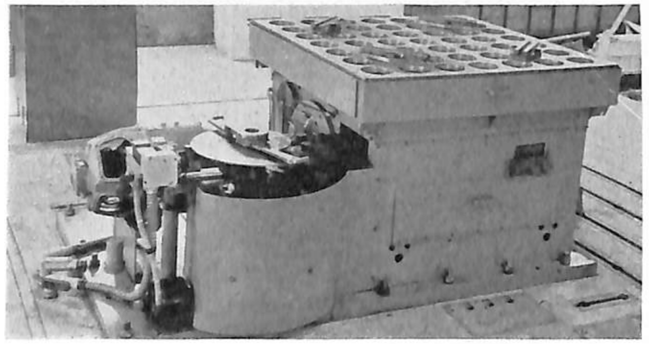
The type test facilities at NEL are housed in four buildings, which provide a total of 14,000 square feet of floor space. Personnel engaged in the tests include electronics and mechanical engineers, chemists, metallurgists, and technicians. The electronic test apparatus consists of such familiar equipment as meters, bridges, signal generators, wave analyzers, and other devices commonly used in the testing or servicing of electronic gear. Included among the facilities already installed and soon to be installed for mechanical testing are machines to perform vibration, shock, and roll tests. The vibration machines test gear as heavy as 500 pounds, with



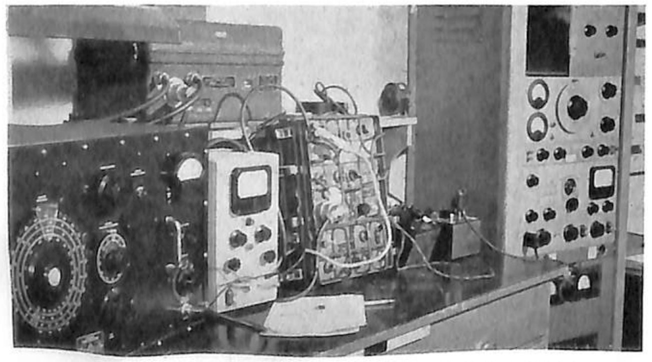
ROLL, VIBRATION, and SHOCK machine.



100-POUND vertical and horizontal vibration machines.



500-POUND vibration machine.



A typical ELECTRONICS TEST AREA.

both horizontal and vertical vibrations at frequencies from 5 to 60 cycles per second over excursion distances ranging from zero to 0.258 inch. Circular vibration tests can be conducted on gear weighing up to 35 pounds at 5 to 53 cycles per second over an excursion distance of 0.065 inch. The shock machines will test gear weighing up to 3000 pounds, delivering both horizontal and vertical shocks with energies up to 18,000 foot-pounds. In one machine, which will handle equipment weighing as much as 2000 pounds, simultaneous testing for shock, vibration, and roll is accomplished. Also included among the mechanical testing devices is a stress-strain machine with a maximum load of 200,000 pounds.

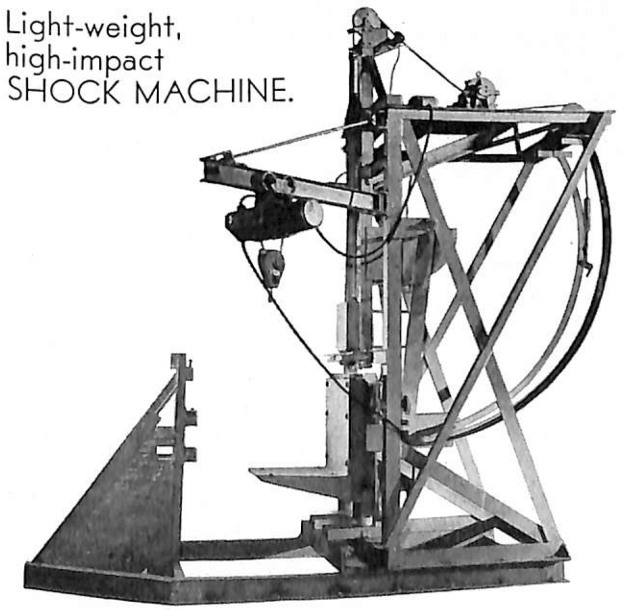
In addition to undergoing electronic and mechanical evaluation under ordinary conditions, gear tested in the NEL facilities will also be given operational tests under extreme conditions of temperature, humidity, and atmospheric pressure. Specially constructed and fitted chambers will be used. At present, only one small chamber, of slightly less than a yard cube in size, is in operation. Two somewhat larger chambers will be operating shortly. Now in the planning stage is a fourth temperature-humidity facility of the "walk-in" type, the inner chamber of which will be an 8-foot cube. The four chambers are designed to provide for the testing of equipment at temperatures ranging from —75 to +85 degrees C., at humidities from 20 to 95 per cent relative over a temperature range of +2 to +70 degrees C., and at pressures corresponding to altitudes up to 53,000 feet. In another chamber, gear will be subjected to salt spray.

A new equipment submitted for evaluation is subjected to a thorough inspection of its materials and workmanship. Are the various parts made of materials which are satisfactory as to mechanical strength, finish, and durability? Is the soldering good, with connections free from excessive amounts of solder and from splatterings of rosin residue? Is the wiring arranged in a neat and workmanlike manner, with flexible conductors securely anchored so that the insulation will not be chafed? How about the insulation—does it support combustion? Are all the components of the gear accessible for maintenance and servicing? Are they of approved types? These, and a myriad of other questions, are answered during the course of the inspection.

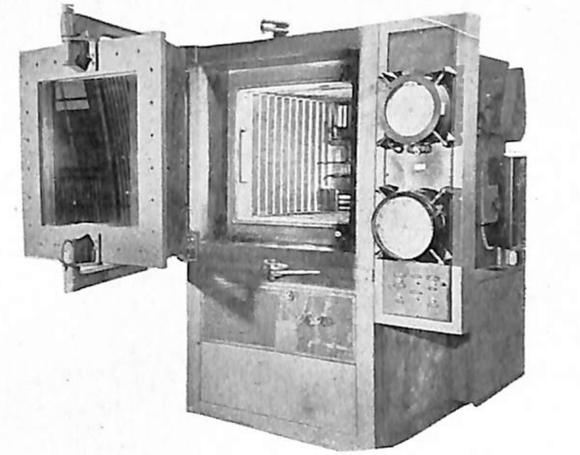
The particular inspection and test procedures employed depend upon the type of gear to be tested, and also upon the specifications. A radio receiver, for example, is first given a mechanical inspection. Electronic tests follow. Voltage checks and point-to-point resistance checks are made and compared with the manufacturer's figures. The power dissipation rating of the resistors is verified, as is the power consumption of the set. A series of tests determine the sensitivity, selectivity, frequency response, distortion, and power output of each circuit. The alignment of the i-f stages is checked. The oscillator calibration is ascertained, and the drift observed under different temperature conditions and with power-source voltages 10 per cent above and below the rated voltage. R-f stages are checked for image response, cross-modulation response, and i-f feed-through. The radiation from the oscillator within the set is measured. Next, the receiver is tested in operation under the conditions of temperature, humidity, and pressure specified in the contract. Shock, vibration, and pitch-and-roll tests are then conducted, simulating the conditions under which the set would be required to function aboard ship. Perhaps salt-spray tests are made. If the receiver is portable equipment, an immersion test may be in order. The set is immersed in water to a specified depth; at the end of a protracted period of time it is brought up, wiped off, and an attempt is made to place it in operation.

Since the establishment of the electronic equipment type-testing facilities at NEL, several different kinds of gear have been evaluated. The thoroughness of the inspections and tests is indicated by a brief outline of the conclusions reached on two of the equipments.

The first is a radio transceiver, which was being considered for use as a portable high-frequency equipment by the U. S. Marine Corps. Although the gear was found usable, mechanical defects such as the following were noted: the case was not watertight; the heavy-duty vibrator was not hermetically sealed; the voltage rating of one section of an electrolytic capacitor was different from the voltage rating of the other two sections; the hand-powered generator lacked a clamp which would permit it to be supported on trees or posts; and reflections from the tuning dial window hindered reading of the dial settings. The foregoing constructional defects are representative of the eighteen which were found. Representative of sixteen deficiencies noted during the electrical tests are the following: the power output of the transmitter was low; the audio response of the modulator was poor below 850 c.p.s.; the radiation of the local oscillator in the receiver was excessive for frequencies near 12.0 Mc.; and the conducted r-f noise interference from the hand-powered generator was excessive at frequencies above 50.0 Mc. Since the shock and vibration test facilities had not yet been installed at the time the transceiver was tested, its suitability for transportable use could not be determined. The results of the tests which could be made, however, indicated that as designed the gear was not acceptable.



