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LONG-RANGE SEARCH SONAR
THE 5-KC SYSTEM

[UNCLASSIFIED TITLE]

N. Shear, C. L. Buchanan,
J. B. Humphrey, and R. H. Houston

Sonar Systems Branch
Sound Division

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NAVAL RESEARCH LABORATORY
Washington, D.C.

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ABSTRACT
[Confidential]

An experimental 5-kc echo-ranging equipment has been developed. The system has a searchlight transducer with an active face of 15 square feet, and is capable of radiating 20 kw of acoustic power. The system uses a towed body as the transducer housing; the towing and electronics systems vehicle is an LSM.

In addition to a conventional electronic driver the system employs a specially developed 5-kc rotary machinery driver. The system is equipped with basic receivers and displays. Space is provided for evaluating experimental receivers and displays. A monitor and 7-channel tape recorder are included as a part of the installation.

PROBLEM STATUS

This is a report on the equipment phase of the problem; work is continuing on other phases.

AUTHORIZATION

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[Unclassified Title]

INTRODUCTION

Background

The post World War II estimate of the ASW problem concluded that greatly improved active sonar was necessary to counter the capabilities of the high-speed submarine and the long-range torpedo. Consequently, ONR made a comprehensive analysis of the problem (1) which was reported in 1948. The report recommended the use of lower frequency, larger transducers, higher power, and improved signal processing to achieve adequate sonar detection ranges. This analysis was followed by the Long-Range-Search program which is a continuing program at NRL for implementing these recommendations and for studying in general the long-range search possibilities offered by the recommended type of active sonar.

The initial analysis by NRL (2) made similar recommendations. The use of low frequency is very attractive from the point of view of decreased attenuation. However, in order to retain high directivity, the low frequency entails large transducers and heavy accompanying equipment. To satisfy these requirements of low-frequency sonar, it is necessary to abandon conventional limitations of weight and space. The selection of the frequency band for each successive phase of the problem is therefore based on a compromise between the desire to make a significant advance in the direction of low frequency and the practical limitation which our current knowledge imposes on our ability to build suitable equipment. Considerations of this type led to the decision to start with 10 kc, to follow with the second step to 5 kc, and then with the third step to 1 kc. Preliminary descriptions of the 10-kc gear are given in Reference 3 and a full description of the program exploiting that equipment is given in Reference 4.

Objectives

The purpose of this report is to describe the design, construction, and operation of the 5-kc gear, known as the LRS 2-5 system.*

It appeared feasible to build a sonar with the following characteristics:

$$I_1^{\dagger} = 136 \text{ db vs } 1\ \mu\text{bar}$$

$$\Delta = 24 \text{ db}$$

$$-\delta = -18 \text{ db}$$

$$T = 20 \text{ db}$$

$$-N = +30 \text{ db vs } 1\ \mu\text{b in a 1-cycle band.}$$

*The designation of the LRS sonars indicate Mod. number and frequency, thus:
LRS 1-10 means Mod. 1, frequency 10 kc.
LRS 2-5 means Mod. 2, frequency 5 kc.

†See Appendix A for discussion and definition of terms.

This would give it an echo excess E_1* (along the axis of the transducer at 1 yard from the face) of 192 db relative to 1 dyne/cm^2. The equipment part of the program is thus a project to design and build a system which satisfies the above E_1, and to learn how to handle it.

Innovations

In devising a system with the above characteristics, changes from the LRS 1-10 (the 10-kc gear) were obviously required. For many reasons, it was not sufficient merely to change the frequency and make a few minor alterations; a completely new design was required. The design which resulted in the LRS 2-5 equipment differed from that of the LRS 1-10 in the following components:

(a) transducers

(b) vehicle

(c) handling methods

(d) equipment layout

(e) employment of rotating machinery as the transmitting power source.

The transducers of the LRS 2-5 have an effective radiating face 5 feet in diameter, those of the LRS 1-10 have an effective radiating face 3 feet in diameter. The transducers have about equal directivity indices. In the LRS 1-10, the active elements are ADP crystals, in the LRS 2-5 they are either magnetostrictive nickel rings or lead-barium titanate ceramic tubes. The ADP crystal plates originally used in the 10-kc transducers were as large as the growers could supply, and it was not considered feasible or economic to grow larger ADP crystals for resonance at 5 kc. Therefore, new element designs were required. The transducers themselves are described in detail in References 5 and 6.

In selecting ways of housing the transducer, it is necessary to take into account both the vehicle to carry the sonar and the methods of handling it aboard that vehicle. Considerations which favor towing the transducer from a surface ship are as follows:

(a) size of the transducer,

(b) serious questions of servicing a large hull mounted transducer with available drydocking facilities, and

(c) the fact that successful experience had already been gained on submarine-installed gear suggested experimenting with an alternate type of vehicle.

The decision was made to employ a landing-type vessel as the vehicle and to build a center well through which the transducer and housing could be hoisted and towed.

*See Appendix A for discussion and definition of terms.

With the assignment of the LSM as the vehicle, a towing system was developed. Originally a tandem tow cable assembly (7) which consisted of a load-bearing wire rope and an electrical cable was used. This assembly was superseded by an electrical cable encased in a load-bearing, steel-wire armor as a single assembly.

Another innovation was a complete duplication of the electrical installation located on opposite sides of the ship. One system named, the "Basic Equipment," contains the electronic devices which are necessary for the operation of the sonar system. The second system called, the "Experimental Equipment," consists of a duplicate of the installations of the Basic Equipment plus permanently installed recording and monitoring equipment and several empty racks which are available for new devices (transient equipment). Thus, a temporary installation can be made on the "Experimental Side" without disturbing the balance, safety, or orderliness of the basic installation. In addition, if some mishap renders equipment inoperative on either side, an exact duplicate is immediately available.

The high power capabilities of the transducers called for novel and more powerful energy sources for the drivers than had previously been employed. Since the basic limitation in power radiation is cavitation, the increased size of the transducers permits the use of considerably more power than previous transducers could handle. To realize this advantage, higher power sources were desired, and research to satisfy this need was in order. Two electrical rotating machinery systems were developed — the 5-kc diesel driver (8) and a motor generator set used in conjunction with a conventional electronic driver, a system employed briefly in the LRS 1-10.

THE SYSTEM

The system is installed on LSM-398. Figure 1, taken from Reference 7, shows schematically the location of the center well, the transducer and fish streaming. It also shows the location of the sonar spaces.

Figure 2 is a block diagram of the system. Details of construction of all the units are contained in the NRL maintenance manual for the 5-kc equipment. Since this sonar is entirely experimental and only one exists, this manual has not been distributed. However, if interest exists for further particulars of the unit designs than given here, they may be obtained from this Laboratory. The system consists of elements which will be described in detail. These elements can be grouped into six classes:

Exterior Components

Transducers — Two types of searchlight transducers have been employed; one, a magnetostrictive transducer, was designed and built at NRL; the other was a barium-titanate transducer, designed and manufactured by the General Electric Company under a contract with the Bureau of Ships. Special trunnions were designed for each of the two transducers, so as to obtain identical mounting dimensions permitting direct replacement of one by the other.

The NRL magnetostrictive transducer (5), designated the XM-1A, is an assembly of fourteen transducing elements arranged in a plane array enclosed in a castor-oil-filled case behind a rho-c-rubber window, the opening of which is 70 inches in diameter. Figure 3 is a cross-section of a typical element; Figure 4 shows the arrangement of the elements in the array. The fourteen transducing elements are of the ring-driven-cavity type, in which a polarized magnetostrictive nickel ring, operated at radial mechanical resonance, drives the cylindrical oil-filled cavity which it surrounds. The depth of the cavity, the bottom of which is acoustically soft, is adjusted for maximum transfer of acoustic energy from the inner surface of the ring to the acoustic load presented by the open water (through the oil and the rubber window) at the open radiating end of the cavity. The ring-driven-cavity elements are fitted into a circular 70-inch-diameter bakelite plate, which provides support and acts as a buffer between elements within the case. Figure 5 is a rear view photograph of the transducer, with junction-box covers removed. Figure 6 is a front view of the XM-1A with the sound window removed.

The placement of the elements in the array was chosen after computing the radiation patterns of a variety of possible spacings and number of cavity elements which could be fitted into a 70-inch circle. The array shown in Fig. 4 was finally chosen as being most likely to provide acceptably low sidelobes. The array is symmetric about the geometric center; consequently, the center-to-center spacing of elements is shown for one quadrant only. The dimension "D" appearing in this figure is the over-all diameter associated with an individual cavity, and is the basic spacing dimension.

The essential characteristics of the transducer are summarized in Table. 1. Figure 7 shows the directional response of the transducer in the horizontal plane, Fig. 8 in the vertical. The over-all weight of the assembled transducer in air is 5800 pounds including the trunnions which support the transducer in its mount.

The high secondary-lobe response in the horizontal plane was unexpected, and is as yet unexplained. A response of approximately -13 db was expected. This point is discussed fully in Reference 5.

The G.E. barium-titanate transducer designated AT-258(XN-1)/WQ described in Reference 6 was developed as an alternative transducer and has the properties listed in Table 1.

The completed transducer consists of 28 units, each one of which contains six barium-titanate transducing elements. The six elements are bonded to an acoustic-rubber window and sealed within a pressure-tight housing. An impedance-matching transformer is located in a separate sealed chamber in the rear of each housing. The 28 units are supported in an array by a structural frame to form the completed transducer assembly. A junction box mounted on the rear of the frame permits complete freedom of interconnection among the individual units. Different views of a transducing unit are shown in Figs. 9 and 10.

