NRL Report 6822

A New NRL Acoustic Research Tank Facility

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NAVAL RESEARCH LABORATORY

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CONTENTS

ABSTRACT

A new Acoustic Research Tank facility designed for precise acoustic measurements on, and the study of, scaled models of sonar transducers, arrays, and related underwater devices has been installed at the Naval Research Laboratory.

The tank is constructed of cypress wood, is 30 ft in diameter and 22 ft deep, and is enclosed in a cinder block house, which contributes to the maintenance of the controlled environment necessary for accurate measurements.

Acoustic measurements are made using an electronic console designed to accommodate two channels of continuous-wave or pulsed-signal excitation. All components in the console are of the latest design and are matched and integrated to provide an accurate, highly flexible, and manually convenient measuring system. Three pieces of instrumentation specially designed for the NRL tank are (a) a triaxial hydrophone positioning and scanning system, (b) a multiaxial underwater rotator (for use with a directivity index computer), and (c) a vector component computer that operates on pulsed signals.

PROBLEM STATUS

This is an interim report on one phase of the problem; work is continuing.

AUTHORIZATION

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A NEW NRL ACOUSTIC RESEARCH TANK FACILITY

INTRODUCTION

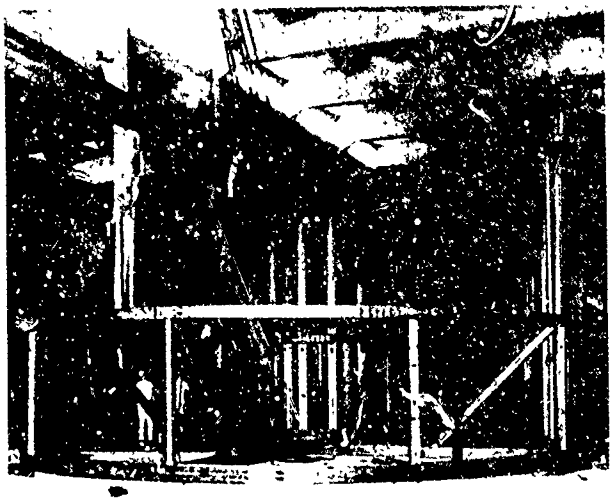
Over the years, experimental acoustic measurements at the Naval Research Laboratory have been made in small indoor water tanks designed for particular problems. Generial acoustic measurements and transducer calibrations were made either at the NRL sound barge located at a spot on the Potomac River where the water depth was approximately 20 ft or at the Underwater Sound Reference Laboratory at Orlando, Florida. Special tests on large transducer arrays or acoustic devices were made at other, more suitable, government facilities, such as Lake Pend O'reille in Idaho, or at sea. The gassy and extremely polluted condition of the Potomac River in recent years has made the local sound barge obsolete and has necessitated the establishment of a more suitable, modern, and extensive transducer calibration facility in New York State at Lake Seneca, where measurements are made at a water depth of approximately 600 ft. This still-expanding facility was designed for tests on large and heavy sonar transducers and equipment.

An NRL need for a fairly large and well-implemented water tank that could be used as an acoustic research tool has recently been fulfilled by the construction of an Acoustic Research Tank facility located in Building A59. The tank and associated electronic instrumentation were designed to make precise acoustic measurements under controlled conditions on applied research experiments in support of a new program. The program involves solutions of acoustic problems through mathematical modeling, which provides answers based on exact analogies or theoretical assumptions, and through experimental verification of these answers by data obtained on scaled physical models of acoustic devices tested in the tank.

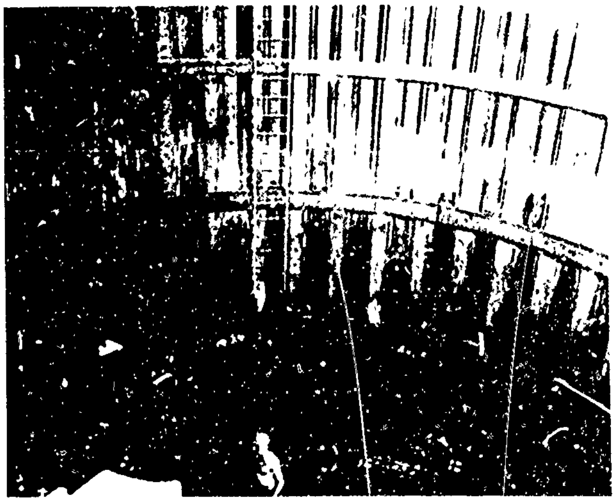
GENERAL DESCRIPTION OF FACILITY

The Acoustic Research Tank facility is housed in a cinder block structure or "tank room" erected in a much larger building designated as Building A59. The tank room encloses a cypress wood tank, which was erected in a 40-ft-diameter, 19-ft-deep pit. Dimensions of the tank are 30-ft in diameter, 22 ft in height, and 3-in. wall thickness. The pit walls are of interlocked steel piling, and the base is a reinforced-concrete slab 18 in. thick. Strips of cork placed between the bottom of the tank and the pit base serve to isolate the tank from groundborne vibrations. The strips are 6 in. wide and 3 in. thick, and extend along the full length of the joists supporting the bottom of the tank. A 5-ft-wide "surround" between the tank and the pit walls isolates the tank sides from ground vibrations and provides adequate space for tank inspection and maintenance. A walkway over the "surround," at floor level, extends the floor to within 1/2 in. of the tank wall. The open-top tank, which extends approximately 3-1/2 feet above floor level, is unlined and was designed for pulsed-signal measurements.

Of the different woods available for tank construction, cypress was selected because of its superior aging and sound-absorption properties. The characteristics of wood, concrete, and steel tanks may be found in a number of reports and will not be discussed here.

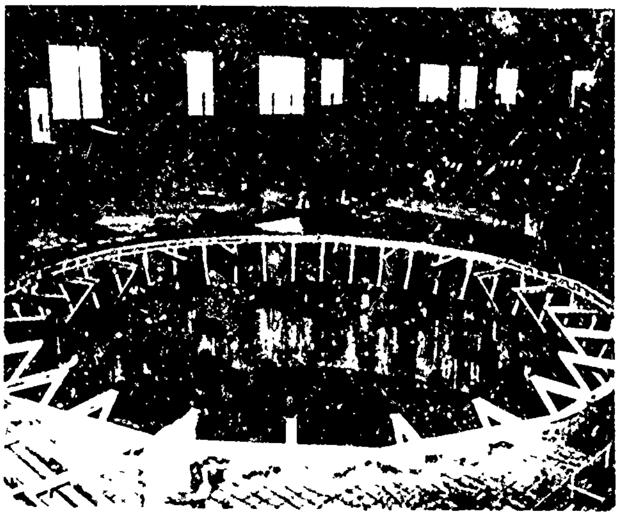


(a) Driving steel piling used to shore up the pit sides



(b) Interlocked piling in place

Fig. 1 - Construction of NRL Acoustic Tank Facility



(c) Completed pit

(d) Completed tank room showing tank, walkway, console, and water filtering tanks

Fig. 1 - Construction of NRL Acoustic Tank Facility (Cont'd)

Figure 1 shows four views of various stages of construction of the tank facility. The upper left view (a) shows the driving of the steel piling used to shore up the pit sides. The view below (b) shows the interlocked piling in place and the steel-rod-reinforced base ready for the pouring of concrete. The upper right-hand view (c) shows the completed pit in which the wooden tank was erected. Brackets along the top of the pit are for supporting the floor-level walkway around the tank. The last view (d) shows one end of the just-completed tank room and portions of the tank, walkway, electronic console, and water filtering tanks in the background.