Light-weight, high-impact SHOCK MACHINE.

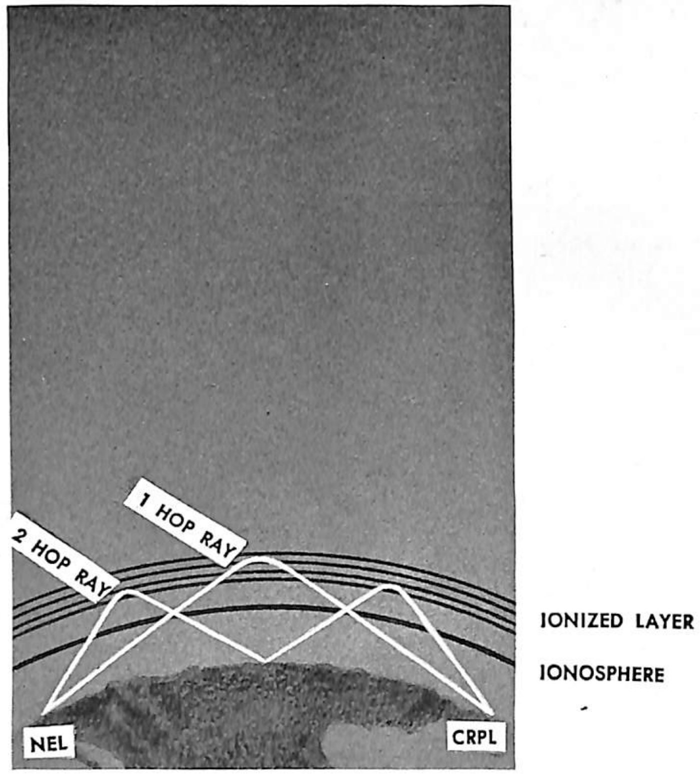


Controlled ATMOSPHERE CHAMBER.

A second example of the thoroughness of the type-tests is provided by the results of an evaluation of a pre-production model of an audio amplifier manufactured for general Navy radio use. Eighteen deviations from the specifications were noted. Although mostly of a minor nature, they rendered the model unsuitable as a production standard. Changes could be made, however, without great difficulty. The unit was finally recommended for Fleet service, provided that: (1) the overall performance at increased and decreased line voltage was improved; and (2) the recommended changes were made in the fasteners, several of the components, and the finish of the unit.

Models of electronic equipment submitted to the Navy Electronics Laboratory for type-testing are given every possible inspection and test necessary for a complete technical evaluation. Recommendations based on the results of the tests are submitted to the manufacturer through the Bureau of Ships, so that the equipment may be redesigned and changed to meet exacting Navy specifications. The type-testing facilities at NEL provide assurance that electronic equipment manufactured for the United States Navy will measure up to the severe requirements of operation ashore and afloat.

IONOSPHERE PULSE PROPAGATION



The ionosphere is the outermost portion of the atmosphere, the earth's cushion against interstellar space. It is a region of charged, or ionized, air particles containing several layers or belts in which ion density is particularly great. These layers make possible long-haul, radio communications circuits.

Scientists have known for many years that these ionized layers have the power to reflect man-produced bursts of electromagnetic or radio energy. They have also known that these layers do not remain at fixed distances from the earth but move up and down in response to variations in solar radiations of various kinds. It is this moving up and down of the layers which creates a condition well known to all short-wave broadcast listeners—a condition which causes international broadcast signals to "come in" better at certain times of the day than others.

A method of predicting the best radio frequency for communication over a particular distance at a given time has been worked out and forms the basis for propagation charts published by the Bureau of Standards. For conventional CW or voice communication purposes, frequencies determined on the basis of these charts have been found remarkably useful. For high-speed, automatic signaling systems, however, these charts are not entirely adequate in a practical sense.

High-speed communications, it has been found, are limited to top speeds of about 250 words per minute despite the proven higher-speed capabilities of electrical and mechanical terminal equipments. Clearly the deficiency does not lie at either the transmitting or receiving ends of such circuits, but represents a drastic altering of the signals themselves somewhere along the transmission path.

That conditions along the path are complex is well known. For example, reflection of a signal may take place between two or more layers of the ionosphere as well as between these layers and the ground. The signal, on its way from transmitter to receiver, may take a number of paths, when only one ionized layer is involved. Then, too, the whole transmission picture sometimes changes without warning, causing a strong, distortion-free signal to appear at the receiver in one instant, and a weak, badly-garbled signal to appear the next. All of these complexities create distortions of the transmitted signal and limit communication speeds.

The first of a series of investigations of these distortions and their causes was begun at the U. S. Navy Electronics Laboratory in August 1947 and was concluded almost a year later in July 1948. These tests were made, cooperatively, with the Central Radio Propagation Laboratory of the Bureau of Standards over a 2300-mile link between Sterling, Virginia, and San Diego, California.

The experiments involved the transmission of pulses from Sterling and their reception at San Diego. The procedure was essentially the same as that employed in measurements of ionosphere layer height wherein the time difference between the propagation of a pulse and the arrival of its reflected component from the layer is used to determine the distance of the layer from the measuring point. In the NEL-CRPL experiments, however, the pulses were not sent out at a steep angle, but over a typical long-haul communication circuit.

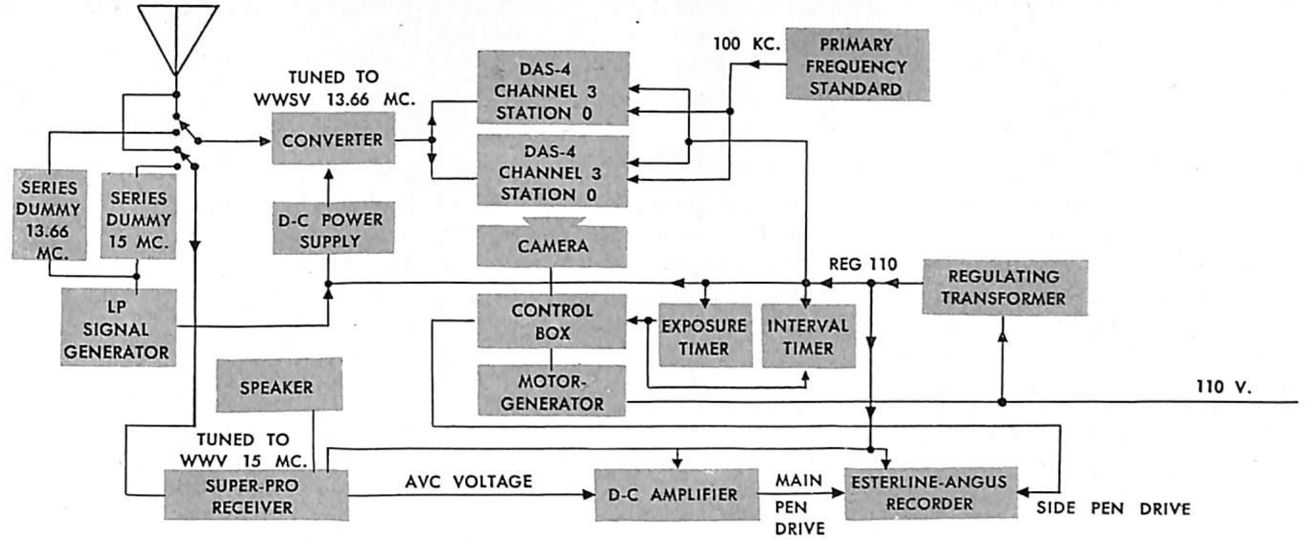


FIGURE 1. *Block diagram of pulse reception equipment.*

The transmitter at the CRPL end of the circuit employed a peak plate power input of 600 kilowatts on a frequency of 13.66 megacycles. The transmitter radiated 40-microsecond pulses at a repetition rate of 25 pulses per second. A rhombic antenna with a beam width of about 30 degrees and pointed five degrees south of San Diego was used.

At the western terminus of the link, the Navy Electronics Laboratory installed a horizontal dipole and a vertical sleeve-type dipole, intersecting at their centers, cut for 13.66-megacycle operation. Provision was made for choosing either of these antennas from the operating position.