Individual units have been successfully driven separately at a power level of 2,000 watts. The over-all efficiency has been determined to be approximately 50%. Beam patterns, impedances, transmitting and receiving responses, etc., are satisfactory. The assembled transducer is shown in Fig. 11. Figures 12, 13, and 14 show the directivity pattern of the transducer.

Towed Body — With the decision to tow the transducer, the housing necessarily had to be a streamlined body. The completed body, Fig. 15, including the Naval Research Laboratory transducer and train-tilt mechanism weighs 29,000 pounds in air. It is a hydrodynamical body with a fineness ratio of 2-1/2:1, and its dimensions including tail surfaces are 27 feet long, 11 feet high, and 8 feet wide. This body is launched through a large center well built into LSM-398. The fish structure is covered with 1/8-inch-thick stainless steel, and has negligible absorption at 5 kc.

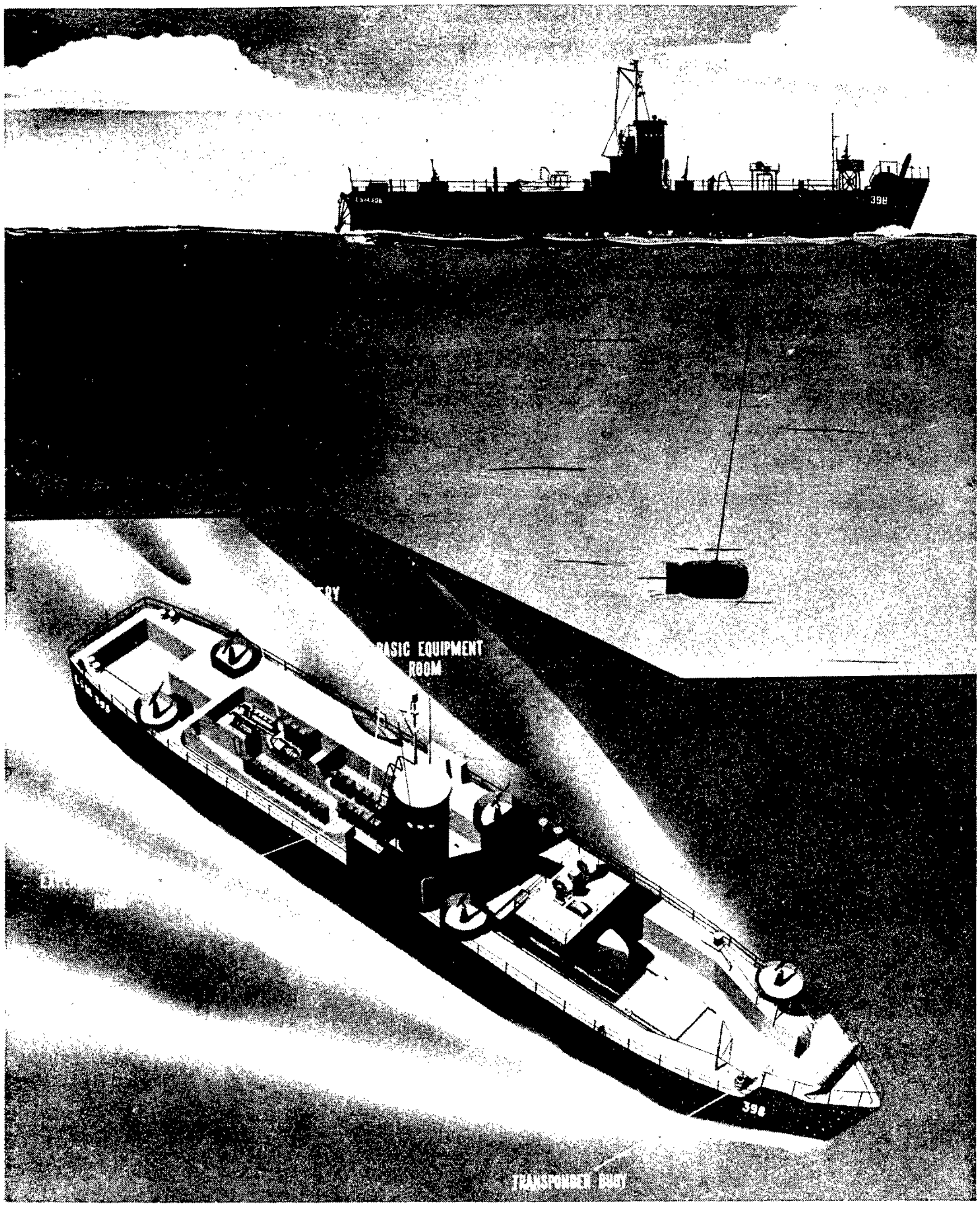


Fig. 1 - Schematic of the LRS 2-5 system

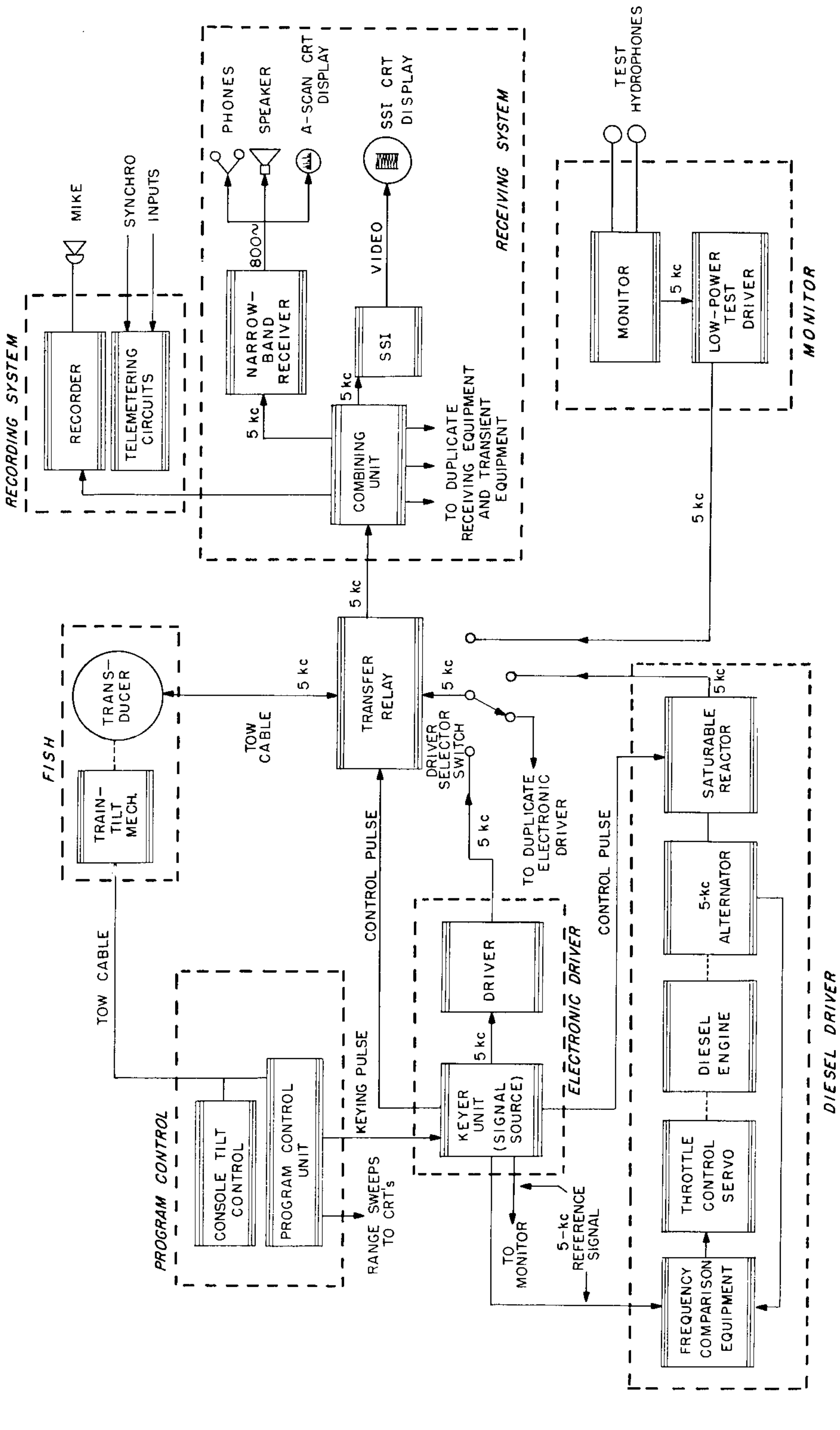


Fig. 2 - Block diagram of LRS 2-5 sonar

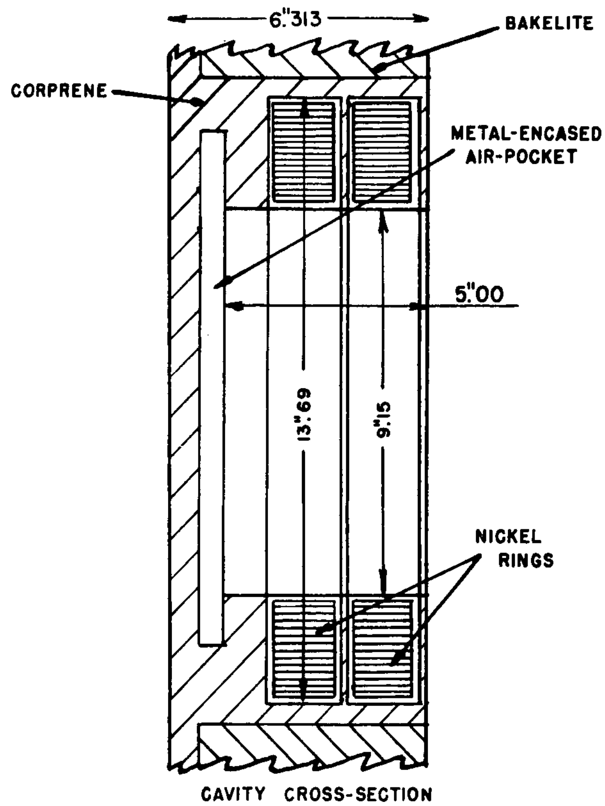


Fig. 3 - Cross section of typical cavity element of magnetostrictive transducer XM-1A