Figure 2 is a close-up view of the Bowser Model 610-D-42 water filtering unit with slurry tank (S). Seven plastic filtering elements with an area of 42 square ft are used in the filtering tank. The filter flow rate is 42 gallons per minute. The small tank contains a slurry used for precoating the filter elements with a layer of diatomaceous earth, which improves the effectiveness of the filtration and extends the time between cleaning or back-flushing the filter elements. Water purity, from the standpoint of bacterial contamination, is maintained by chlorination with calcium hypochlorate of the standard grade used in swimming pools but at a lower concentration level of 0.6 ppm. Water clarity is maintained by a swimming-pool, water-surface skimmer, which is used as necessary to remove airborne dust particles and contaminants from the water surface. An underwater vacuum cleaner with a long, aluminum, tubular handle is used for periodic cleaning of the tank bottom. Since contamination in an acoustic tank is much less than in a swimming pool, a water filtering system for a tank is adequate if the filtering capacity is approximately one-tenth of that required for a swimming pool of equal volume.

Personnel walkways across the tank and the supporting girders are shown in Fig. 3. No structure is supported by the top of the tank. A view across the center portion of the tank and across the test well formed by the two girders which support the carriage runways is shown in Fig. 4. The carriage shown in this view is for supporting model transducer arrays, which may have a maximum size as large as a 5-ft cube and weigh as much as 3000 pounds. One of the two overhead monorail cranes, each of 1-1/2-ton load capacity, is shown supporting a lightweight model of a transducer array. A top view of the two carriages, which are normally mounted on the runways across the tank, is shown in Fig. 5. The guard chains and posts have been removed from the personnel walkway in the foreground to provide picture clarity. The transducer carriage is shown at the left. Arrays or transducers may be supported at various water depths by means of pinned sections of stainless steel round stock or rods fitted with adjustable collars that span a groove cut in the platform of the supporting carriage as shown. During measurements, the rod shown at the edge of the carriage is moved to the far end of the slot, where the collar locks into a circular recession. The cylindrical housing resting on the carriage is a rotating head that slips over the upright section of rod and is used to rotate a transducer through an angle of 360 degrees during beam pattern measurements. The carriage at the right in Fig. 5 is a triaxial hydrophone positioning and scanning system controlled from the main electronic console. A detailed discussion of this system is given in another section.

An overall view of the side of the tank room containing the instrumentation console and office spaces is shown in Fig. 6. The tank room is maintained at a constant temperature of 75°F and a humidity of 50% by a combination heating and air conditioning system installed outside the room.

PROGRAM FOR ACOUSTIC RESEARCH TANK

The long-range program for using the Acoustic Research Tank is centered on studies of scale models of acoustic devices. These will be studied for confirmation of (a) theory, (b) analysis of mathematical models, and (c) design optimization. These studies will include:

Fig. 2 - Bowser Model 610-D-42 water filtering unit with slurry tank (S)

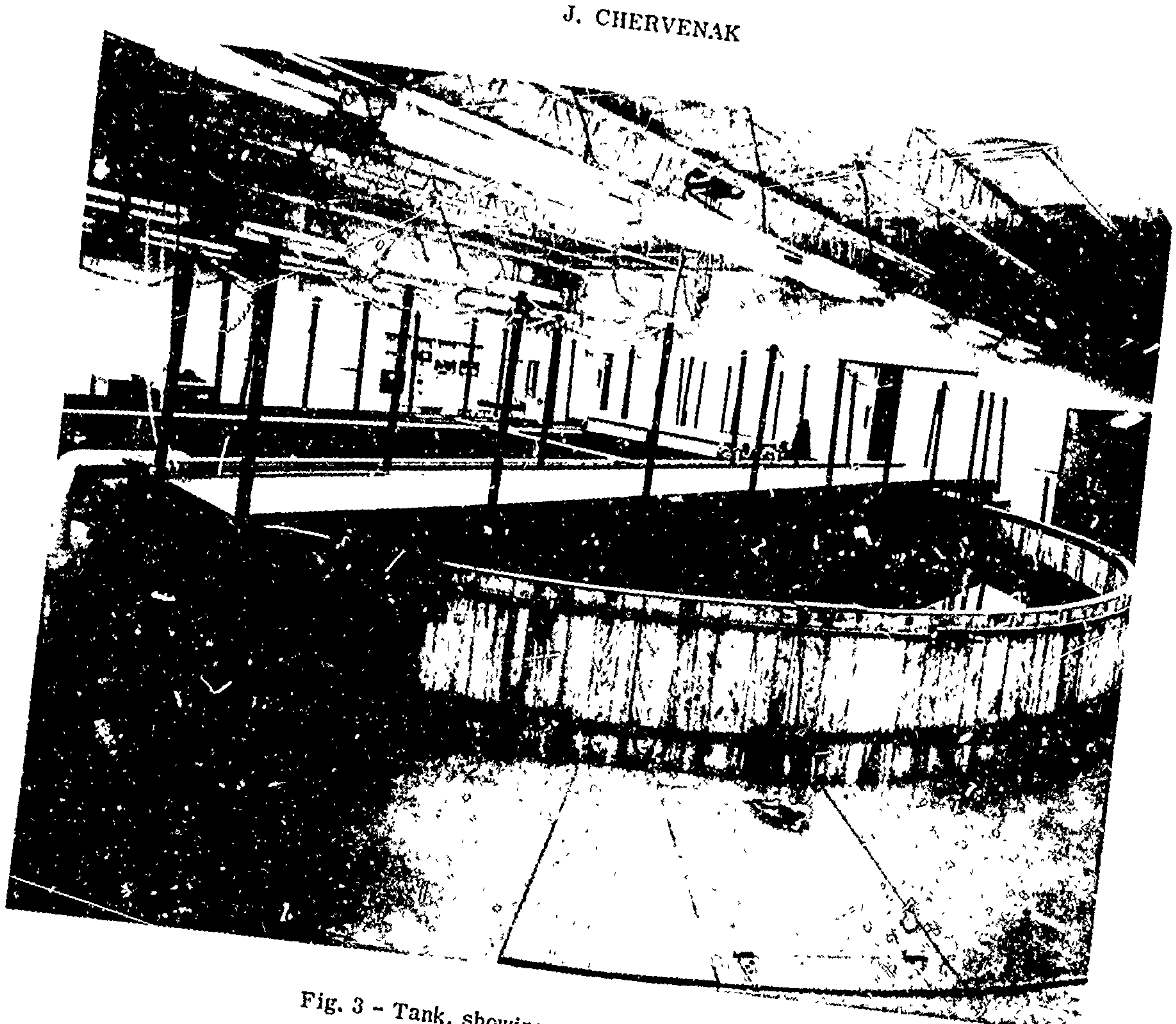


Fig. 3 - Tank, showing personnel walkways

1. Acoustic · eractions between transducers of a multielement array
2. Directional biplanar arrays
3. Surfa-e velocity of radiating piston
4. Piston-baffle combinations
5. Near field/far field techniques
6. Scattering from bodies of similar shape
7. Radiation from zones, zonal spheres, spheroids, etc.
8. Transmission through layered media
9. Transient radiation (indicial admittance)
10. Radiation from multipoles