A converter tuned to 13.66 megacycles and having an output frequency of 1.9 megacycles was connected to two DAS-4 loran receiver-indicators. The loran equipments were modified to give a 4.5-millisecond sweep and utilized an external 100-kilocycle General Radio primary frequency standard for control of the sweep-rate and marker generators. The external source was held to an accuracy of about one part in 30 million to make possible 24-hour unattended operation of the system.

Photographs of the loran scope faces were made automatically by a Fairchild Type A recording camera. Single-frame, 35-mm. exposures of 2 seconds each at f5.6 were made every 2 minutes throughout the operating period. The time interval between exposures was determined by two mutually triggering electric timers. Amplitude recordings of the 15-megacycle signal of station WWV were made by applying the a-v-c voltage output of a receiver, after amplification, to a recording voltmeter. Calibration of these circuits was accomplished by coupling an LP signal generator into their inputs. A block diagram of the receiving layout is shown in figure 1.

Three forms of data were gathered so that the received pulses could be studied in great detail. Photographic records of the structure of the arriving pulse trains were made by the automatic camera arrangement; measurements were recorded of the amplitudes of the several pulse groups in the signal trains; and concurrent measurements of the amplitude of WWV signals, two megacycles away from the signals under study, provided a reference point for the pulse-signal amplitudes.

As had been expected, wide variations of the received train structure were observed at San Diego. Night train structures were found to be products of both one-hop and two-hop transmissions. In the one-hop night transmission, the earliest arriving pulse was found at times to have traveled a low path, close to the earth, and to have been composed of extraordinary and ordinary magneto-ionic components not resolved in time. The next pulse, arriving a millisecond or so later, came by way of a high path and was composed of resolved extraordinary and ordinary components.

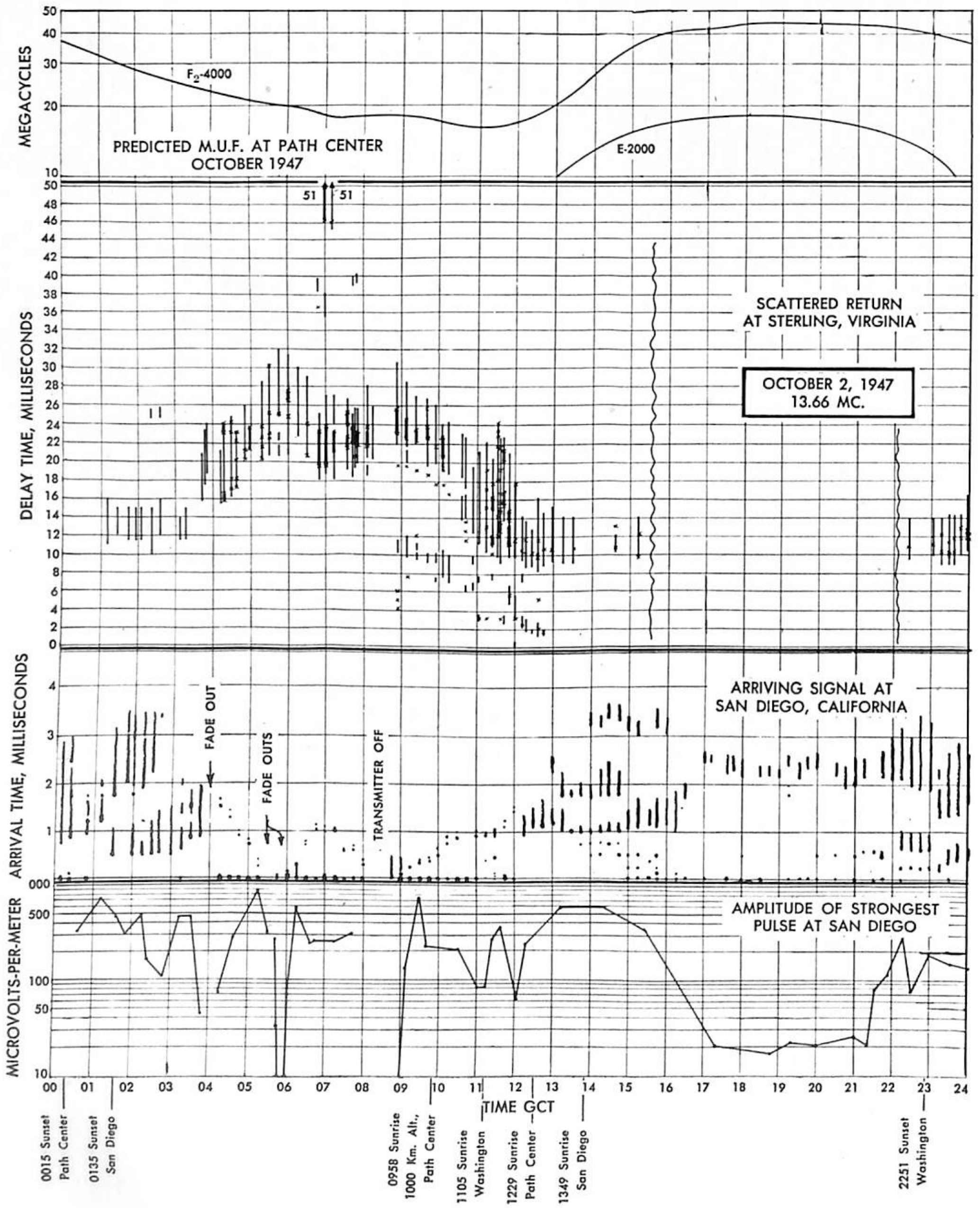
Two-hop transmissions were diffused by the reflection of pulses from the earth somewhere along the path. This peculiarity was seen easily when the ragged, scattered character of pulses comprising this type of transmission was compared with the clean, sharply centered character of the one-hop transmitted pulses.

During the daylight hours, when many layers exist in the ionosphere, and the F_2 layer maximum usable frequency was much greater than the operating frequency, the pulse train became extremely complex and broke down into several diffuse groups. The many pulses of which these diffuse groups were composed changed rapidly in phase relationship and the resulting continuous amplitude variation of every portion of the group gave it a writhing appearance. As the maximum usable frequency decreased to approach the operating frequency, the low and high signal paths converged and became coincident and the train length was minimized. At the same time this effect occurred, it was found that the received signal increased in intensity because of ionosphere focussing.

A typical run covering a day's operation is shown in figure 2. Reading from top to bottom, the first plot is the predicted maximum usable frequency at the center of the path. This information is taken from the tables of frequency predictions published by the Bureau of Standards. Next is plotted the delay between the transmission of a pulse and the receipt of scattered return at the transmitter. The structure of the signal as it arrived in San Diego is shown in the next plot; and, finally, for reference purposes, the last plot records the amplitude of the strongest pulse received in San Diego. All of the plots are drawn to the same time-of-day horizontal scale.

When the total path between Sterling and San Diego is in daylight, the train structure as observed at San Diego is seen to be fairly long, between 2.5 and 3 milliseconds. This condition exists between the hours of 1400 and 2300 GCT. When the path becomes dark, the train length decreases rapidly to about 1.5 milliseconds. With darkness also comes a recombination of ions and a consequent lessening of the density of the ionosphere reflecting layer, and the pulse trains change from those of a diffuse structure to those having two groups of clean pulses separated by 1 or 1.5 milliseconds. During this transition period, the received signal often fades out completely.

FIGURE 2. *24-hour signal propagation over experimental path.*



As night progresses, the pulse train becomes still shorter, the two pulse groups previously noted converge, until finally the signal disappears altogether. These periods of disappearance are much longer than those noted in the transient period just at nightfall, and correspond to the fadeout of high-frequency communications commonly experienced in short-wave broadcast listening. Occasionally, however, as can be seen from figure 2, the signal reappears for short periods during the darkness hours because of short-time increases in ion density in the ionosphere layer.

With the first illumination of the signal path, around 1130 GCT, the first effect noted at the receiving end of the circuit is the appearance of a short, diffuse train. When all of the path becomes illuminated, the typically long diffuse trains are again observed.

The NEL-CRPL tests were conducted over a path whose length closely approached the limiting distance for one-hop F$_2$ layer propagation. Throughout the period of the tests, the operating frequency approached the F$_2$ layer maximum usable frequency only at night. Under these two unique conditions certain experimental conclusions were reached.