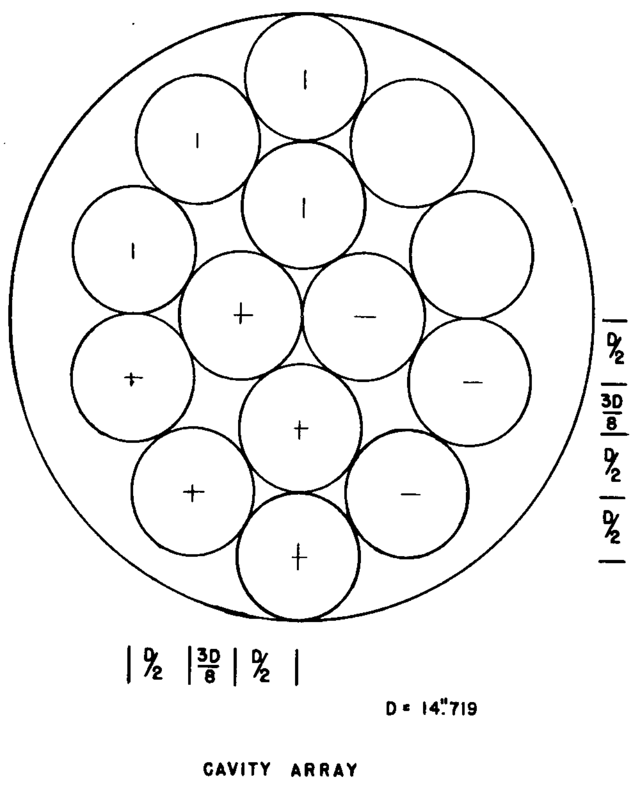


Fig. 4 - Arrangement of elements in the transducer array of XM-1A transducer

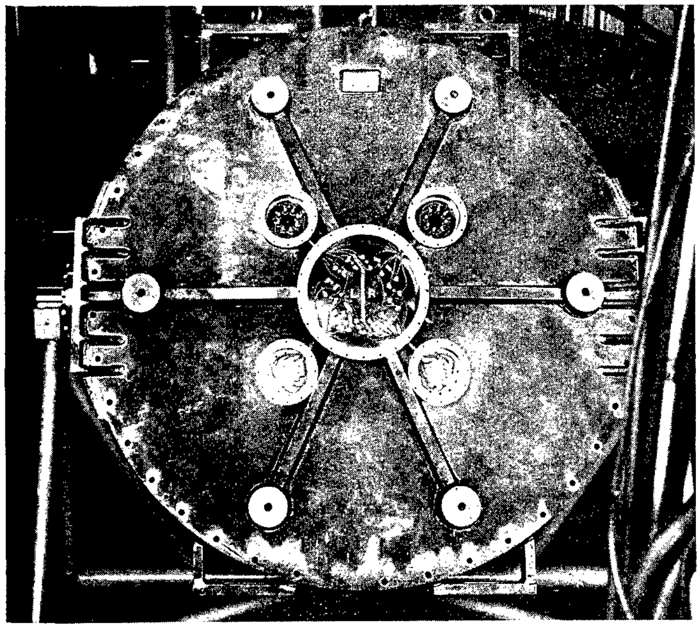


Fig. 5 - Rear view of XM-1A transducer
with junction box covers removed

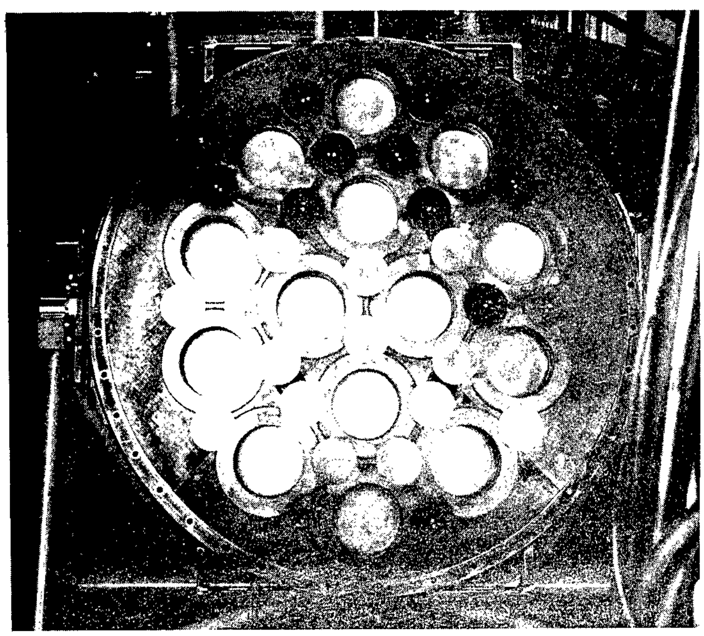


Fig. 6 - Front view of XM-1A transducer
with sound window removed

TABLE 1
Properties of XM-1A and AT-258 Transducers at Resonance

Property	XM-1A	AT-258	Reference
Resonant frequency, f_o	5.2 kc	5.0 kc	
Sharpness of mechanical resonance, Q_m	15.5	6.5	
Horizontal-plane beamwidth (10 db down)	24^0	19^0	
Maximum secondary lobe response	-9 db	-20 db	0^0 Response
Vertical-plane beamwidth (10 db down)	18^0	19^0	
Maximum secondary lobe response	-14 db	-19 db	0^0 Response
Rear response	-30 db	-27 db	0^0 Response
Directivity index	19 db	24 db	
Projector current response (0^0)	102 db	112 db	1 μb/amp, at 1 m
Free-field voltage response (0^0)	-65 db	-56 db	1 volt/μb
Impedance	58 + j 108	100 + j 0	ohms
Equivalent noise pressure (1-cps band)	-115 db	-122 db	1 μb
Projector efficiency (at low power output)	35%	50%	
Projector efficiency (at designed maximum output)	30%	50%	
1-Yard source level (at designed maximum output) (0^0)	131 db	141 db	1 μbar