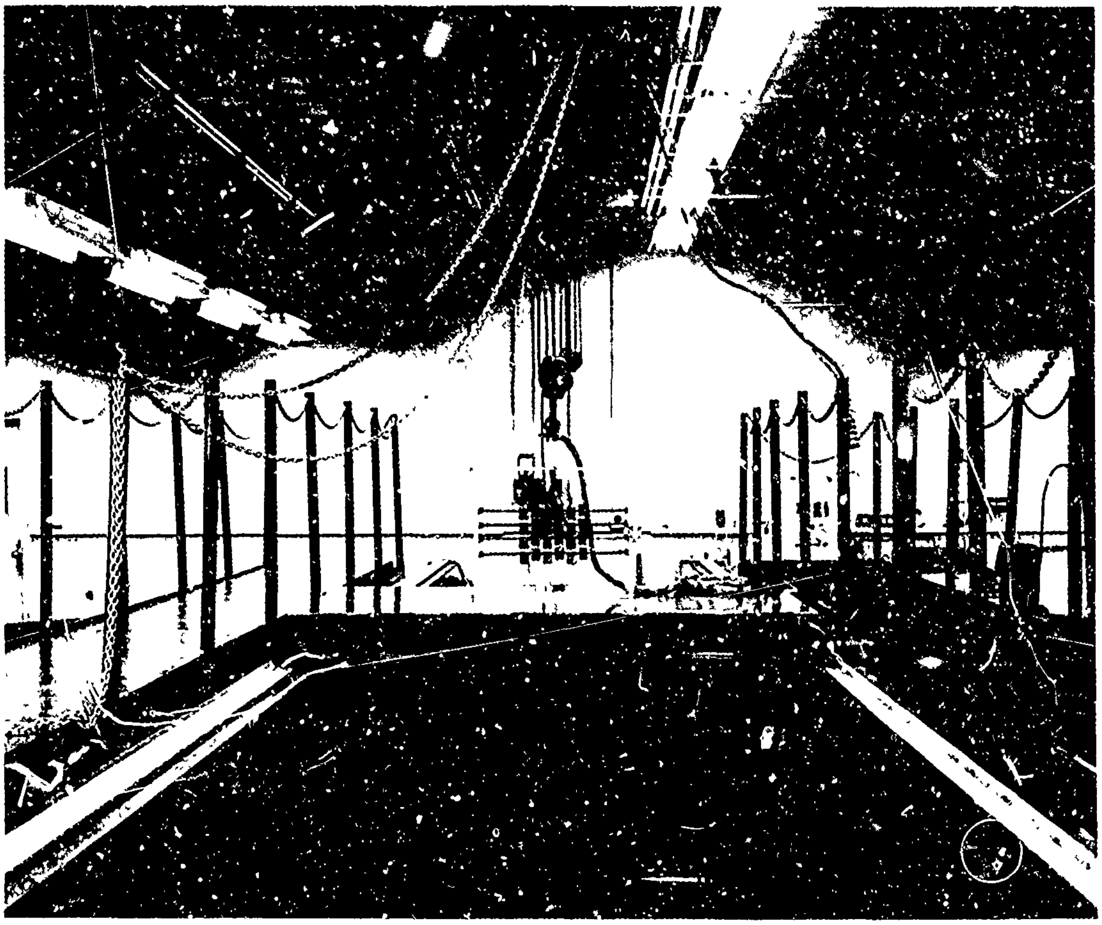


Fig. 4 - View across center of tank showing test well

11. Random fields

12. Pressure release materials

13. Very-high-frequency radiation (re acoustic image theory)

14. Broadband transducers

15. Impulse transducers (underwater sonic boom)

16. Holography techniques in acoustics

17. Feedback circuitry for phase and velocity control of radiators in a multielement array.

The problem listing, as shown, does not constitute a priority sequence. Urgent problems, listed or unlisted, may receive attention as soon as an appropriate model of the transducer array or device is available for initiating the study.

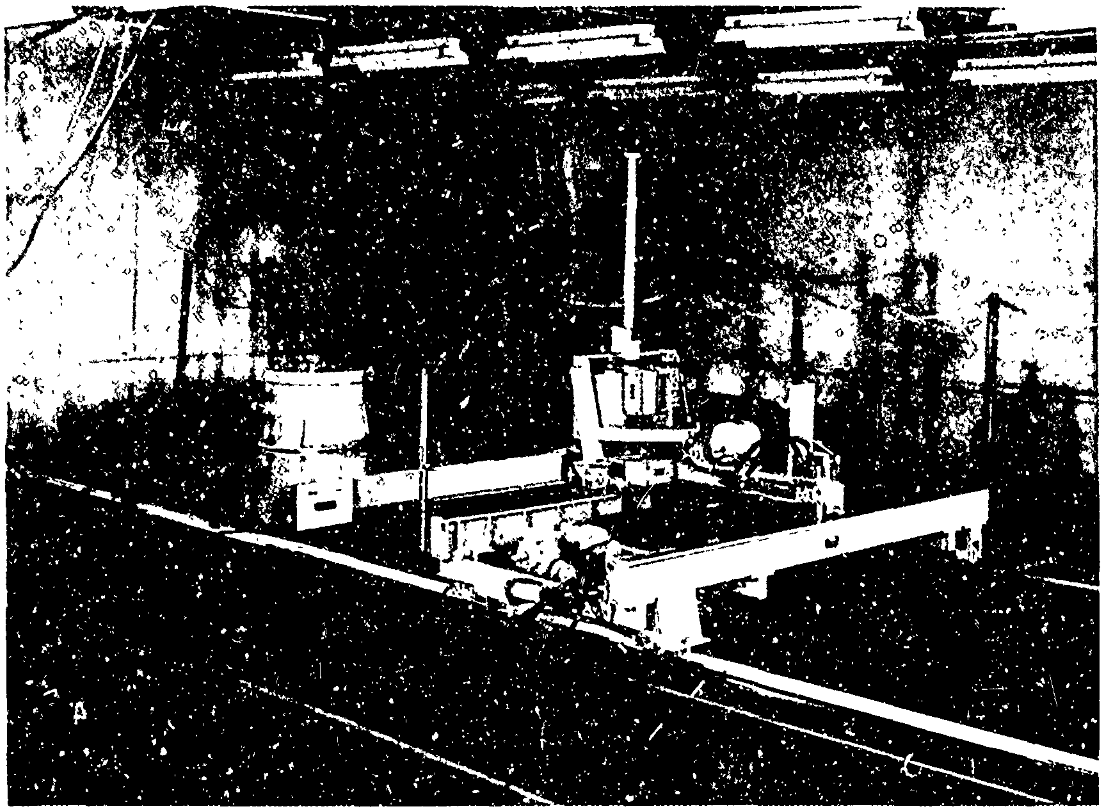


Fig. 5 - Test carriages, showing transducer carriage at left. Carriage at right is a triaxial hydrophone positioning and scanning system.

ELECTRONIC EQUIPMENT

General

The electronic console for acoustic measurements was designed by Scientific Atlanta, Inc., to accommodate two channels of continuous-wave or pulsed-signal excitation. Since the tank is unlined, pulsed signals are used to eliminate reflections. Console components consist of various makes of items and special items of Scientific Atlanta design, all matched and integrated to provide an accurate, highly flexible, and manually convenient measurement system. Although the acoustic tank may be used for measurements extending from 3 to over 100 kHz, the operating frequencies for model transducer arrays and devices will generally be below 50 kHz and mostly in the 5- to 20-kHz frequency range where the scaling factors involved in making miniature models will present fewer dimensional problems than at the higher frequencies.