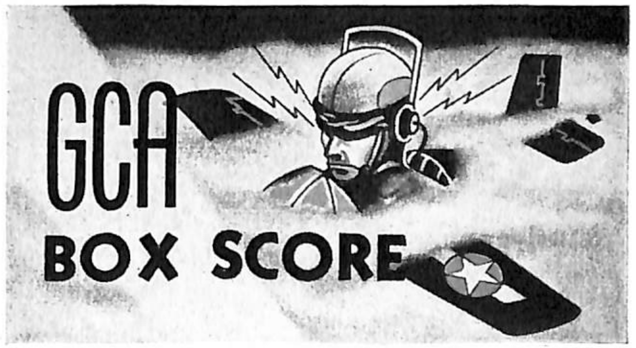
One of the most significant of these is the discovery that the optimum frequency for long-haul communications over a 2300-mile path cannot be predicted accurately long in advance. This finding is tempered somewhat, however, by another discovery that a phenomenon of back-scatter, observed at the transmitting point, is a good indication of the quality of conditions at the receiver at the other end of the path.

If pulse transmission is used for communication, this back-scatter serves as an instantaneous measurement of signal conditions at the receiver. It comes about in this manner. When a pulse leaves the transmitting antenna, it is propagated virtually without attenuation upwards into space until it reaches the reflecting ionosphere layer. There it is returned to earth, where again it is reflected back to the layer, and so on until it reaches the receiving point. This, as mentioned before, is the method by which long-haul communications are accomplished on high and medium frequencies. But not all of the energy contained in the pulse is transmitted in a forward direction to the desired receiving point. Some of this energy, upon being reflected back to the earth from the ionospheric layer, is diffused and scattered by the earth and returns to the vicinity of the transmitter to produce the back-scatter effect. It is the measure of the delay time between the start of a pulse and the arrival back at the transmitter of this scatter reflection that makes it possible to determine the distance with which communication may be accomplished with least signal distortion and maximum signal strength.

Pulse transmission, it was determined, offers a means of reducing interference-type fading where single-hop transmission is involved. In addition, it was found that progressive lengthening of the received pulse trains takes place as the F$_2$ layer maximum usable frequency increases beyond the operating frequency, and it was determined experimentally that the optimum frequency for high-speed communications over the path is just below the one-hop maximum usable frequency.

The experiments also provided additional information on the actual mechanics of the reflection of a signal from the earth and the ionospheric layers. Earth reflection, it was found, causes serious mutilation of the signal by diffusing its energy. The ionosphere, on the other hand, was found to behave almost as a specular reflector which splits the signal into four components.

Some of the theories of electromagnetic wave propagation have been confirmed by the NEL-CRPL experiments while the validity of others has been questioned. More experimentation, now in progress on higher frequencies, is being conducted as part of a program to permit the full capabilities of the higher-speed electromechanical terminal equipments to be realized in practice.



Type of Approach	Last Month	To Date
Practice Landings	7,198	167,621
Landings Under Instrument Conditions	345	7,212

TABULATION OF DEFINITE INTEGRALS OCCURRING IN ANTENNA THEORY

By Lieut. Comdr. Charles W. Harrison, Jr., USN
Electronics Design Division, Bureau of Ships

The sine and cosine integrals have long played an important part in the theory of antennas. One is led almost inevitably to these functions in deducing formulas for the radiation impedance of antennas, whether a simple symmetrical center-driven antenna or an array of antennas be involved. Specifically, suppose that it is desired to calculate the vector potential at some arbitrary point in space, due to a sinusoidal distribution of current flowing along a conductor. The total potential at the point may be obtained in terms of the sine and cosine integrals, by integrating the contributions of the elementary sources over the length of the conductor and taking proper cognizance of the phenomenon of retardation. Due largely to the splendid work of the National Bureau of Standards, in collaboration with the Federal Works Agency, Work Projects Administration for the City of New York, an excellent tabulation of the sine and cosine integrals has been prepared.[1-3]

Several years ago the writer encountered two integrals, when formulating a solution for the problem of coupled antennas,[4] similar in some respects to the sine and cosine integrals, but not reducible to their form. In the more modern theories of the symmetrical center-driven antenna and antenna arrays[5-7] these integrals arise. They are defined by

$$\text{Suv}\,H = \int_0^H \frac{\sin\sqrt{U^2+V^2}}{\sqrt{U^2+V^2}}\,dU \quad \ldots\ldots\ldots\ldots (1)$$

and

$$\text{Cuv}\,H = \int_0^H \frac{\cos\sqrt{U^2+V^2}}{\sqrt{U^2+V^2}}\,dU \quad \ldots\ldots\ldots\ldots (2)$$

Originally (1) and (2) were evaluated over a rather limited range by graphical methods.[4] Subsequently, a method of evaluating them through summation of series appeared,[8] but the labor involved is comparable to the graphical method.

In 1944 the Bureau of Ships, Navy Department, originated a computation project for the evaluation of Suv *H* and Cuv *H*. The work was accomplished by the Harvard University Computation Staff utilizing an I.B.M. Automatic Sequence-Controlled Calculator.

Table I provides a tabulation of the function Suv *H* over the range

$0 \leqq \beta h \leqq 6.5;\quad 0 \leqq \beta b \leqq 6.3$

$(\beta b = H \text{ and } \beta b = V)$.

The incremental steps are

$\Delta\beta h = 0.5$ and $\Delta\beta b = 0.1$

An error of less than 8.5 x 10^{-7} is assured for all tabulated values in this table.

Table II provides a tabulation of the function Cuv *H* over the range

$0 \leqq \beta h \leqq 6.5;\quad 0.1 \leqq \beta b \leqq 6.3$

with

$\Delta\beta h = 0.5$ and $\Delta\beta b = 0.1$

An error of less than 3 x 10^{-5} is assured for all tabulated values in this table.

Tables I and II were prepared from photographs of the results typed out by the calculating machine, and are therefore not subject to human errors that might be involved in transcribing the figures.

A large variety of integrals may be reduced to Suv *H* or Cuv *H* form by the processes of the calculus; accordingly, with the publication of tables I and II, such integrals are now in the class of "known functions."

Table I.

Tabulation of the function Suv H.