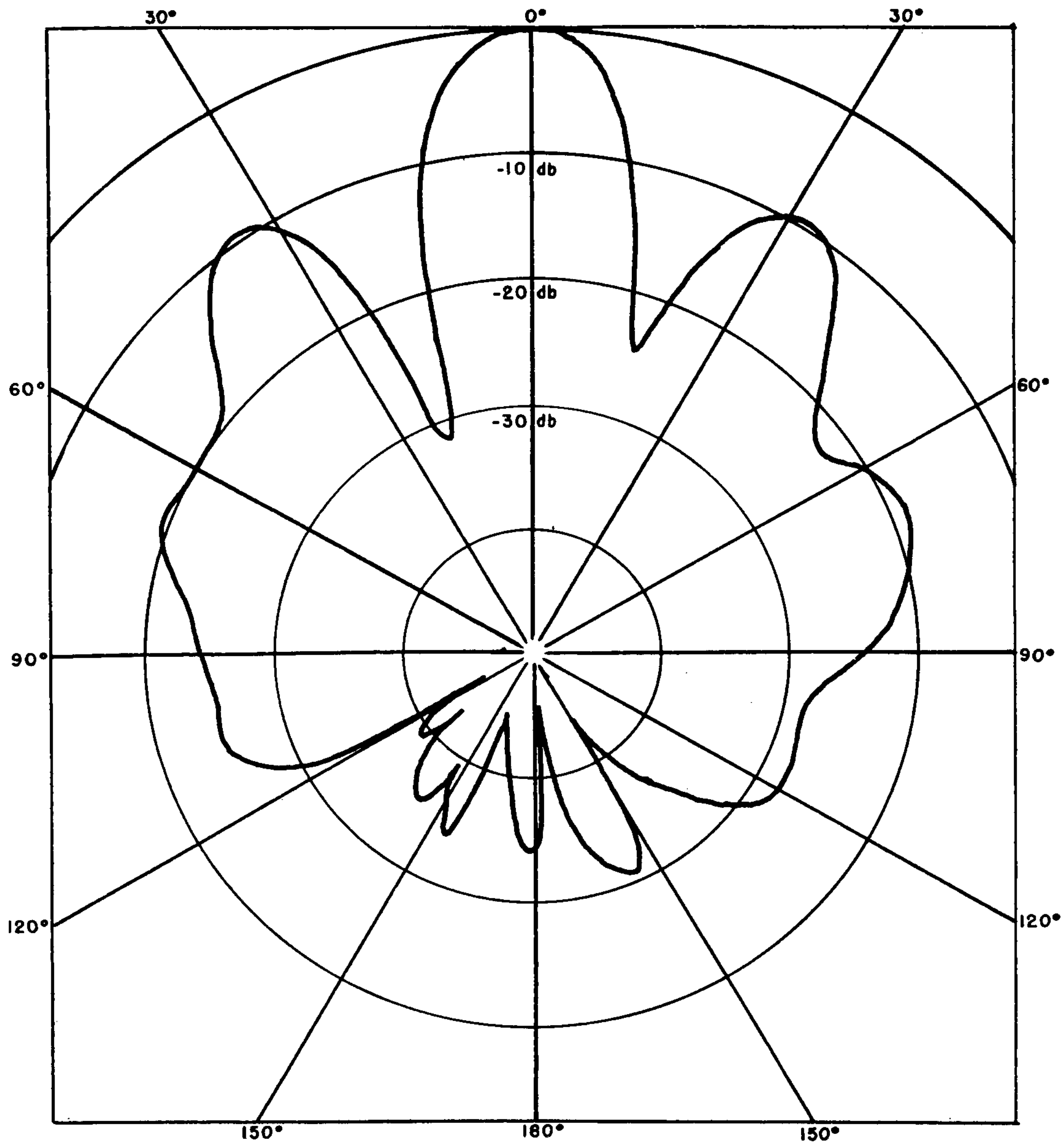


Fig. 7 - Directional response of XM-1A transducer in the horizontal plane

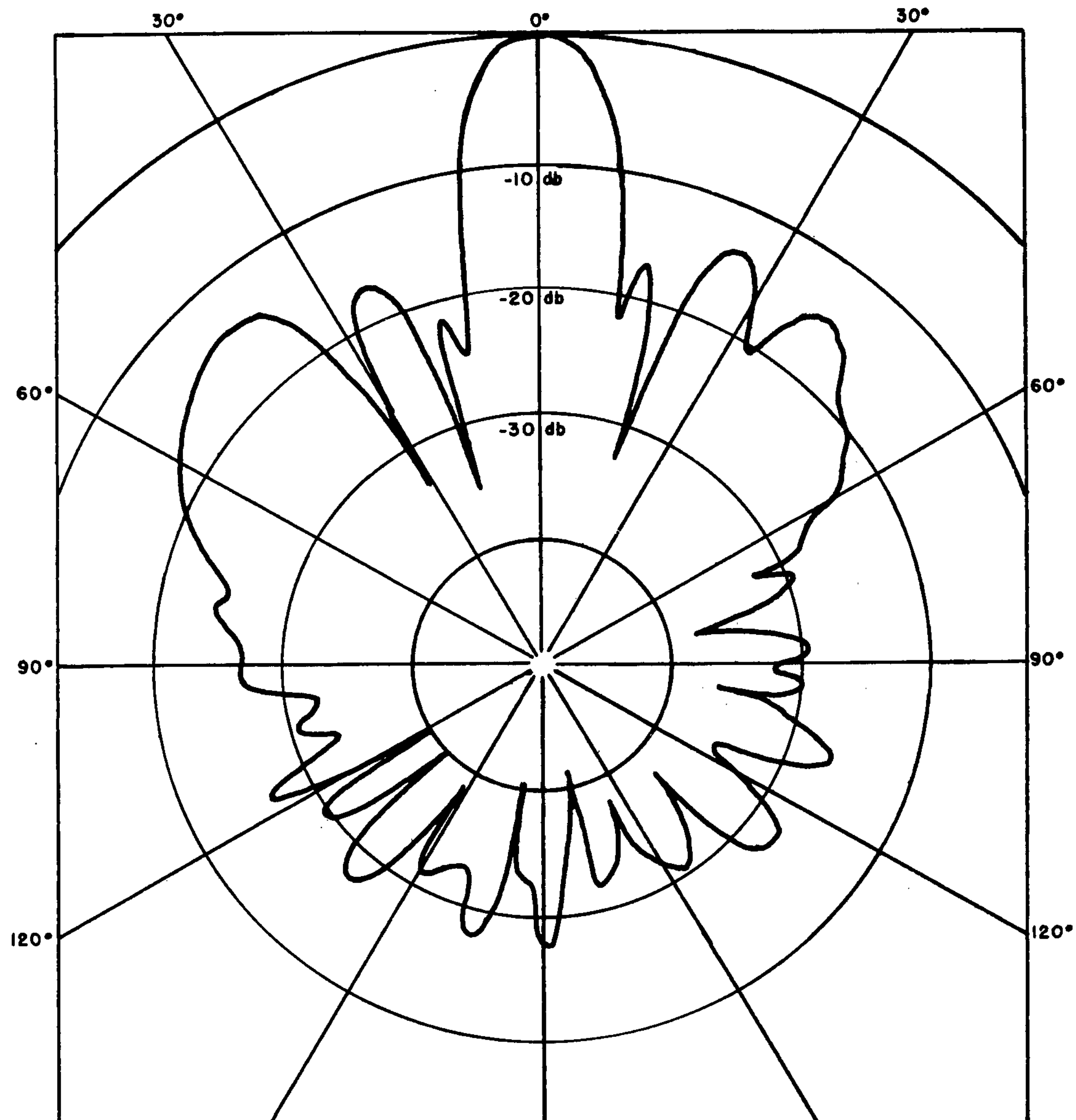


Fig. 8 - Directional response of XM-1A transducer in the vertical plane

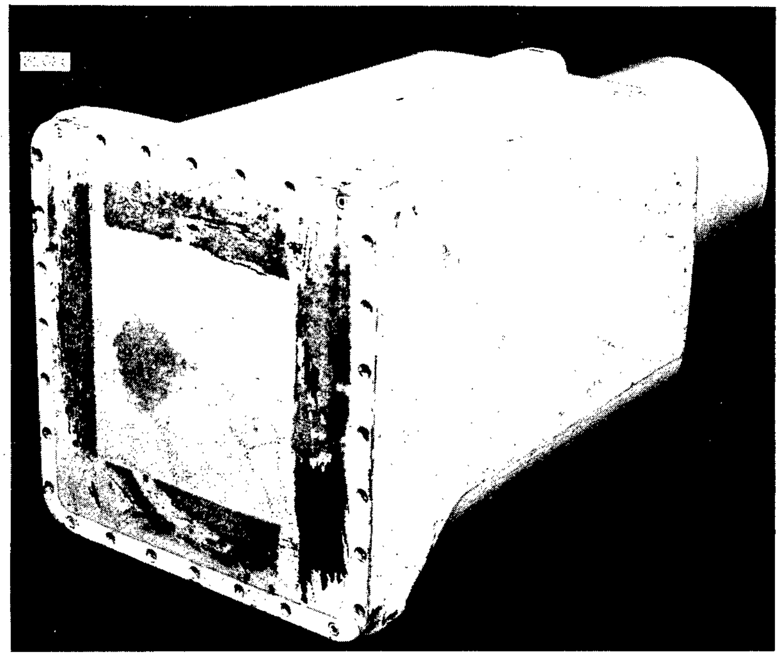


Fig. 9 - Transducer unit of AT-258(XN-1) transducer
(with cover on)

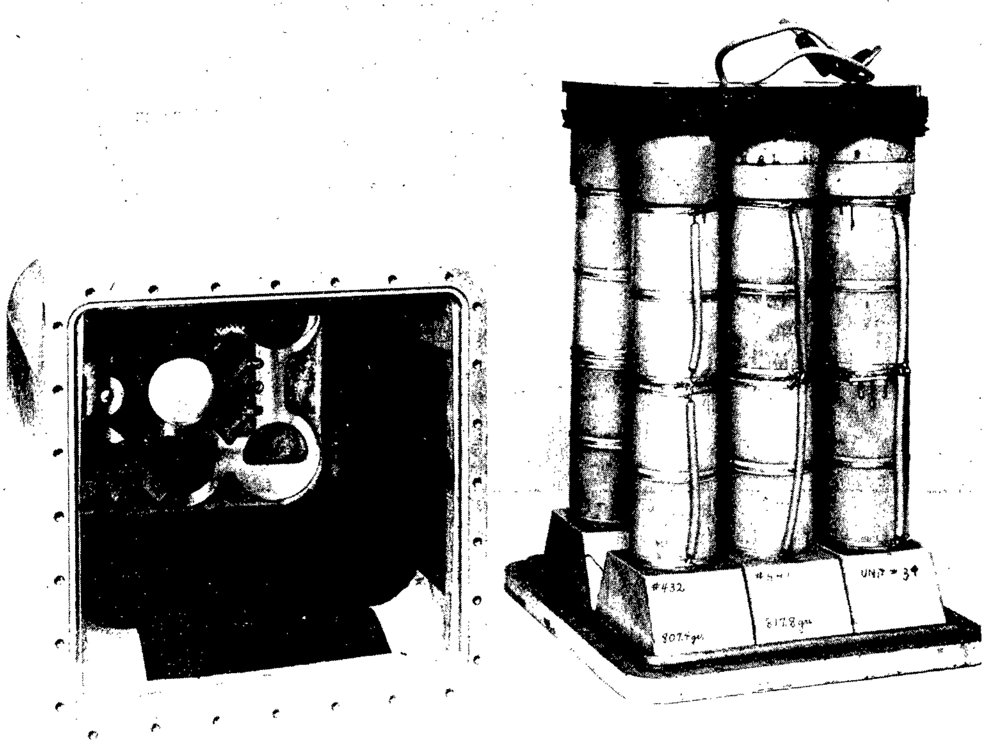
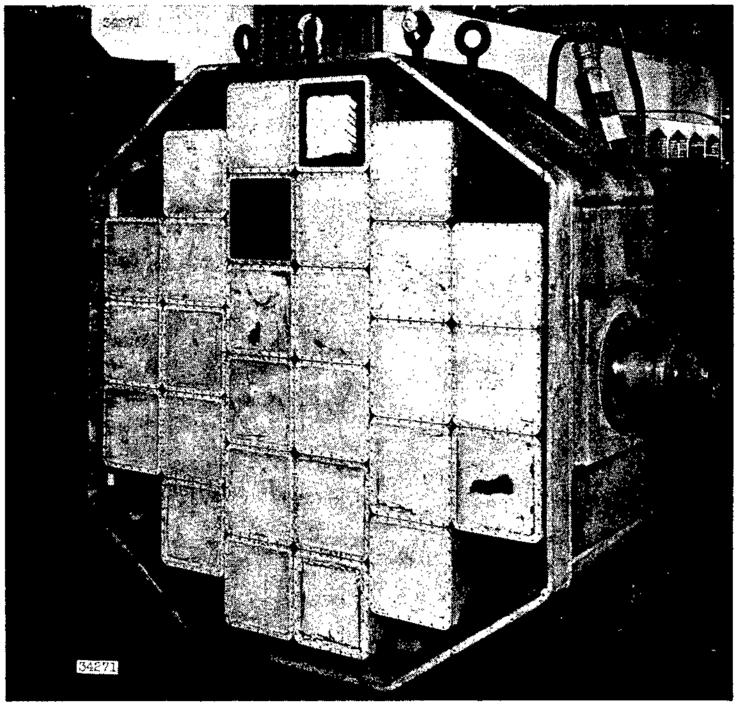
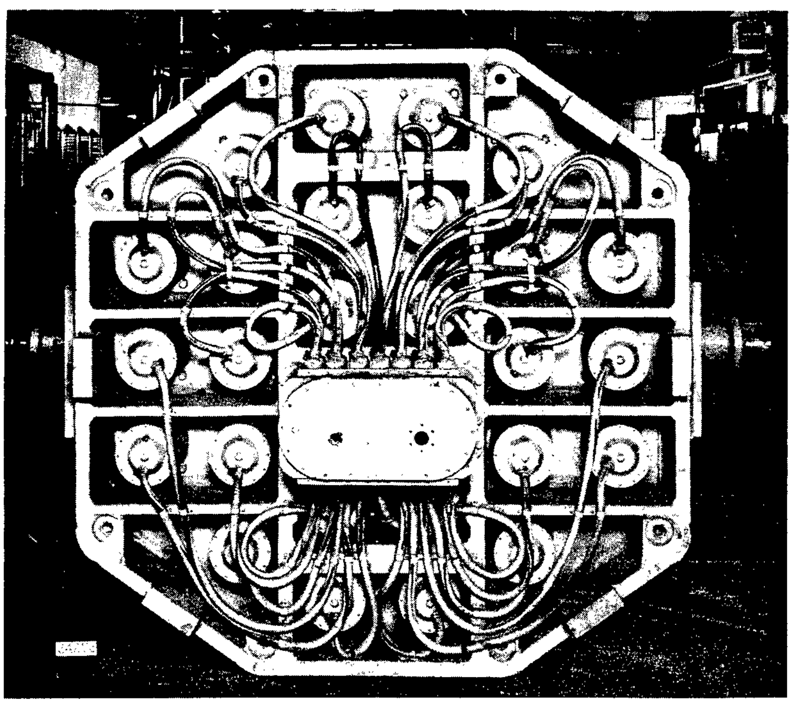