Figure 7 shows a picture of the electronic console taken before the last of the six cabinets of instrumentation was installed. The first four cabinets, from left to right, generally provide adequate instrumentation for the usual tank measurements involving calibration, transmitting or receiving response curves, admittance or impedance values, beam patterns, etc. The NRL requirements for measurements in the Acoustic Research Tank include two additional cabinets of instrumentation. Both of these cabinets were designed to NRL specifications. The fifth cabinet from the left in Fig. 7 contains instrumentation for the automatic hydrophone positioning and scanning system. The sixth and

Fig. 6 - Instrumentation console and office spaces

last cabinet (not installed at the time the photograph in Fig. 7 was taken) contains instrumentation for programming and computing the directivity index of complex acoustic pressure fields that must be reconstructed from a series of beam patterns, and provides controls for array orientation and rotation necessary to obtain the patterns.

The electronic console consists of the items of instrumentation listed below with their formal Scientific Atlanta, Inc., designations.

Series or Model No.	Nomenclature
Series 111	Transmitter Signal Gate
Series 1114	Frequency Tracking Servo
Series 1118	Pulse Timing Generator
Series 1153	EI Normalizer
Series 1155B	EI Sampler
Series 4100	Positioner Control Unit
Series 5115C-3	Rotating Head or Positioner
Series 5103-1	Positioner
Series 1112	Receive Signal Gate

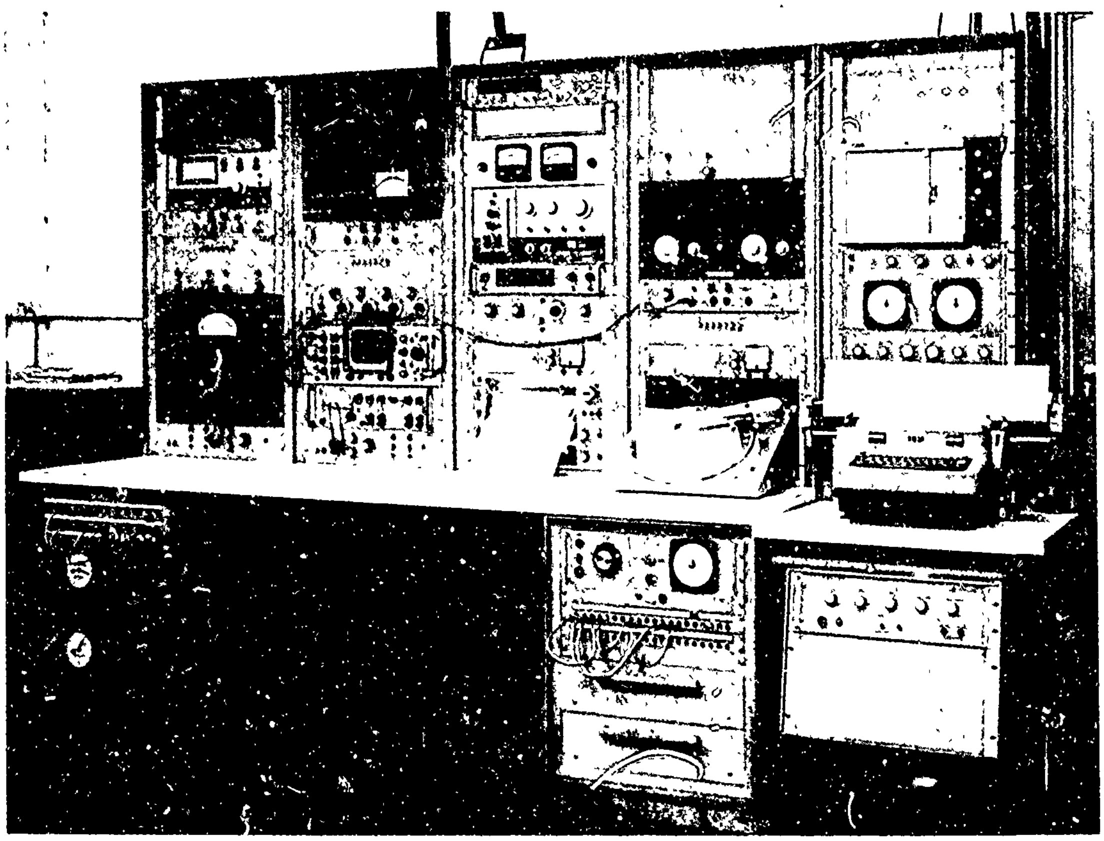


Fig. 7 - Electronic console, near completion

Series or Model No.	Nomenclature
Series 1520	Rectangular Coordinate Pattern Recorder
Series 1530	Polar Pattern Recorder
Model 4111	Position Control Unit, (y axis)
Model 4114	Position Control Unit (xz axis)
Model 2004	Positioner Programmer
Model 4422-66	Indicator
Model 82143A	Recorder Control Unit
Series 1800	Radiation Distribution Printer (RDP Unit)
Model 2611	Pattern Integrator
Model 2621	Spherical Integrator Converter Unit

Close-up views of all sections of the instrumentation console are presented in Figs. 8 through 13 to show front panel details, model numbers, arrangement, and names of components in the racks. A simplified block diagram (Fig. 14) shows how the principal components of the console are interconnected. Circuit flexibility is provided by plug-in connectors for including or excluding instruments as required by the measurements being made. For example, the oscillator shown in the block diagram may be either the special-purpose General Radio wave analyzer (Type 1900A) shown in panel 1 of Fig. 8 or the Hewlett-Packard function generator (Model 203A) shown in panel 2 of the same figure. The latter oscillator has a built-in phase shifter and provides a reference-phase output and a variable-phase output, which is used in dual-channel, biplanar array tests. Figure 8 shows how the dial of each oscillator is connected to a drive unit that sweeps the frequency over a selected range during current or voltage response measurements.

Information Flow

The sequence of signal travel in the block diagram of Fig. 14 shows that the output of the oscillator is simultaneously applied to the transmitter signal gate or gates and through a digital frequency counter to a frequency tracking servo. When charts of frequency characteristics are plotted on the rectangular plotter shown in the first panel of Fig. 9, the chart drive control is received from the frequency tracking servo. This unit consists of a precision frequency-to-analog voltage converter followed by a high-speed potentiometer balance servomechanism. It converts a variable-frequency input from the digital counter into a synchro rotation proportional to the input frequency. The recorder chart scale can be expanded about any frequency to give a 20-in. chart cycle for either 1/5 or 1/10 of a frequency decade.

Inputs to the transmitter signal gates in the dual-channel outputs, shown in the block diagram, consist of two signals: an oscillator or drive signal and a timing pulse generator or control signal. The pulse timing generator provides the pulses required to operate the gates and detectors in the measurements system. Controls are provided to adjust the repetition rate, transmitter and receiver gate widths, and receiver gate pulse delay. Alternative modes of operation permit either remote or manual triggering of a single pulse. For all modes of operation, the unit can be synchronized to a test oscillator gating an integral number of cycles per pulse. The transmitter signal gate converts the signal oscillator input into pulses that retain the original waveform. An emitter-follower transistor buffer amplifier in the transmitter signal gate provides an ungated output for driving a digital frequency counter. Gating action can be stopped by a front panel switch so that a continuous output signal is available at the gated-output connector of each unit. The input and output signals, and the switching signals, can be monitored at test jacks on the front panel.