βb \ βh	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5
0.0	0.49311	0.94608	1.32468	1.60541	1.77852	1.84865	1.83313	1.75820	1.65414	1.54993	1.46872	1.42469	1.42179
0.1	0.49228	0.94447	1.32236	1.60249	1.77512	1.84490	1.82914	1.75410	1.65000	1.54582	1.46467	1.42071	1.41788
0.2	0.48981	0.93965	1.31542	1.59374	1.76493	1.83366	1.81722	1.74182	1.63762	1.53352	1.45256	1.40880	1.40616
0.3	0.48570	0.93164	1.30389	1.57921	1.74801	1.81500	1.79744	1.72145	1.61709	1.51312	1.43246	1.38906	1.38674
0.4	0.47999	0.92049	1.28785	1.55900	1.72449	1.78905	1.76992	1.69312	1.58854	1.48476	1.40453	1.36163	1.35975
0.5	0.47270	0.90628	1.26739	1.53323	1.69450	1.75598	1.73487	1.65703	1.55218	1.44866	1.36897	1.32671	1.32541
0.6	0.46389	0.88909	1.24264	1.50206	1.65823	1.71600	1.69250	1.61343	1.50827	1.40507	1.32606	1.28458	1.28397
0.7	0.45360	0.86901	1.21375	1.46569	1.61592	1.66937	1.64310	1.56262	1.45711	1.35431	1.27610	1.23555	1.23576
0.8	0.44189	0.84618	1.18090	1.42433	1.56782	1.61639	1.58699	1.50494	1.39906	1.29674	1.21947	1.17999	1.18113
0.9	0.42883	0.82073	1.14429	1.37825	1.51425	1.55740	1.52456	1.44078	1.33454	1.23278	1.15659	1.11831	1.12051
1.0	0.41451	0.79280	1.10413	1.32773	1.45554	1.49278	1.45621	1.37058	1.26399	1.16289	1.08791	1.05097	1.05434
1.1	0.39900	0.76257	1.06067	1.27307	1.39206	1.42295	1.38239	1.29483	1.18790	1.08757	1.01393	0.97849	0.98315
1.2	0.38240	0.73022	1.01417	1.21461	1.32419	1.34834	1.30358	1.21401	1.10680	1.00735	0.93521	0.90140	0.90745
1.3	0.36481	0.69593	0.96490	1.15270	1.25237	1.26944	1.22030	1.12870	1.02126	0.92282	0.85232	0.82027	0.82783
1.4	0.34632	0.65991	0.91316	1.08772	1.17703	1.18675	1.13309	1.03944	0.93187	0.83456	0.76586	0.73571	0.74487
1.5	0.32704	0.62237	0.85926	1.02006	1.09863	1.10077	1.04252	0.94684	0.83923	0.74321	0.67646	0.64835	0.65920
1.6	0.30709	0.58352	0.80351	0.95012	1.01767	1.01206	0.94917	0.85152	0.74400	0.64941	0.58476	0.55882	0.57146
1.7	0.28657	0.54359	0.74623	0.87831	0.93461	0.92116	0.85363	0.75410	0.64680	0.55382	0.49142	0.46778	0.48229
1.8	0.26561	0.50280	0.68775	0.80507	0.84997	0.82863	0.75652	0.65522	0.54831	0.45709	0.39712	0.37589	0.39237
1.9	0.24433	0.46139	0.62842	0.73081	0.76425	0.73505	0.65845	0.55553	0.44918	0.35992	0.30252	0.28383	0.30234
2.0	0.22283	0.41958	0.56856	0.65596	0.67796	0.64097	0.56002	0.45567	0.35007	0.26295	0.20829	0.19226	0.21286
2.1	0.20124	0.37762	0.50851	0.58095	0.59159	0.54697	0.46186	0.35628	0.25165	0.16687	0.11509	0.10183	0.12458
2.2	0.17967	0.33572	0.44861	0.50620	0.50566	0.45360	0.36456	0.25800	0.15456	0.07231	0.02358	0.01319	0.03813
2.3	0.15824	0.29411	0.38918	0.43214	0.42064	0.36141	0.26871	0.16142	0.05943	-0.02009	-0.06562	-0.07305	-0.04586
2.4	0.13707	0.25302	0.33054	0.35916	0.33702	0.27093	0.17488	0.06717	-0.03313	-0.10971	-0.15190	-0.15628	-0.12682
2.5	0.11626	0.21266	0.27301	0.28767	0.25526	0.18268	0.08363	-0.02420	-0.12254	-0.19597	-0.23467	-0.23592	-0.20417
2.6	0.09591	0.17323	0.21687	0.21803	0.17580	0.09716	-0.00451	-0.11212	-0.20823	-0.27831	-0.31339	-0.31144	-0.27738
2.7	0.07614	0.13494	0.16241	0.15061	0.09906	0.01482	-0.08904	-0.19609	-0.28968	-0.35621	-0.38754	-0.38233	-0.34597
2.8	0.05703	0.09796	0.10991	0.08574	0.02545	-0.06388	-0.16951	-0.27562	-0.36642	-0.42919	-0.45665	-0.44813	-0.40949
2.9	0.03867	0.06248	0.05962	0.02376	-0.04467	-0.13854	-0.24546	-0.35026	-0.43798	-0.49680	-0.52028	-0.50843	-0.46752
3.0	0.02115	0.02865	0.01177	-0.03505	-0.11096	-0.20879	-0.31652	-0.41961	-0.50396	-0.55865	-0.57805	-0.56284	-0.51970
3.1	0.00454	-0.00338	-0.03344	-0.09043	-0.17310	-0.27429	-0.38231	-0.48331	-0.56401	-0.61439	-0.62963	-0.61105	-0.56573
3.2	-0.01109	-0.03346	-0.07580	-0.14213	-0.23083	-0.33473	-0.44254	-0.54105	-0.61782	-0.66371	-0.67473	-0.65279	-0.60534
3.3	-0.02568	-0.06149	-0.11514	-0.18994	-0.28389	-0.38986	-0.49693	-0.59255	-0.66513	-0.70639	-0.71311	-0.68783	-0.63835
3.4	-0.03917	-0.08737	-0.15133	-0.23369	-0.33209	-0.43946	-0.54525	-0.63760	-0.70572	-0.74221	-0.74461	-0.71603	-0.66458
3.5	-0.05151	-0.11099	-0.18423	-0.27321	-0.37526	-0.48335	-0.58734	-0.67603	-0.73946	-0.77105	-0.76910	-0.73727	-0.68396
3.6	-0.06269	-0.13230	-0.21376	-0.30840	-0.41327	-0.52140	-0.62306	-0.70772	-0.76622	-0.79282	-0.78652	-0.75150	-0.69645
3.7	-0.07266	-0.15125	-0.23984	-0.33917	-0.44602	-0.55351	-0.65234	-0.73262	-0.78598	-0.80749	-0.79685	-0.75874	-0.70206
3.8	-0.08140	-0.16779	-0.26242	-0.36547	-0.47347	-0.57966	-0.67514	-0.75069	-0.79873	-0.81509	-0.80015	-0.75904	-0.70088
3.9	-0.08891	-0.18192	-0.28148	-0.38727	-0.49560	-0.59983	-0.69149	-0.76200	-0.80454	-0.81571	-0.79652	-0.75253	-0.69304
4.0	-0.09519	-0.19362	-0.29703	-0.40459	-0.51243	-0.61406	-0.70143	-0.76661	-0.80351	-0.80948	-0.78612	-0.73938	-0.67872
4.1	-0.10024	-0.20291	-0.30908	-0.41746	-0.52403	-0.62245	-0.70510	-0.76467	-0.79582	-0.79658	-0.76914	-0.71981	-0.65815
4.2	-0.10408	-0.20984	-0.31770	-0.42597	-0.53050	-0.62511	-0.70263	-0.75636	-0.78167	-0.77726	-0.74586	-0.69411	-0.63163
4.3	-0.10673	-0.21443	-0.32295	-0.43021	-0.53197	-0.62222	-0.69422	-0.74191	-0.76132	-0.75180	-0.71658	-0.66258	-0.59948
4.4	-0.10823	-0.21677	-0.32494	-0.43032	-0.52859	-0.61396	-0.68012	-0.72159	-0.73508	-0.72053	-0.68164	-0.62559	-0.56207
4.5	-0.10860	-0.21692	-0.32377	-0.42644	-0.52058	-0.60059	-0.66060	-0.69572	-0.70328	-0.68381	-0.64144	-0.58356	-0.51983
4.6	-0.10790	-0.21497	-0.31958	-0.41878	-0.50816	-0.58237	-0.63597	-0.66464	-0.66631	-0.64206	-0.59640	-0.53691	-0.47319
4.7	-0.10618	-0.21103	-0.31254	-0.40752	-0.49158	-0.55960	-0.60658	-0.62874	-0.62459	-0.59572	-0.54699	-0.48613	-0.42264
4.8	-0.10349	-0.20522	-0.30281	-0.39289	-0.47112	-0.53262	-0.57290	-0.58842	-0.57856	-0.54526	-0.49370	-0.43172	-0.36869
4.9	-0.09991	-0.19766	-0.29058	-0.37515	-0.44709	-0.50177	-0.53503	-0.54414	-0.52869	-0.49117	-0.43705	-0.37420	-0.31187
5.0	-0.09549	-0.18849	-0.27605	-0.35456	-0.41981	-0.46743	-0.49369	-0.49635	-0.47548	-0.43399	-0.37756	-0.31412	-0.25278
5.1	-0.09031	-0.17784	-0.25943	-0.33139	-0.38961	-0.43000	-0.44923	-0.44553	-0.41945	-0.37424	-0.31580	-0.25204	-0.19181
5.2	-0.08445	-0.16587	-0.24094	-0.30593	-0.35685	-0.38989	-0.40210	-0.39219	-0.36112	-0.31248	-0.25233	-0.18853	-0.12970
5.3	-0.07799	-0.15274	-0.22082	-0.27849	-0.32189	-0.34750	-0.35277	-0.33683	-0.30104	-0.24927	-0.18771	-0.12416	-0.06698
5.4	-0.07099	-0.13861	-0.19931	-0.24937	-0.28511	-0.30329	-0.30173	-0.27996	-0.23973	-0.18517	-0.12253	-0.05952	-0.00420
5.5	-0.06356	-0.12363	-0.17663	-0.21888	-0.24688	-0.25766	-0.24943	-0.22211	-0.17776	-0.12073	-0.05734	0.00483	0.05806
5.6	-0.05577	-0.10799	-0.15304	-0.18735	-0.20758	-0.21107	-0.19638	-0.16378	-0.11565	-0.05651	0.00728	0.06834	0.11924
5.7	-0.04771	-0.09183	-0.12878	-0.15507	-0.16758	-0.16394	-0.14303	-0.10548	-0.05393	0.00694	0.07080	0.13045	0.17883
5.8	-0.03945	-0.07533	-0.10408	-0.12237	-0.12726	-0.11669	-0.08986	-0.04771	0.00687	0.06909	0.13268	0.19064	0.23628
5.9	-0.03109	-0.05864	-0.07920	-0.08954	-0.08699	-0.06974	-0.03732	0.00904	0.06626	0.12944	0.19241	0.24840	0.29112
6.0	-0.02270	-0.04194	-0.05435	-0.05690	-0.04712	-0.02350	0.01414	0.06432	0.12375	0.18751	0.24951	0.30326	0.34286
6.1	-0.01437	-0.02536	-0.02977	-0.02472	-0.00800	0.02165	0.06412	0.11767	0.17889	0.24282	0.30352	0.35478	0.39112
6.2	-0.00615	-0.00907	-0.00567	0.00671	0.03005	0.06534	0.11219	0.16868	0.23124	0.29495	0.35402	0.40254	0.43545
6.3	0.00186	0.00681	0.01774	0.03713	0.06672	0.10722	0.15800	0.21695	0.28042	0.34352	0.40062	0.44617	0.47552