Fig. 10 - Transducer unit of AT-258(XN-1) transducer (with cover off)



(Front)



(Rear)

Fig. 11 - AT-258(XN-1) transducer (front and rear)

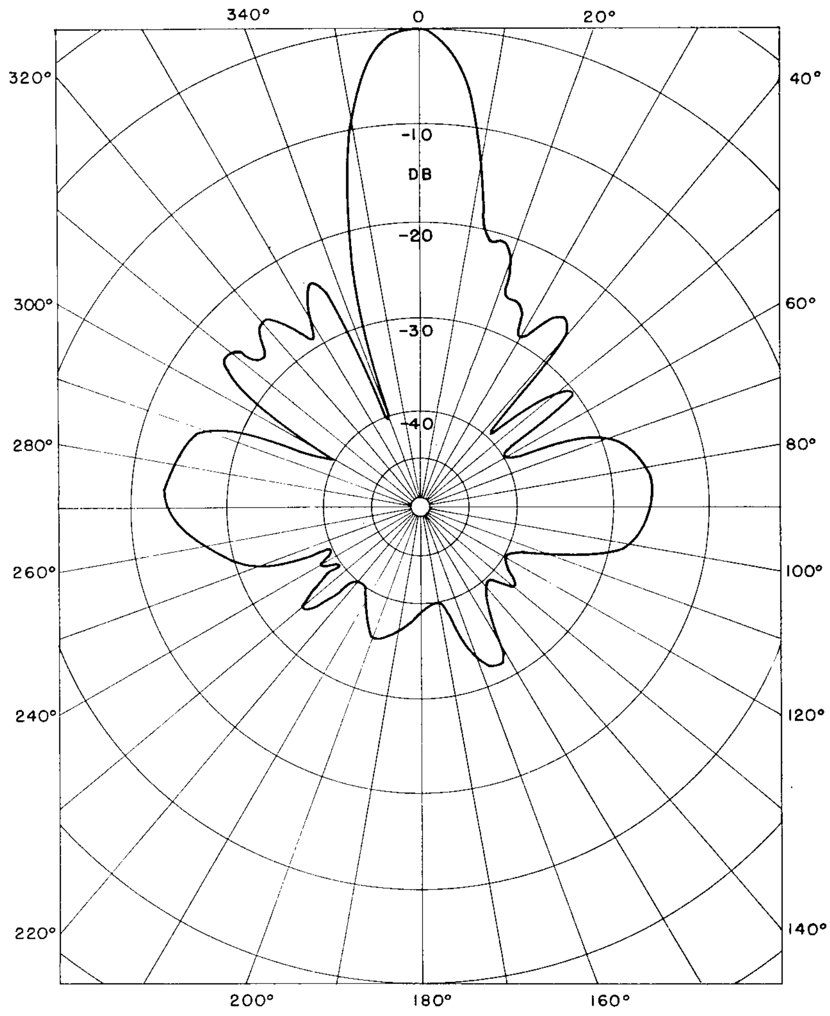


Fig. 12 - Directional response of AT-258(XN-1) transducer in horizontal plane

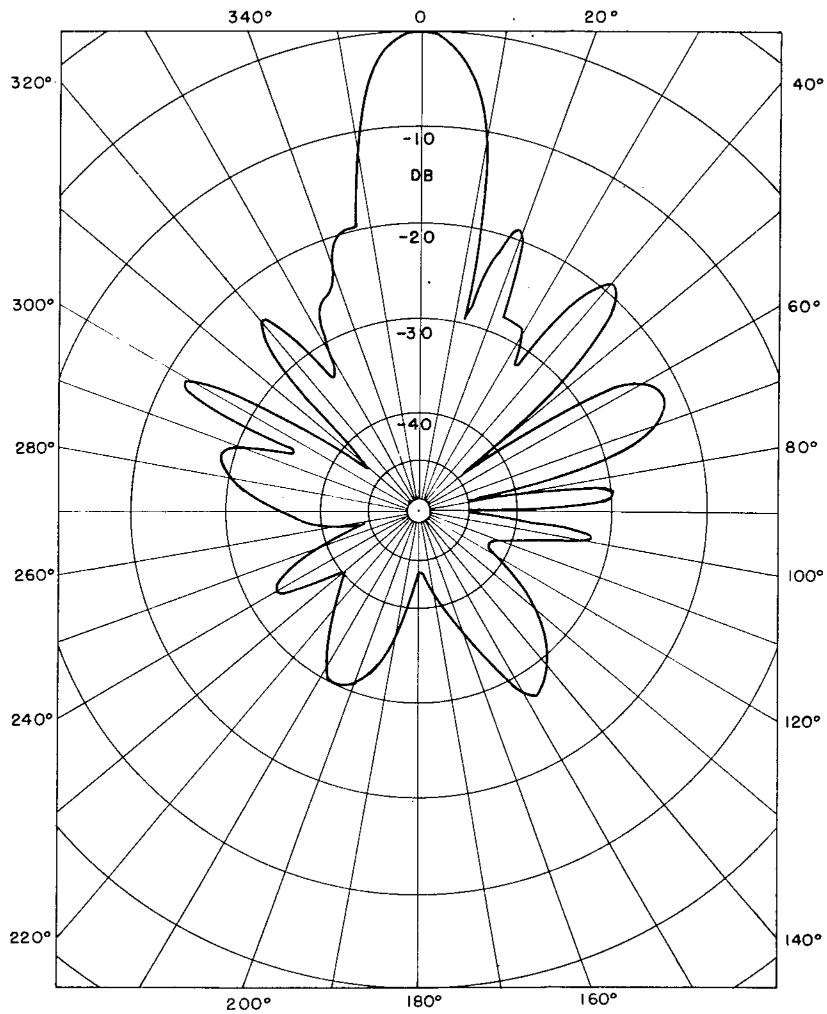


Fig. 13 - Directional response of AT-258(XN-1) transducer in vertical plane

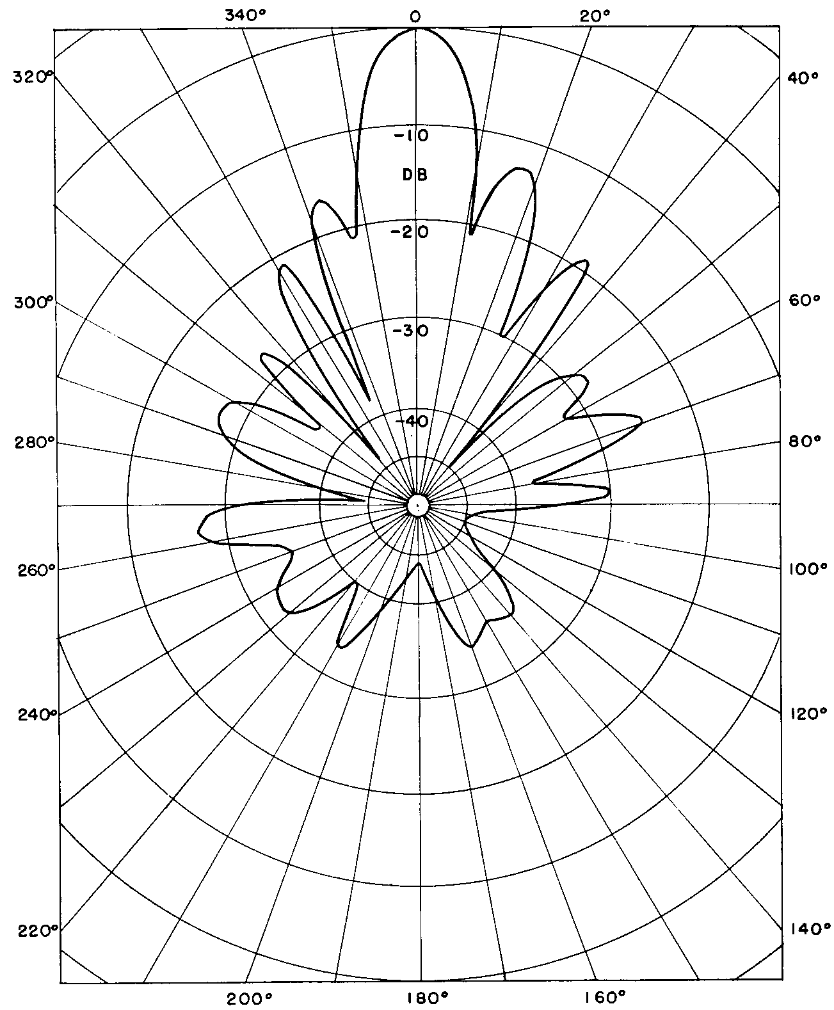


Fig. 14 - Directional response of AT-258(XN-1) transducer in plane 45^0 to the vertical

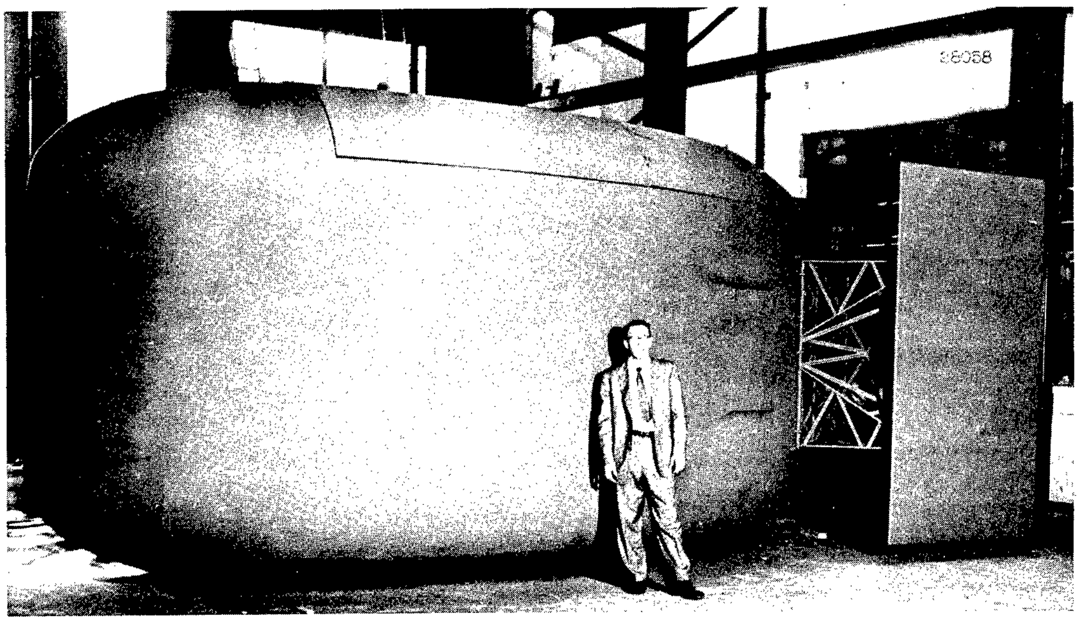


Fig. 15 - Towed body (fish)

Tilt-Train Mechanism — The tilt and train mechanisms are located in the towed body. There are separate mechanisms each with its own prime mover. The tilt mechanism can depress the transducer to any angle between 0 and 20 degrees. The train mechanism can drive the transducer through a 400° arc (centered on 0° relative bearing) as fast as one degree per second (1/6 rpm) and as slow as two minutes of arc (1/30 degree) per second or 1/180 rpm.

Handling Mechanism — The handling mechanism (9) consists of the machinery and auxiliaries necessary to raise and lower the towed body. The essential elements, Figs. 16 and 17, are a drum-type winch, around which the cable is wrapped; and a cradle, which constrains the body until it is ready to be launched into the water. The winch is located on a special platform raised above the main deck. The rotation of the winch is effected by a 15-hp motor.

The cradle consists of a rectangular structure with open framework, the bottom of which conforms to the upper part of the fish. The cradle is constrained to move up and down on rails from an initial position near the upper platform through the center well to the water line. During hoisting, the cradle rests on the upper part of the fish. The combination of cradle restraint, cradle weight, and tension on the cable controls the motion of the towed body. In this way, the pendulum effect is eliminated and water entry is accomplished with a minimum of shock. The ship must be under way