The output of the transmitter gate passes through an attenuator and enters an EI normalizer. The normalizer is a closed-loop servo system used to maintain the output voltage or current of a power amplifier at a constant, preselected level. Regulation is independent of power amplifier load, gain, or input voltage. The power amplifier output may be balanced or unbalanced, and its output voltage or current may be cw or pulsed sine wave. The output of the power amplifier is sampled directly for voltage and by a current transformer for current. The sample is amplified, detected, and summed against a fixed reference voltage. The resultant error voltage positions a log potentiometer which controls the power amplifier input signal. A unique detector circuit allows drift-free operation at low pulse-repetition frequencies. This is impossible with conventional detector circuits, because of leakage that occurs in circuits storing charges between pulses. The detector in the normalizer charges a storage capacitor, and the discharge of the storage capacitor is controlled to the extent that it matches the servosystem velocity response and is therefore of sufficient duration to let the servosystem

Fig. 8 - Desk-top racks 1 and 2 of console

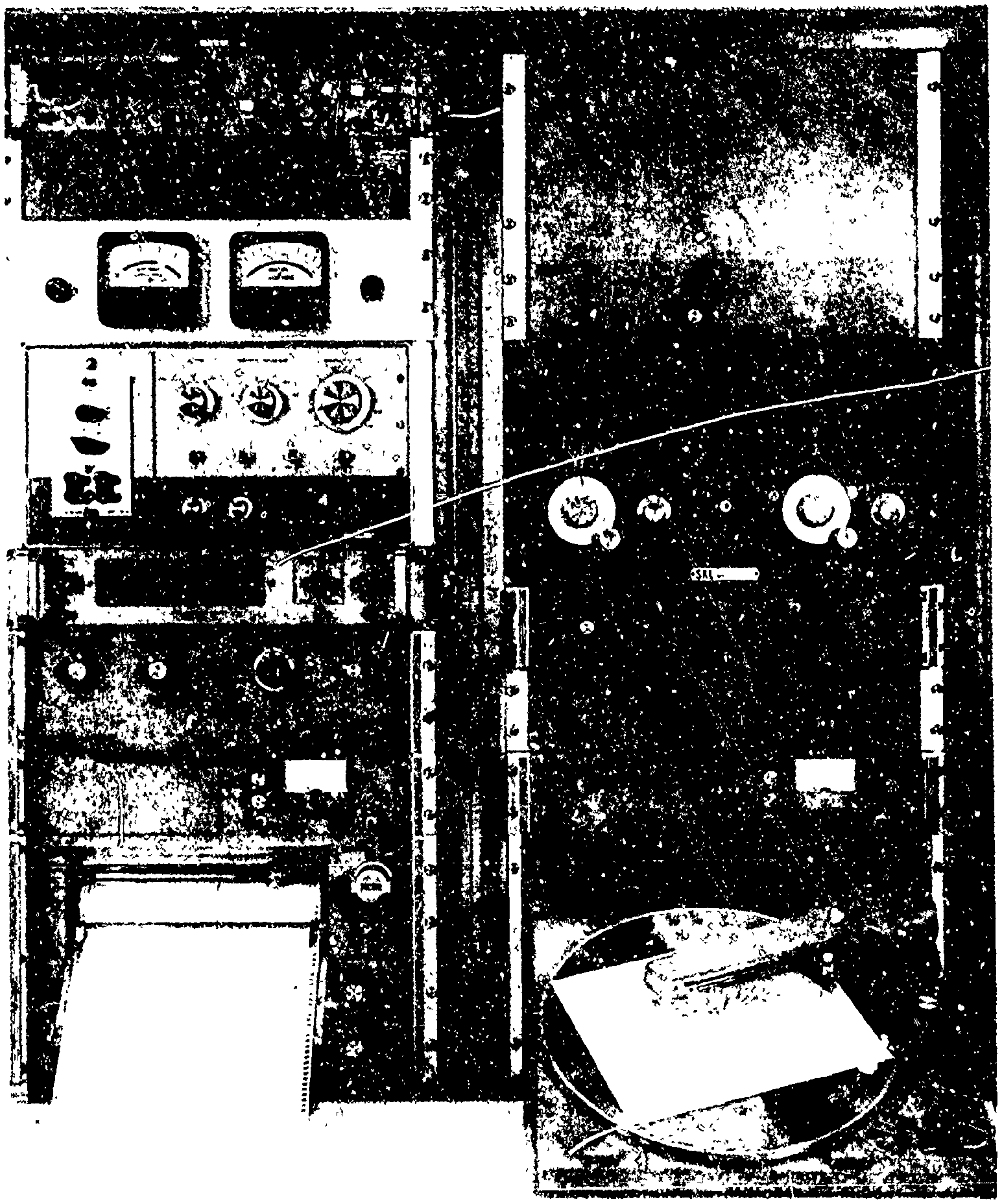


Fig. 9 - Desk-top racks 3 and 4 of console

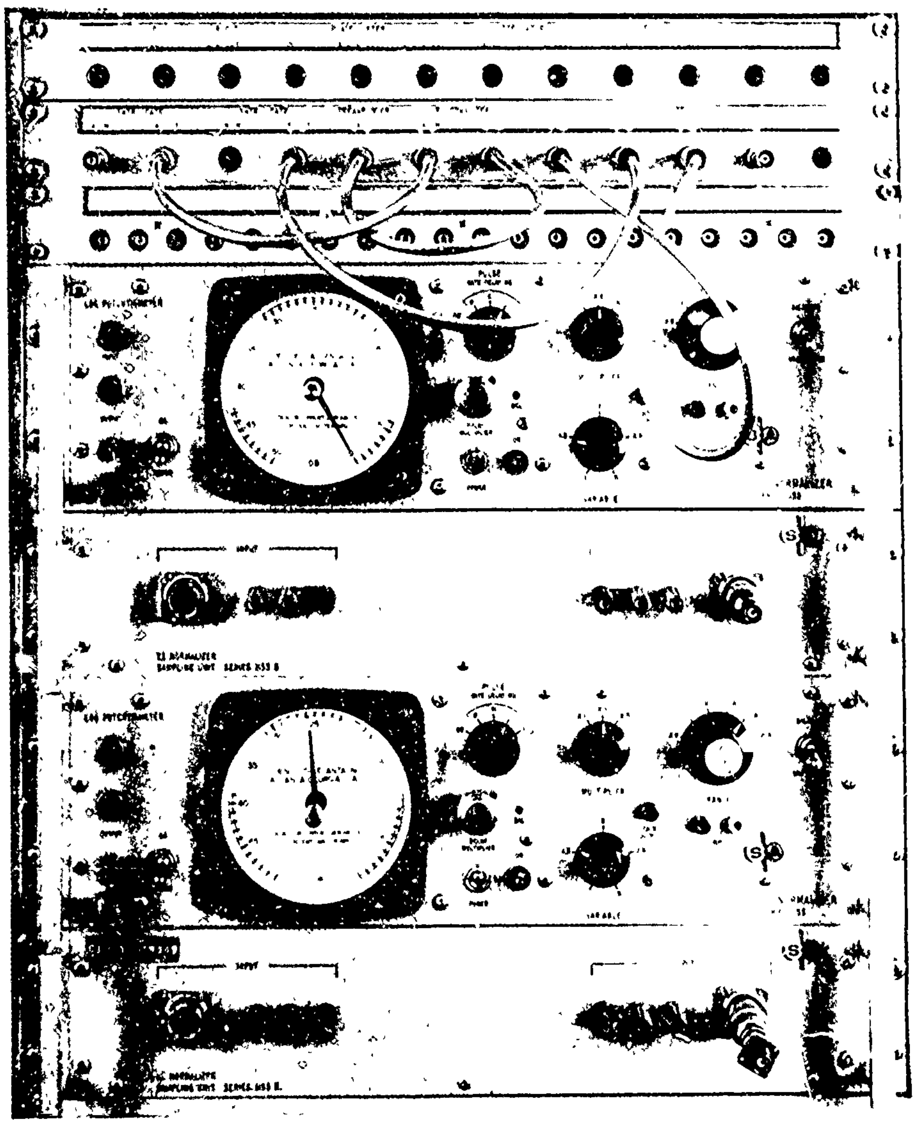


Fig. 10 - Lower cabinet 1 of console

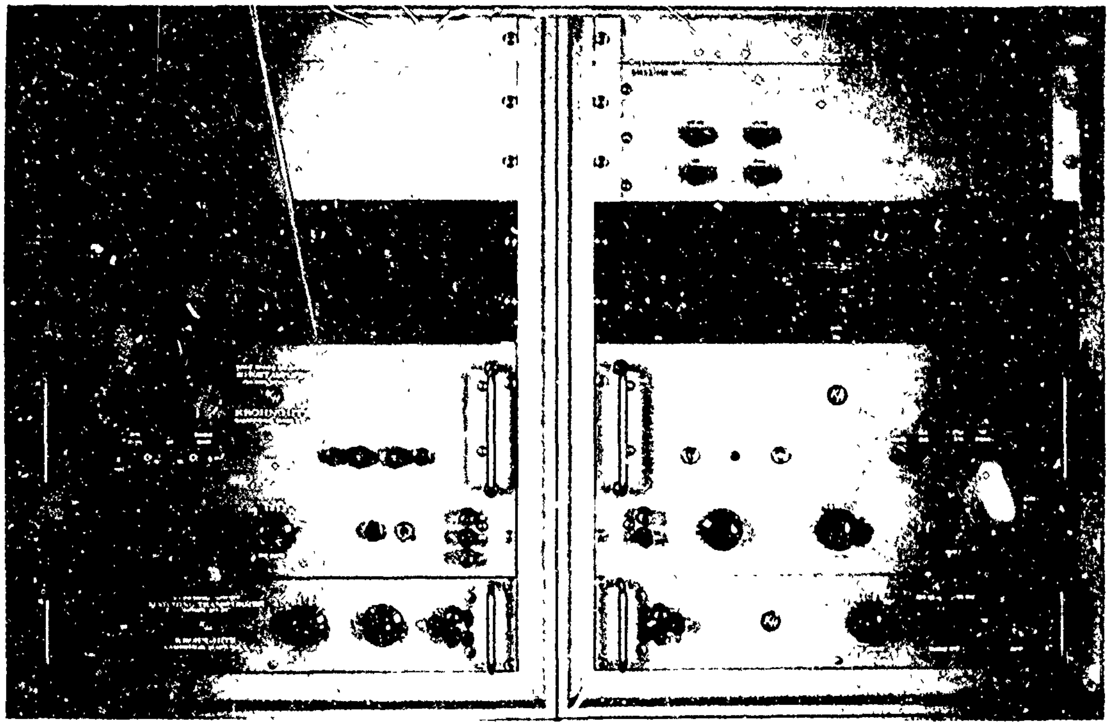


Fig. 11 - Lower cabinet 2 and 3 of console