Table II.

Tabulation of the function Cuv H.

βb \ βh	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5
0.1	2.24365	2.74998	2.88089	2.83278	2.69541	2.52915	2.37749	2.26877	2.21640	2.21997	2.26802	2.34204	2.42119
0.2	1.56446	2.04584	2.17076	2.12044	1.98232	1.81600	1.66462	1.55633	1.50437	1.50826	1.55652	1.63062	1.70975
0.3	1.18362	1.62796	1.74325	1.68933	1.54998	1.38358	1.23269	1.12509	1.07381	1.07826	1.12685	1.20109	1.28018
0.4	0.92821	1.32805	1.43056	1.37177	1.23075	1.06427	0.91406	0.80743	0.75712	0.76232	0.81139	0.88581	0.96464
0.5	0.74193	1.09370	1.18086	1.11608	0.97303	0.80647	0.65716	0.55179	0.50270	0.50687	0.55855	0.63321	0.71216
0.6	0.59871	0.90164	0.97151	0.89980	0.75440	0.58782	0.43963	0.33580	0.28820	0.29555	0.34596	0.42090	0.49975
0.7	0.48435	0.73946	0.79067	0.71130	0.56332	0.39680	0.24996	0.14795	0.10212	0.11085	0.16211	0.23737	0.31610
0.8	0.39035	0.59971	0.63147	0.54390	0.39320	0.22684	0.08161	-0.01828	-0.06209	-0.05179	0.00044	0.07605	0.15462
0.9	0.31137	0.47757	0.48957	0.39346	0.23999	0.07396	-0.06941	-0.16690	-0.20843	-0.19636	-0.14306	-0.06707	0.01132
1.0	0.24385	0.36977	0.36210	0.25731	0.10111	-0.06440	-0.20562	-0.30042	-0.33942	-0.32541	-0.27093	-0.19453	-0.11637
1.1	0.18538	0.27395	0.24705	0.13365	-0.02516	-0.18991	-0.32869	-0.42050	-0.45673	-0.44060	-0.38486	-0.30805	-0.23015
1.2	0.13426	0.18842	0.14299	0.02120	-0.13999	-0.30370	-0.43974	-0.52827	-0.56149	-0.54309	-0.48601	-0.40876	-0.33118
1.3	0.08927	0.11188	0.04886	-0.08094	-0.24421	-0.40657	-0.53953	-0.62451	-0.65449	-0.63366	-0.57516	-0.49749	-0.42028
1.4	0.04953	0.04336	-0.03615	-0.17344	-0.33841	-0.49905	-0.62862	-0.70975	-0.73627	-0.71288	-0.65291	-0.57483	-0.49804
1.5	0.01435	-0.01790	-0.11267	-0.25681	-0.42303	-0.58157	-0.70740	-0.78440	-0.80726	-0.78118	-0.71970	-0.64122	-0.56492
1.6	-0.01677	-0.07252	-0.18121	-0.33145	-0.49840	-0.65443	-0.77618	-0.84877	-0.86778	-0.83890	-0.77587	-0.69702	-0.62129
1.7	-0.04423	-0.12097	-0.24218	-0.39770	-0.56481	-0.71789	-0.83520	-0.90312	-0.91810	-0.88633	-0.82173	-0.74255	-0.66746
1.8	-0.06835	-0.16369	-0.29595	-0.45584	-0.62250	-0.77217	-0.88469	-0.94769	-0.95846	-0.92373	-0.85756	-0.77810	-0.70374
1.9	-0.08938	-0.20099	-0.34281	-0.50613	-0.67169	-0.81747	-0.92486	-0.98269	-0.98912	-0.95136	-0.88363	-0.80396	-0.73040
2.0	-0.10755	-0.23319	-0.38306	-0.54881	-0.71260	-0.85401	-0.95592	-1.00836	-1.01032	-0.96948	-0.90022	-0.82040	-0.74776
2.1	-0.12303	-0.26054	-0.41696	-0.58413	-0.74545	-0.88201	-0.97811	-1.02495	-1.02233	-0.97839	-0.90763	-0.82776	-0.75613
2.2	-0.13598	-0.28330	-0.44476	-0.61233	-0.77047	-0.90169	-0.99167	-1.03271	-1.02543	-0.97840	-0.90620	-0.82636	-0.75585
2.3	-0.14656	-0.30168	-0.46672	-0.63365	-0.78791	-0.91333	-0.99687	-1.03195	-1.01995	-0.96983	-0.89627	-0.81657	-0.74729
2.4	-0.15489	-0.31591	-0.48308	-0.64836	-0.79804	-0.91719	-0.99403	-1.02300	-1.00623	-0.95307	-0.87823	-0.79878	-0.73086
2.5	-0.16110	-0.32620	-0.49410	-0.65673	-0.80115	-0.91360	-0.98347	-1.00622	-0.98467	-0.92853	-0.85251	-0.77344	-0.70700
2.6	-0.16531	-0.33275	-0.50003	-0.65904	-0.79755	-0.90288	-0.96556	-0.98200	-0.95567	-0.89663	-0.81957	-0.74101	-0.67617
2.7	-0.16765	-0.33577	-0.50115	-0.65561	-0.78758	-0.88542	-0.94070	-0.95076	-0.91970	-0.85786	-0.77988	-0.70199	-0.63889
2.8	-0.16822	-0.33548	-0.49773	-0.64675	-0.77160	-0.86158	-0.90930	-0.91296	-0.87724	-0.81272	-0.73398	-0.65690	-0.59567
2.9	-0.16714	-0.33209	-0.49005	-0.63280	-0.74998	-0.83181	-0.87164	-0.86909	-0.82880	-0.76175	-0.68241	-0.60631	-0.54709
3.0	-0.16454	-0.32581	-0.47841	-0.61411	-0.72313	-0.79653	-0.82878	-0.81967	-0.77492	-0.70550	-0.62576	-0.55080	-0.49373
3.1	-0.16052	-0.31687	-0.46310	-0.59105	-0.69147	-0.75621	-0.78063	-0.76523	-0.71618	-0.64458	-0.56462	-0.49097	-0.43620
3.2	-0.15521	-0.30548	-0.44444	-0.56400	-0.65542	-0.71134	-0.72793	-0.70633	-0.65315	-0.57959	-0.49961	-0.42747	-0.37512
3.3	-0.14873	-0.29188	-0.42274	-0.53334	-0.61544	-0.66242	-0.67120	-0.64355	-0.58645	-0.51114	-0.43137	-0.36091	-0.31114
3.4	-0.14119	-0.27628	-0.39832	-0.49947	-0.57199	-0.60996	-0.61101	-0.57749	-0.51669	-0.43988	-0.36054	-0.29197	-0.24490
3.5	-0.13272	-0.25893	-0.37151	-0.46280	-0.52554	-0.55448	-0.54792	-0.50875	-0.44450	-0.36646	-0.28779	-0.22128	-0.17705
3.6	-0.12343	-0.24005	-0.34264	-0.42373	-0.47657	-0.49652	-0.48252	-0.43792	-0.37052	-0.29152	-0.21376	-0.14951	-0.10825
3.7	-0.11345	-0.21988	-0.31203	-0.38268	-0.42555	-0.43660	-0.41537	-0.36564	-0.29538	-0.21570	-0.13911	-0.07732	-0.03915
3.8	-0.10289	-0.19863	-0.28001	-0.34005	-0.37295	-0.37527	-0.34705	-0.29250	-0.21970	-0.13966	-0.06449	-0.00534	0.02962
3.9	-0.09187	-0.17655	-0.24690	-0.29626	-0.31927	-0.31304	-0.27814	-0.21910	-0.14412	-0.06402	0.00947	0.06580	0.09742
4.0	-0.08051	-0.15385	-0.21303	-0.25170	-0.26496	-0.25045	-0.20920	-0.14603	-0.06923	0.01060	0.08215	0.13547	0.16367
4.1	-0.06891	-0.13075	-0.17871	-0.20676	-0.21048	-0.18800	-0.14077	-0.07388	0.00438	0.08360	0.15296	0.20309	0.22777
4.2	-0.05720	-0.10747	-0.14424	-0.16184	-0.15629	-0.12619	-0.07339	-0.00319	0.07612	0.15441	0.22132	0.26809	0.28917
4.3	-0.04547	-0.08421	-0.10992	-0.11729	-0.10280	-0.06549	-0.00756	0.06550	0.14547	0.22249	0.28669	0.32995	0.34735
4.4	-0.03383	-0.06117	-0.07603	-0.07349	-0.05044	-0.00637	0.05622	0.13169	0.21190	0.28731	0.34857	0.38816	0.40182
4.5	-0.02237	-0.03855	-0.04285	-0.03076	0.00040	0.05075	0.11749	0.19490	0.27494	0.34841	0.40648	0.44226	0.45214
4.6	-0.01119	-0.01651	-0.01063	0.01057	0.04934	0.10545	0.17583	0.25468	0.33413	0.40533	0.45999	0.49184	0.49791
4.7	-0.00038	0.00478	0.02040	0.05021	0.09606	0.15736	0.23083	0.31064	0.38907	0.45769	0.50872	0.53653	0.53877
4.8	0.00999	0.02514	0.05000	0.08787	0.14022	0.20613	0.28213	0.36239	0.43940	0.50512	0.55232	0.57600	0.57440
4.9	0.01985	0.04446	0.07798	0.12331	0.18153	0.25145	0.32941	0.40962	0.48480	0.54731	0.59050	0.60997	0.60455
5.0	0.02911	0.06258	0.10414	0.15629	0.21975	0.29304	0.37239	0.45205	0.52499	0.58401	0.62302	0.63821	0.62901
5.1	0.03773	0.07941	0.12833	0.18662	0.25464	0.33066	0.41081	0.48942	0.55974	0.61501	0.64968	0.66056	0.64761
5.2	0.04566	0.09483	0.15041	0.21413	0.28601	0.36411	0.44448	0.52156	0.58888	0.64014	0.67035	0.67689	0.66027
5.3	0.05283	0.10875	0.17025	0.23866	0.31369	0.39322	0.47323	0.54830	0.61227	0.65930	0.68493	0.68715	0.66693
5.4	0.05923	0.12112	0.18776	0.26010	0.33758	0.41787	0.49696	0.56956	0.62985	0.67243	0.69340	0.69130	0.66760
5.5	0.06482	0.13187	0.20285	0.27836	0.35756	0.43797	0.51559	0.58528	0.64157	0.67952	0.69578	0.68940	0.66233
5.6	0.06957	0.14097	0.21548	0.29338	0.37359	0.45348	0.52908	0.59546	0.64746	0.68062	0.69213	0.68154	0.65124
5.7	0.07348	0.14837	0.22561	0.30514	0.38564	0.46440	0.53747	0.60013	0.64758	0.67583	0.68257	0.66786	0.63447
5.8	0.07653	0.15409	0.23324	0.31363	0.39373	0.47074	0.54079	0.59938	0.64205	0.66529	0.66728	0.64855	0.61225
5.9	0.07873	0.15811	0.23837	0.31887	0.39789	0.47259	0.53916	0.59333	0.63103	0.64919	0.64647	0.62385	0.58486
6.0	0.08008	0.16047	0.24104	0.32092	0.39822	0.47004	0.53270	0.58217	0.61473	0.62776	0.62039	0.59404	0.55249
6.1	0.08060	0.16118	0.24130	0.31985	0.39480	0.46324	0.52159	0.56609	0.59338	0.60128	0.58937	0.55944	0.51559
6.2	0.08032	0.16030	0.23923	0.31577	0.38779	0.45236	0.50605	0.54535	0.56728	0.57006	0.55372	0.52043	0.47450
6.3	0.07926	0.15788	0.23491	0.30680	0.37733	0.43760	0.48631	0.52023	0.53673	0.53446	0.51384	0.47738	0.42962