when the fish enters the water to permit the fish to align itself with the ship's motion. Similarly, the ship must be in motion when the fish leaves the water in order to permit proper alignment with the cradle. The cradle carries a towing horn which provides a large radius contact for the cable, and thus prevents a sharp bend at the towing point as the cable passes from the drum through the cradle to the fish.

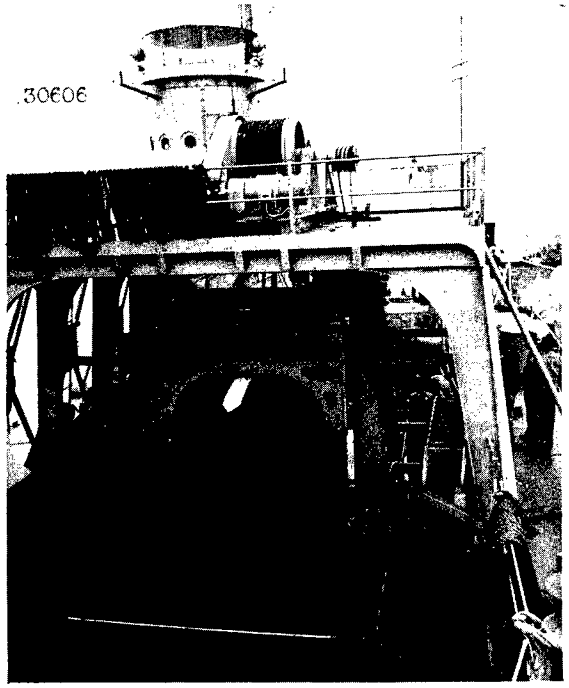


Fig. 16 - Towed-body handling mechanism, front view

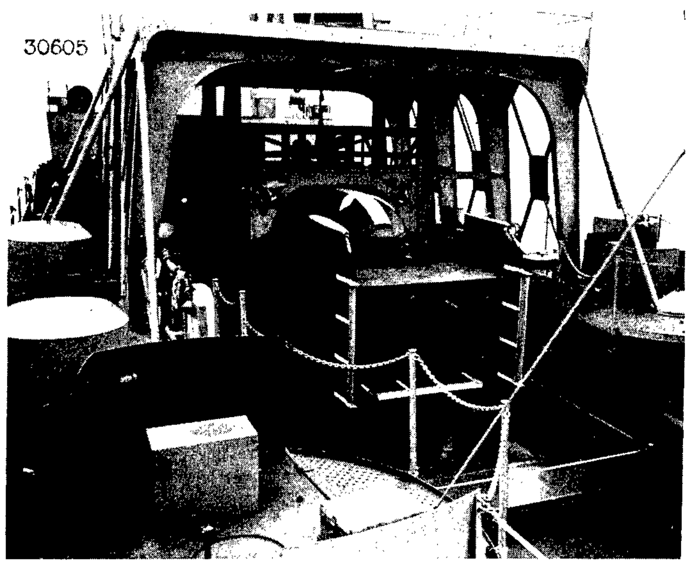


Fig. 17 - Towed-body handling mechanism, rear view

Cable — The special electric tow cable consists of a multiconductor cable surrounded by two oppositely wound lays of galvanized steel wire, 23 wires in the inner lay and 29 wires in the outer lay making a total diameter of approximately two inches. This cable has a calculated breaking strength of 235,000 pounds.

The cable is allowed to stream through the water without any measures being taken to reduce either its drag or vibration. Neither the towing configuration nor the cable noise affects the sonar equipment adversely. Vibration did cause a mechanical breakage of many of the small electrical conductors located toward the periphery, but none of the larger coaxial conductors located about the center broke during cumulative periods of towing totalling several hundred hours at speeds varying from 3 to 10 knots.

A redesign of the cable, which provides more flexible conductors and locates the smaller conductors toward the center of the cable, is expected to alleviate the difficulties which were encountered in the earlier single tow cable.

Transmission Components

The primary function of the transmitter system is to supply electrical power to the transducer at the sonar frequency and this power may be generated in several ways. Since the transducer radiates this power in pulses and since power is energy per unit time, the necessary energy may be generated at low level, stored during the interval between pulses, and radiated at the desired level.