respond without over- or undercorrecting. Since the detector is a peak detector, circuits are incorporated in the normalizer to delay the current or voltage sample, eliminating the detection of leading-edge transients.

Circuit Description

A calibration dial on the front panel of the normalizers (Fig. 10), located in each of the dual output channels of the block diagram, provides a general indication that the normalizer is operating in its dynamic range; this will be the case as long as the pointer arm does not overshoot at the 0- or 50-dB positions. The position of the pointer arm also indicates the input signal attenuation required to maintain the preset level. Voltage values between 100 mV and 50 V rms and current levels from 10 mA to 5 A rms can be handled by the normalizer. In the pulse mode, it will accept pulsewidths from 10 μsec to 1.1 sec at repetition rates from 1 Hz to 11 kHz.

The preamplifiers, amplifiers, and matching transformers in the normalizer loop are shown in Fig. 11. These units are located under the desk portion of the console (Fig. 7). The Model DCA-50R Krohn-Hite amplifier, shown in the close-up view (Fig. 11), is a wideband, low-distortion, direct-coupled power amplifier. It will deliver 50 V-A (100 V-A peaks) into a 330-Ω resistive or inductive load over the frequency range from dc to 250 kHz (up to 50 kHz into a capacitive load) and will deliver 100 W continuously at dc. Over the frequency range from 1 Hz to 500 kHz, the amplifier will deliver 50 W (100-W peaks) into a 200-Ω resistive load.