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INTERPRETING SOME QHB SCOPE INDICATIONS

The following article, most of which is taken from SurASDevFor letter SADD/S68(05:jac) Serial 084, is written for information and use of the Fleet.

From tests conducted using a Model QHB Scanning Sonar Equipment, it was found that the strength of the wake of a Guppy submarine varied considerably depending on the condition of the ship's propellers. One submarine, upon her initial arrival at Key West, presented a very strong wake on the QHB scope at a speed of 5 knots. After having been drydocked for propeller repairs, little or no wake could be seen from this submarine at a speed of 5 knots, even at periscope depth. Operations with other Guppy submarines have shown varying wake conditions which may be attributed, in part, to the sonar conditions prevailing at the time.

If the MCC switch of the Model QHB is left in the OFF position to increase echo strength, "lost contact" will usually occur at about 400 yards when the target submarine is 200 to 300 feet deep. Wake indication is usually lost just before "lost contact." If the equipment is now switched to MCC operation, contact is usually regained together with a fair wake indication.

Although wake indication is of great assistance to an experienced QHB operator, it tends to confuse the uninitiated. Since the wake and target echoes merge, the inexperienced operator is often at a loss as to where to place his cursor. In this connection, it should be pointed out that under most operating conditions there will be a slightly larger (thicker) echo appearing at the submarine's position at the end of the wake. The operator should bisect this with the cursor. Under adverse conditions, where no definite echo indication from the sub itself is obtained, the operator should place the cursor approximately half the width of a normal echo back from the leading edge of the wake. It is of interest to note, however, that the preponderance of attacks on medium-speed submarines have been either direct bow or stern attacks, which produce little or no wake indication.

The operator must be alert to insure that he does not interpret an echo returned by the knuckle from submarine acceleration as the submarine echo. Submarine acceleration, in addition to forming a knuckle, produces considerable noise, which tends to overload and reduce the gain of the QHB receiver, thereby reducing the amount of wake information visible on the QHB scope.

While conducting these tests, a method of obtaining early information on submarine evasive maneuvers was noted. With gain enough to produce a noise spoke on the QHB scope, it was found that the center bearing on the target echo differed from the center bearing on the noise spoke. As the target aspect approaches a beam aspect and the range decreases, this difference becomes more pronounced and can be as much as five to ten degrees at the time that sonar contact is lost. When attacking a medium-speed submarine, if the operator will closely note any changes in location of the echo in relation to the noise spoke, information on target turns (change of aspect) can be obtained long before the change in bearing is noted and a change in course is indicated.

In one instance, a beam aspect target at a range of 500 yards showed the center of the echo approximately even with the left edge of the noise spoke (see figure 1). Although in this case the actual echo appeared to indicate aspect by itself, such a clear-cut indication is not normally obtained, because adverse conditions such as high acceleration noise tend to make the echo weak thereby reducing the presentation to one or two segments and leaving little or no aspect indication in the echo. Therefore, under adverse conditions, knowledge of the noise spoke–echo relationship is a great help in interpreting what is taking place, as indicated by the QHB scope presentation.

High reverberation areas are sometimes encountered which might be of assistance to submarines in selecting a location offering a minimum possibility of detection. Such a high reverberation area was found off Key West (see figure 2). The area was closely inspected by an ASW vessel but no reason was found for its existence. Since the water depth was 120 fathoms and the reverberation area did not remain at constant range, it is not believed to have been caused by bottom echoes.

In addition to indicating submarine wake, the Model QHB Scanning Sonar Equipment gives a very good presentation of wake from high-speed torpedoes (Mark 14). Where other methods of locating a submarine are not available, this torpedo wake indication could be used by the ASW surface vessel to help itself to arrive at the approximate position of the submarine.