There are alternative methods of storage and of power generation. The conventional storage system uses a bank of capacitors; a mechanical system employs a flywheel. The power may be generated at high level at the sonar frequency and fed directly to the transducer, or a very small signal may be generated by a precision oscillator and amplified to the desired power level as in the conventional electronic system.

In the LRS 2-5 electronic system, the signal is generated in a 5-kc crystal oscillator located in the keyer oscillator unit. This unit also selects the pulse length. From there the signal goes to a high-power amplifier (or driver) and the output of the amplifier goes through the transfer relay to the transducer.

The driver consists of an electronic amplifier utilizing four 3X-2500F3 tubes in push-pull parallel in the final stage, and is powered by a specially designed power supply consisting of a 15-hp dc motor driving an 86-kva 3-phase 400-cycle alternator. A suitable flywheel is used to permit mechanical storage of the required energy. A 3-phase full-wave rectifier and a smoothing filter convert the alternator output to high-voltage dc for the final amplifier plate supply. This driver and power-supply system has been operated at a power output of 35 kw for pulse lengths up to two seconds.

The alternative generation system used in the LRS 2-5 involves direct generation of electrical energy at the sonar frequency in a speed-controlled induction alternator. A diesel engine provides mechanical or prime power, which drives an ac generator. This alternator provides electrical energy directly to the transducer. Frequency control is achieved by means of a mechanism in which the frequency of the alternator output is compared with the frequency of a precision oscillator. The difference in frequencies controls a servo mechanism which increases or decreases the rate of fuel supply. The rate of fuel supply determines the speed of the diesel, which is mechanically coupled to the alternator. The fuel-supply rate therefore determines the alternator speed, and thus the frequency of the ac output.

Details of the diesel equipment and its operation are given in Reference 8. A summary of the equipment characteristics is given in Table 2.

TABLE 2
Characteristics of Diesel System

Output power	40 kw at transformer output terminals, 2000 volts, single phase.
Waveform	Less than 5% distortion.
Frequency	5000 cps, adjustable over a range of +300 and -500 cps and controlled to an accuracy within ±2.0 cycles of the reference frequency.
Transient response	Frequency is stabilized to within ±2.0 cycles of the reference frequency within 0.7 second after step application of full load. Maximum frequency deviation during this step load is approximately 100 cps. Voltage deviation is directly proportional to frequency deviation.
Duty cycle	Three seconds full load, 5 seconds no load. The permissible duration of on time can be increased by addition of forced air cooling of the alternator, transformer, and saturable reactor switch.
Diesel-Alternator	3984 pounds; 40 in. wide × 99 in. long × 48 in. high.
Control Racks	600 pounds; 14 in. wide × 60 in. long × 60 in. high; 24 in. × 72 in. floor space.

The control circuit is shown in block diagram form in Fig. 18. The maximum power output of this particular diesel-alternator combination is about 50 kw. The complete machine is shown in Fig. 19.

The characteristics of the frequency control are indicated in Fig. 20 which is a representative load cycle showing frequency deviation versus time upon the application of a 40-kw step load. The initial load application transient shows a maximum frequency shift of 110 cps, with the major transient subsiding one-half second after the load was applied. During the two-second steady-state period, the maximum frequency deviation is -2 cycles to +1 cycle. This response represents an average curve, since some load cycles may have a steady-state error of less than ±0.5 cps and others may deviate as much as ±2.0 cps.

Some discussion is in order on the use of rotating machinery power supply. Direct generation systems at present use diesel engines for prime power. On submarines, when submerged, there is, of course, no air supply, and so internal combustion engines cannot be used. On ships using low-energy sonar, a diesel system would not be efficient with regard to weight and space. For these reasons, the direct generation systems were not favored in the past. Instead, electronic drivers were developed and employed.

In electronic drivers, electronic tubes with banks of capacitors are used to generate pulses of high power. In order to generate this power, these tubes require high-voltage dc. As the power requirements of the sonars increased, the size of the capacitor banks increased and so did the voltage required to operate the power tubes. To develop power electronically at the 10-kw level, about 6 kv is required. As a consequence, the weight and space of the storage system and power supply increased to a point where it became desirable to experiment with other forms of signal generation, power supply, and storage.

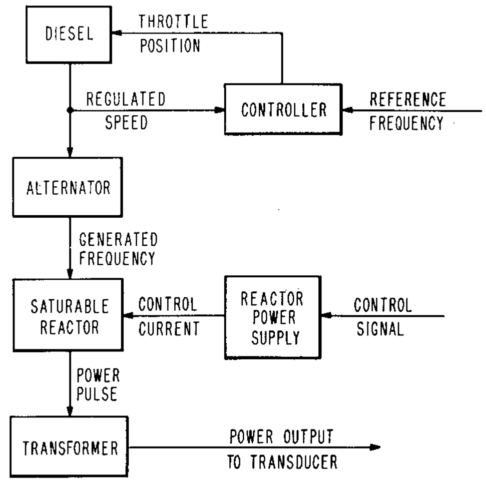


Fig. 18 - Block diagram control circuit of diesel-alternator

In the LRS system, two changes were made:

a. The bank of capacitors was replaced with a mechanical storage system in the form of a rotating flywheel operating with a motor generator plus a rectifying unit.

b. Direct generation at sonar frequency was developed. In the case of the flywheel used with the motor generator set, kinetic energy equal to $1/2\ Iw^2$ is imparted to the flywheel during the charging interval in accelerating it from rest to an angular velocity, w. In the discharge or pulse period, some fraction of this kinetic energy is available for conversion to electrical energy while the flywheel is decelerated. This subject is discussed in some detail in Reference 10.

Sonars with energy requirements equivalent to that of the SQS-4 are the largest in which banks of capacitors are reasonably efficient. In systems such as the LRS 1-10 and LRS 2-5 mechanical storage used with a motor-generator set to power electronic tubes is both feasible and efficient.

Problems encountered in the employment of direct generation systems, particularly the frequency transient at the time of load application, preclude a decision at this time as to the competitive standing of such systems.

Reception Components

Receivers — Two receivers are used in this equipment, a conventional narrow-band receiver and an SSI Receiver.