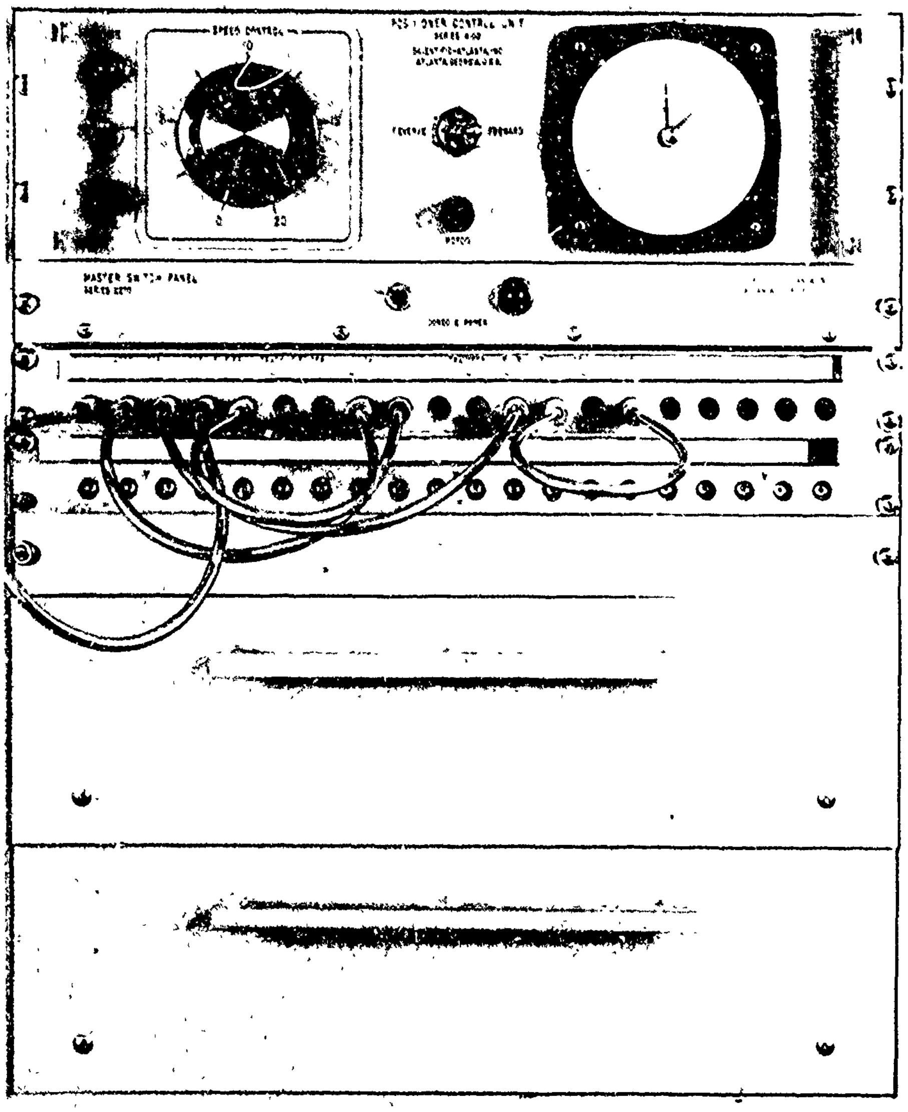


Fig. 12 - Lower cabinet 2 and 3 of console

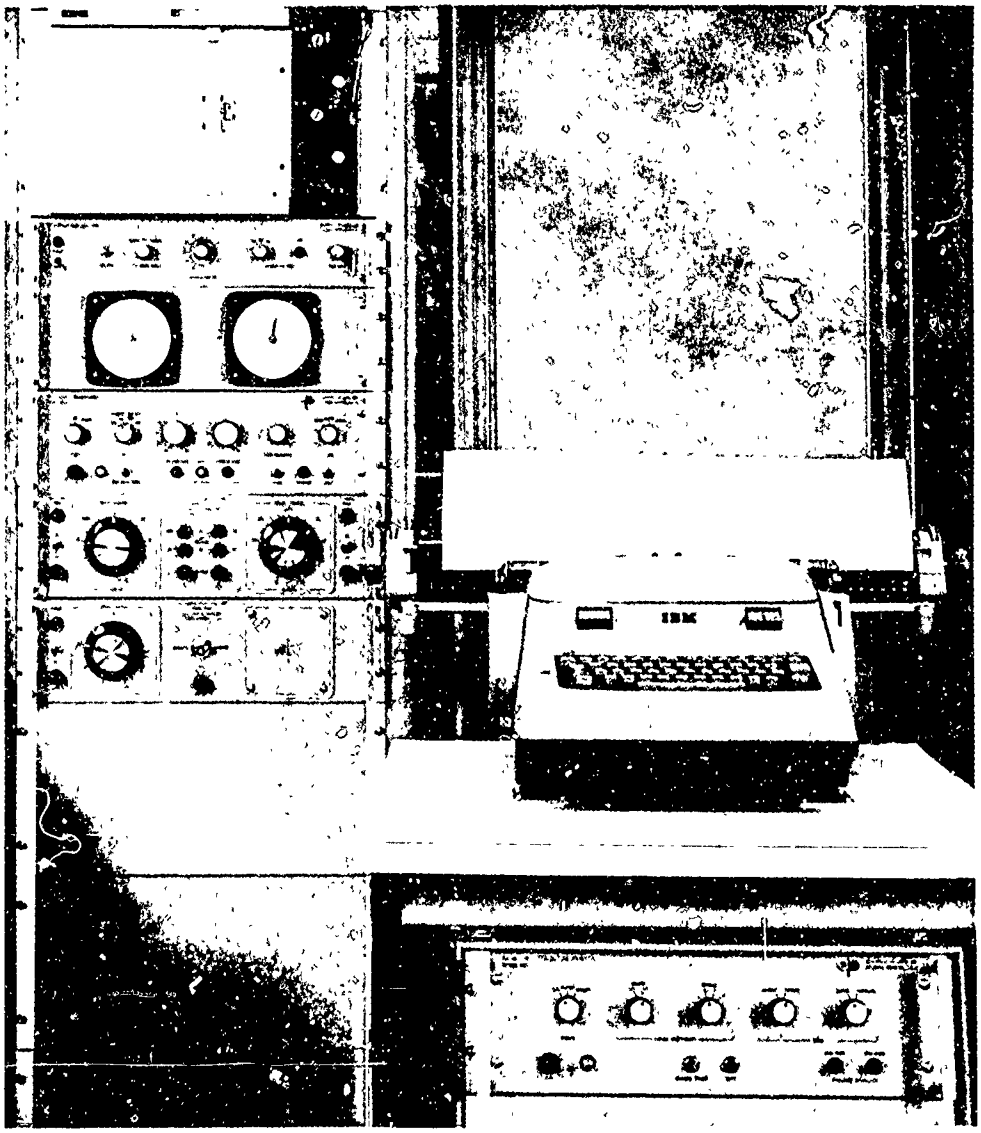


Fig. 13 - Desk-top rack 5 of console

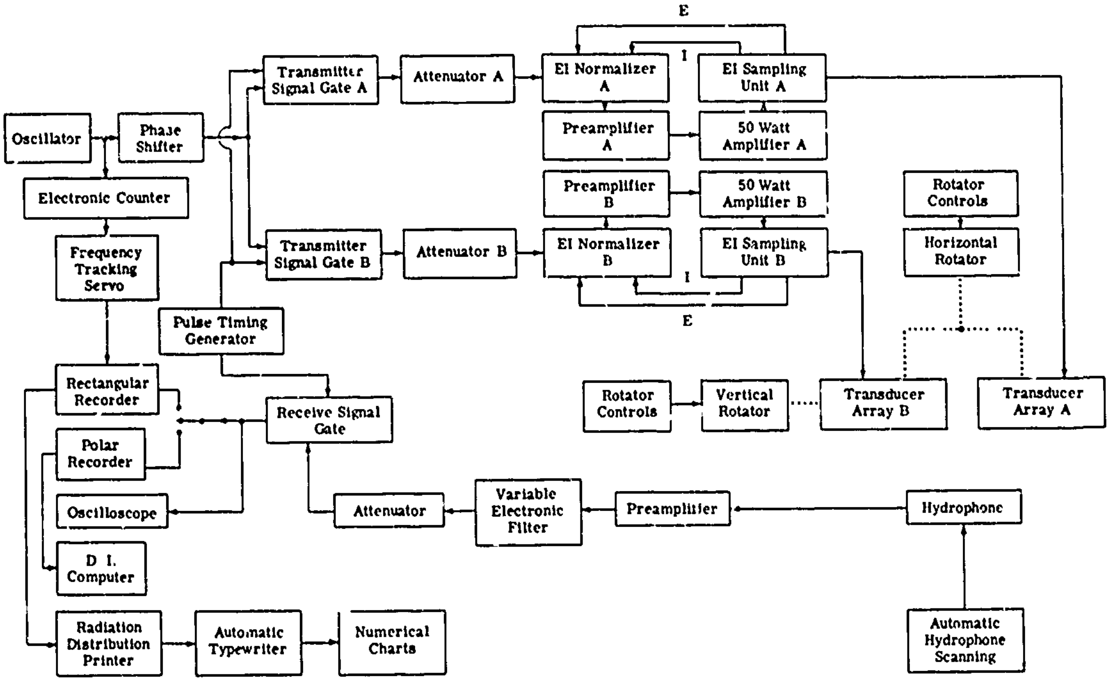


Fig. 14 - Block diagram of instrumentation console for the acoustic research tank

The amplifier provides a choice of three voltage gains as determined by the setting of the INPUT SELECTOR switch: fixed voltage gains of 10 (20 dB) with no phase reversal, or 1 (0 dB) with a phase reversal, or a continuously variable gain (between 0 and 10) with no phase reversal by means of the front panel GAIN control. For each gain setting, the input may be either direct coupled or capacitor coupled with a low cutoff frequency of 1 Hz.

Since the Model DCA-50R has a phase reversal in the fixed unity-gain position, it can convert a single-ended signal in to a balanced signal. Two Model DCA-50R amplifiers can be cascaded to provide a balanced 100-W output by operating the second amplifier at unity gain.