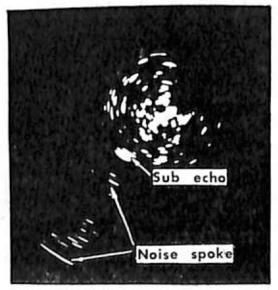


FIGURE 1.

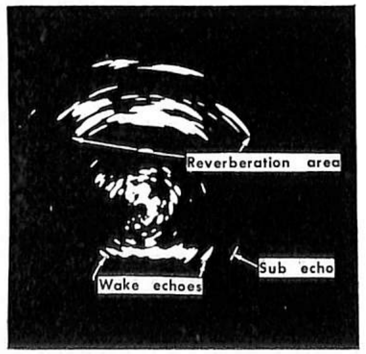
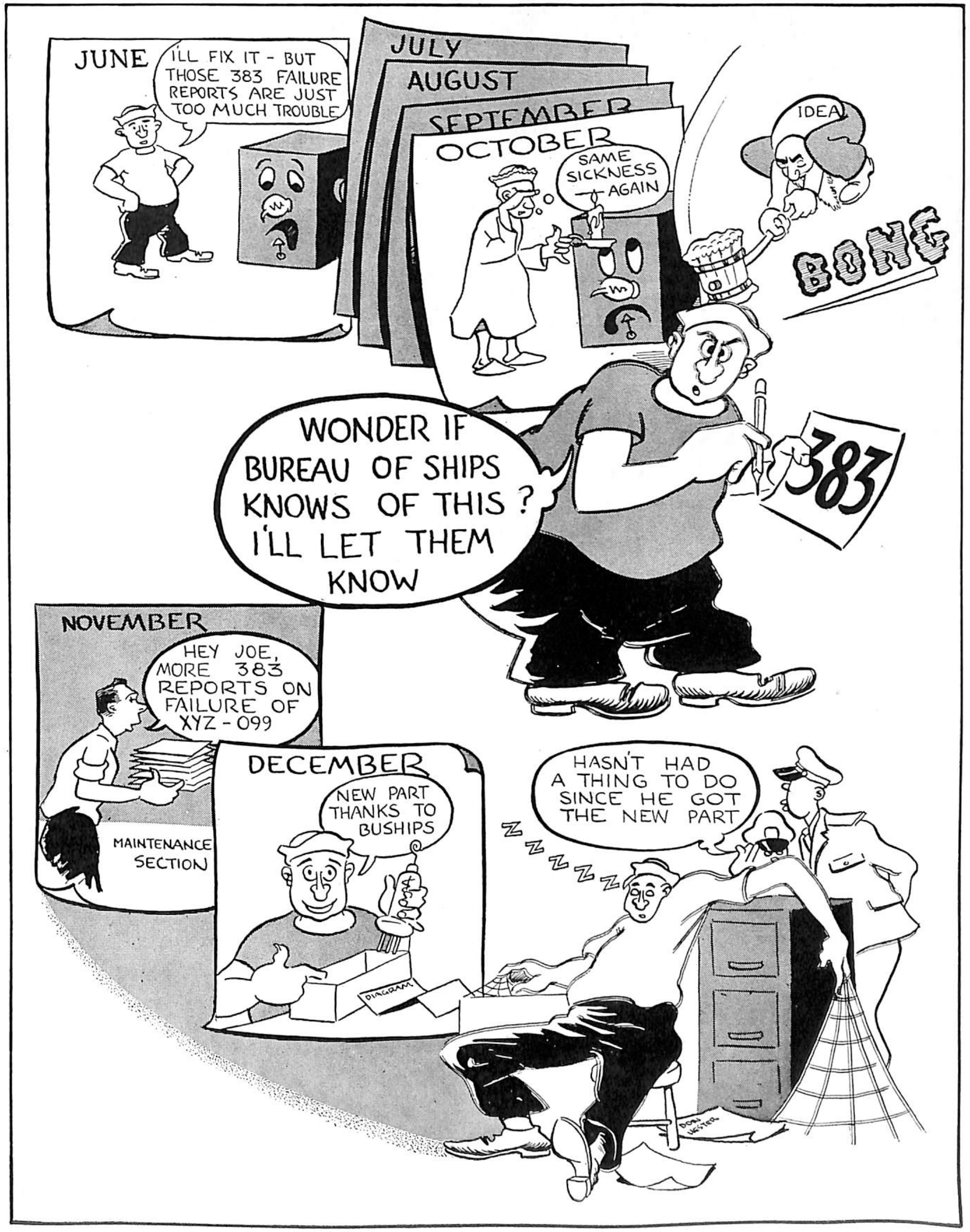


FIGURE 2.



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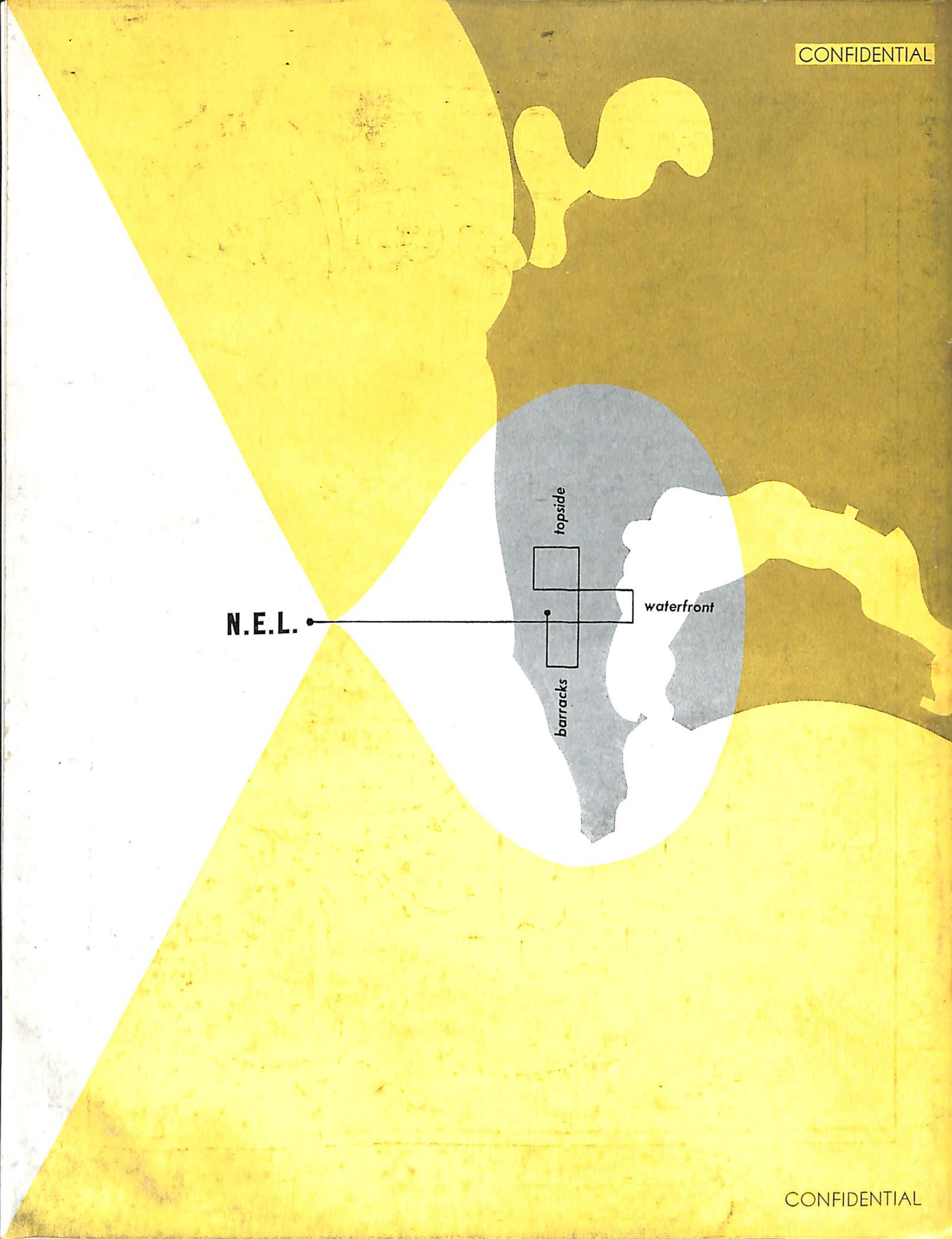

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