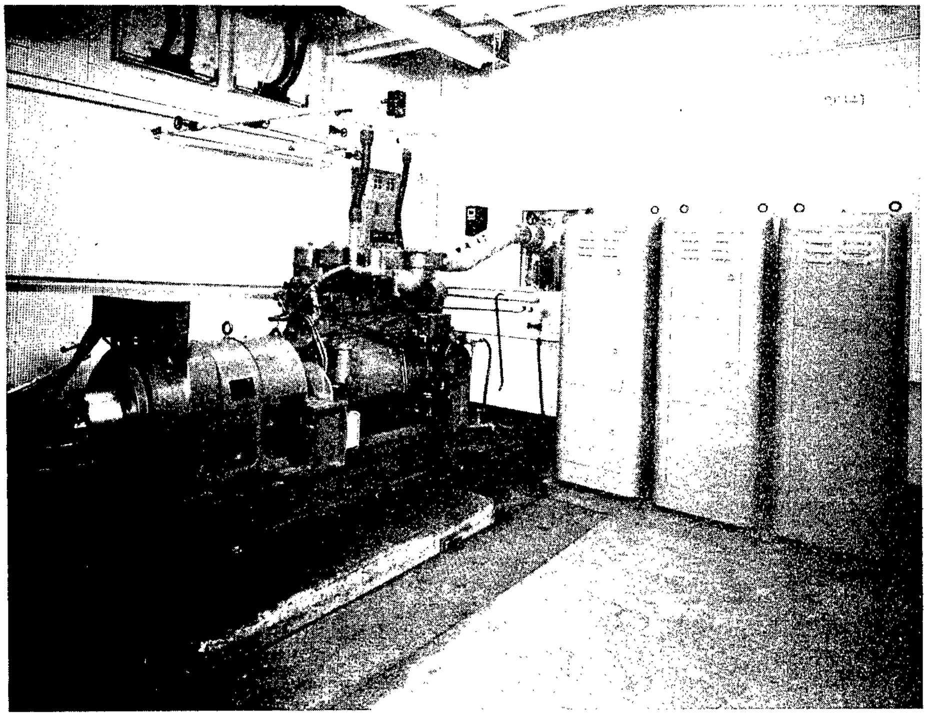


Fig. 19 - Diesel-alternator

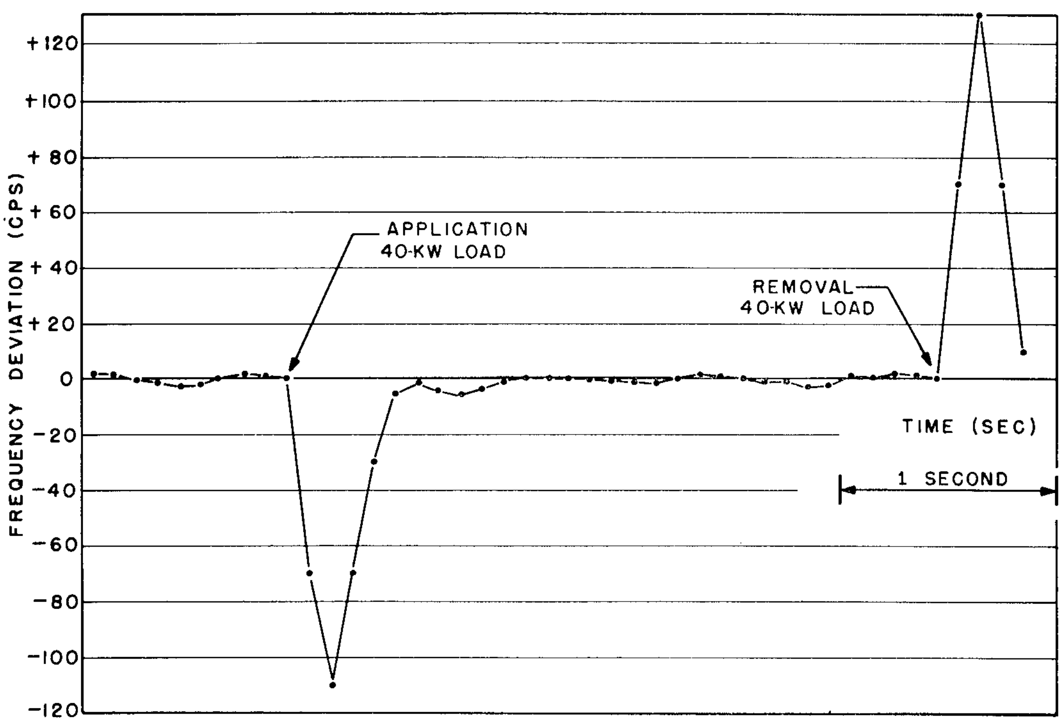


Fig. 20 - Frequency-control characteristics of diesel-alternator

The narrow-band receiver is a high-gain unit which processes input signals to present sonar information at audio frequencies. The general design pattern of this receiver resembles that of a tuned radio frequency receiver, since it possesses two tuned-input high-gain stages, a local beat oscillator and an audio output stage. Five different input center frequencies can be selected. These vary in 25-cps steps from 4950 to 5050 cps, inclusive. In addition, three different tuned bandwidths are provided, centered about the selected frequency. The bandwidths are 25, 50, and 100 cps. The audio output frequency is nominally 800 cps.

The SSI Receiver (described in detail in Reference 11) is a dual-channel phase-sensitive receiver which processes received sonar signals to yield an output indicative of the angle of arrival of the signal. In addition, certain advantages are realized in signal-to-noise ratio and other factors.

Displays — A display console houses displays which present the results of signal reception and signal processing. Two displays are employed in LRS 2-5, an A-scan and an SSI display, the latter essentially a B-scan. Five-inch cathode-ray tubes are used for both displays.

An A-scan shows signal amplitude versus range. Range is presented on the horizontal axis and is a function of time. Amplitude is presented as a vertical displacement.

The B-scan presents signal amplitude, range, and bearing deviation angle. Range is a vertical displacement proportional to time. Bearing deviation (from transducer heading) is presented as a horizontal displacement and is proportional to the phase difference between the signals in the two halves of the transducer. Signal amplitude is presented as spot brightening.

The A-scan display requires a saw-tooth-current drive for horizontal deflection and a step-current drive for vertical deflection. The SSI display requires a saw-tooth-current drive for vertical deflection, a 2000-cps saw-tooth-current drive for horizontal deflection, and signal pips for spot brightening.

The display console contains two compartments, designated as the upper and lower. The lower compartment houses the two cathode-ray tubes including tube shields. The A-scan crt is mounted above the SSI crt. The controls most frequently required by the operator are mounted on the left panel of the upper compartment.

Program Control

To operate the transducer in a search pattern, the desired range and a bearing-search program must be selected. These two factors are controlled by the program-control unit.

Range control is governed by the pulse repetition rate. This rate may be selected in multiples of 12, from 12 to 120 seconds, to give effective ranges of 10 to 100 kyd, in 10-kyd steps; with the 70- and 90-kyd steps omitted. The transmitted pulse length is controlled in the keyer oscillator unit. However, the transmitted pulse is initiated by a keying switch in the program-control unit.

The training program can be controlled either manually or automatically. In "manual control," the train angle is controlled by a slewing motor operated with a panel switch. This motor drives a commutator transmitter which, in turn, drives a synchro used as a motor to position the transducer. In "automatic control," the search is about a given bearing through a given arc at a given rate. Thus, three quantities must be selected: the center of search arc, the search arc, and the search rate. The "Center of Search Arc" dial is set on the desired bearing. The Search Arc is infinitely variable from 20 to 180 degrees. The control knob marked "Search Arc" is manually set and is graduated to show every 10 degrees from 20 to 180. Appropriate stops are incorporated at the extreme positions. The Search Rate is based on the train angle between successive pings. This can be selected manually at 4, 8, or 12 degrees per ping.

In tilt, the transducer can be depressed by remote control between the limits of 0 and 20 degrees (see Tilt-Train Mechanism).

Research Auxiliaries

Monitors – The function of the monitor system is to obtain quantitative measures of the behavior of the sonar system both on transmission and reception. The monitor can check the operation of the electronics separately from that of the transducer.

On system transmission, the monitor measures acoustic pressure. In this way, it can check I_1, and when the pressure is plotted versus the rotation of the transducer, the monitor can also check the beam pattern. In beam-pattern determination, it is advantageous to use a continuous signal. To avoid using the high-power system driver and yet to provide a signal level sufficient to override the background noise, the monitor system contains a 50-watt low-power driver which may be used to drive the main transducer.

In addition, the monitor can check the waveform of the output of the transducer, and the voltage output and waveform of the drivers.

To check system reception, the monitor can provide a calibrated signal into the water through the hydrophones, and the output of either the basic or experimental receivers can be compared with predetermined normal operating conditions. The monitor can also provide a calibrated signal directly to the receiving system to calibrate only the electronics parts of the system.

The monitor can provide a calibrated signal to a low-power test driver, for the purpose of testing the whole receiving system.

Data Recording System – The objective of the data recording system is to permit pertinent data to be recorded in the field during test and then to be analyzed at greater length on the ship or under more favorable conditions in the Laboratory. The data which are recorded on a field trip consist of "raw data" (the unprocessed signal output of the combining unit) and the telemetered information relative to ship's course, transducer heading, and transducer-tilt angle. Provision is made for simultaneously recording pertinent remarks or notations through a microphone.

The recorder used in this system is a standard 7-channel commercial tape recorder. The inputs to the seven recording amplifiers and the outputs from the seven playback amplifiers are connected to a jack panel so that various signals may be easily connected or disconnected.

Channel 1 is reserved to record additional data (such as target aspect angle) at a later date without disturbing information already recorded on the other six channels. Voice can be recorded on Channel 2. Two-channel output of the combining unit is fed via the jack panel to Channels 3 and 4. A 400-cps signal is recorded on Channels 3 and 4 during the transmitting time. This signal is used to synchronize displays or other devices as the tape is played back. A continuous 400-cps signal is recorded on Channel 6. Channels 5 and 7 are used to record a continuous 400-cps signal which has a phase difference from the signal on Channel 6. This phase difference can be made proportional to ship's course, transducer heading, or transducer-tilt angle. This information is fed to the jack panel via a 60-cps synchro follower mechanically coupled to a 400-cps control transformer which acts as a phase shifter. Any two of the above signals can be recorded at one time.

The information recorded on all the channels can be played back and analyzed on the ship if desired; but the information is usually analyzed at the Laboratory, where the analyzing equipment is more elaborate and more time is available.

Transient Equipment

Various devices for special sonar purposes were tested from time to time. These will be reported separately when significant results are obtained.

EQUIPMENT PERFORMANCE

The objective of the phase of the program here reported on was to design and develop a system which fulfills the preliminary design requirements and to learn how to handle it for research purposes.

This equipment was employed as a primary research tool in the 5-kc part of the LRS program. The following observations are made regarding the system performance in the research program.

Two transducers were successfully built and operated. The barium-titanate transducer was more efficient and easier to handle than the magnetostrictive transducer.

Rotating machinery as a source of electrical power for sonar transmission was employed with positive success. The flywheel, used in conjunction with a motor-generator set plus a rectifying unit, was a reliable and convenient mechanism for storing energy. Together they generated dc power at high voltage to operate the electronic driver. In the LRS 1-10 system, the motor generator set and flywheel combination had been used only enough to demonstrate its feasibility; in the LRS 2-5 system, the mechanism was used operationally.

The system for direct generation of ac power at sonar frequency was shown to be feasible.

The handling method used proved feasible in slow-speed experimental operations. The ready access to the transducer afforded by this method of handling proved very useful and convenient. The primary problem encountered was the failure of conductors in the electrical cable. In laboratory tests a redisigned cable has indicated a great improvement in this respect.

The use of duplicate electronics and ample working space resulted in a saving of ship operating time.

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APPENDIX A
Definition and Discussion of Terms

In Reference 4, it was found convenient to use an expression E_1 as a significant characteristic of a sonar system. The echo excess, E (without subscript), was defined as the echo excess in decibels of the echo level over the level required for 50% probability of detection. The quantity E_1 is defined as the hypothetical echo excess at the range of 1 yard. The two terms are related by the equation

$$E = E_1 - \text{losses} \qquad \text{(A1)}$$

At the range at which the losses equal E_1, E vanishes. At that range, there is a 50% probability of detection.

The delineation of E_1 is contained in the following equation.

$$E_1 = (I_1 + T) - (N - \Delta + \delta) \qquad \text{(A2)}$$

where I_1 = intensity at 1 yd from the source

T = target strength

N = omnidirectional noise in a 1-cycle band

Δ = directivity index at reception

δ = recognition differential, i.e., the ratio of signal to noise in a 1-cycle band out of the transducer for 50% probability of detection.

The value of E_1 as a characteristic function lies in that it takes into account the radiating capabilities of the equipment (I_1 and Δ), the conditions under which it will be used (T and N), and the effectiveness of the signal processing auxiliaries (δ).

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NAVY-DPPO PRNC. WASH., D.C.