The amplifier output may be either direct coupled (dc) or capacitor coupled (ac) for applications requiring a 0-dc output level. When the ac output is used, the low cutoff frequency is approximately 25 Hz with a 330-Ω resistive load. The level of the direct-coupled (dc) output may be zeroed by the front panel OUTPUT DC LEVEL screwdriver control.

The Model DCA-50R is basically a three-stage, direct-coupled amplifier. The first two stages are gain stages connected as balanced differential amplifiers for drift cancellation and are operated in a push-pull configuration to minimize distortion and provide a balanced output. Four series-parallel-connected power tubes are used in the power output stage in a unique circuit that provides 50 W conservatively over an extremely wide frequency range with low distortion, which is characteristic of push-pull operation.

When the amplifier is operated at the maximum gain of 10 (20 dB), the input is applied to one grid of the first balanced stage and the voltage feedback is applied to the opposite grid. This provides gain with no phase reversal, which is typical of voltage feedback amplifiers. To obtain unity gain with a phase reversal, one grid of the first balanced stage is grounded and the junction of an input-output summing network is applied to the opposite grid as in operational feedback amplifiers.

After the output of the power amplifier is checked by the EI sampler for proper constant current or voltage level, it is transmitted to an experimental transducer array which may consist of a single plane of elements or a number of planes as shown in the block diagram, Fig. 14.

The block diagram shows two separate rotator controls, which are used to rotate a transducer in more than one plane (both the horizontal and vertical) and to obtain as many different acoustic beam patterns as are necessary to reconstruct a complex acoustic pressure field and to obtain an accurate directivity index. Generally, only a horizontal rotator is used in most beam pattern measurements. If a vertical pattern is desired, the array is hoisted, rotated 90 degrees, and bolted back to the rotator; then a pattern is obtained at that angle. Patterns at intermediate angles involve slow and tedious work, which is sometimes eliminated by assuming that the patterns between quadrantal angles consist of smooth curves. The NRL arrangement utilizes a new type of array-supporting frame, designed to provide an automatic rotation capability in both the horizontal and vertical planes. Horizontal beam patterns are obtained by rotating the shaft that supports the transducer array. The lower end of this shaft terminates in a circular rotatable structure in which a square frame for holding the array is mounted. Vertical beam patterns are obtained by rotating the frame in its mount. The vertical patterns for various fixed angular positions of the main shaft represent cuts through a spherical volume enclosing the array and the acoustic pressure field. The total number of beam patterns required for an accurate representation of the pressure field is determined by the complexity of the initial patterns taken.

Remote control of the direction of rotation, speed, and angular position of an array during beam pattern measurements in the horizontal plane is provided by the positioner control unit shown at the top of the rack in Fig. 12. The position indicator meter on the control panel displays the angular position of the transducer array as generated by a synchro transmitter geared to the drive motor of the rotating head shown on the left-hand carriage in Fig. 5. The long or vernier pointer of the meter is geared 1:1 with respect to the synchro, and the shorter or coarse pointer is geared 1:36 with respect to the synchro; therefore, one revolution of the monitored motion results in 36 revolutions of the vernier pointer and one revolution of the coarse pointer. The accuracy of the display is 0.03 degree.

The rotating head or positioner mentioned above is equipped with a variable-speed, reversible, dc motor which drives a worm gear reducer through a timing belt and pulley system. Special features of this unit are

1. Maximum vertical load is	10,000 lb
2. Capacity of drive motor is	1/3 hp
3. Delivered torque is	300 ft-lb
4. Full-load operating speed is	3 rpm
5. Limit-to-limit travel =	400 degrees
6. Turntable diameter =	20 in.
7. Height =	14 in.
8. Weight =	185 lb.

A smaller positioner (Model 5103-1) weighing 55 pounds and having a vertical load capacity of 250 pounds is used on lightweight arrays.

Signals generated by transducers under test are picked up by one of a series of hydrophones and transmitted in sequence through an H. H. Scott Type 140B preamplifier, a variable electronic filter, and an attenuator to a receive signal gate (Fig. 14 and right-hand rack of Fig. 9). The variable electronic filter is a Spencer-Kennedy Laboratories Model 302 unit with dual filters and an integral power supply provided to make the unit as stable as possible and reduce the inherent noise and hum to a very low level. Magnetic shielding permits operation adjacent to low-level equipment without trouble from hum pickup. Conversely, the lack of inductive elements in the circuit makes the filter relatively immune to magnetic fields.

Each variable electronic filter section may be operated either as a low-pass or a high-pass filter. In either case, the cutoff characteristic or voltage transfer function is identical to that of an underdamped, constant-K, pi-section, inductance-capacitance-resistance filter which has a sharp-shouldered curve with a constant, 18-dB-per-octave slope in the rejection band. By appropriate combinations of filter sections, higher rejection rates, bandpass operation, or band-rejection operation may be obtained.

In either high-pass or low-pass operation, the cutoff characteristic of the filter is obtained by means of active resistance-capacitance circuits of considerable accuracy and stability. The resistive parts of these circuits are the sections of a precision, ganged rheostat, capable of a decade range; the capacitive parts and precision capacitors, arranged to be switched in four-decade steps. Thus, for either low-pass or high-pass operation, the cutoff frequency of the variable electronic filter may be set at any point within a four-decade range without changing the shape of the response curve.

The receive signal gate is supplied as a unit of the Scientific-Atlanta Transmission Measurement System. A variable-width, variable-position pulse, whose repetition rate is synchronized with the transmitted pulse, gates the output of the unit to allow any desired portion of the received signal to be admitted to the detector unit. During the gating interval, an output is delivered that is identical in waveform to the input signal. Provisions are also made for disabling the gating action so that a continuous output is available. Tables 1 and 2 give the specifications for the receive signal gate and the requirements for the gating pulse, respectively.

Table 1
Specifications for Receive Signal Gate

Signal	Specification
Input voltage	1 V rms, normal full-scale signal
Imput impedance	75 Ω (nominal)
Signal frequency	dc to 3 MHz
"Off" time output leakage and switching transients	More than 50 dB below full-scale input of 1 V rms
Linearity	Less than 0.5-dB error over 50-dB dynamic range
Signal output	Intended for 600-Ω or high-impedance load through short, unterminated cable

Table 2
Gating Pulse Requirements

Parameter	Requirement
Pulse amplitude	9 to 20 V
Polarity	Positive-going pulse rising from O-V level
Rise and fall times	0.5 μsec or less
Input impedance	10 kΩ in parallel with 68 pF
Pulse width and prf	Limited only by switching time of less than 1 μsec
Trigger pulse	15 V rising from 0.5-μsec rise and fall time

The output of the receive signal gate may be switched to either the rectangular or polar recorders shown in a close-up view in Fig. 9.

The rectangular coordinate pattern recorder basically consists of two high-response, closed-loop servosystems. The chart servosystem positions the recording paper as a function of angular position, or operating frequency, and the pen servosystem positions a pen for recording the amplitude of the signal applied to the input of the recorder preamplifier. After insertion of the proper function potentiometer, the pen servosystem automatically provides a translation of the signal amplitude into either a logarithmic, a linear, or a square-root pen response.

When fed from a square-law detector or transducer, an amplitude recording may be presented as a function of received voltage, or the logarithm of the received power or voltage. When fed from a linear detector or transducer, the recording may be presented as a function of the received voltage or as the logarithm of the received power or voltage.

The recorder may be furnished with either or all of the following pen functions: linear pen motion versus recorder input voltage, square-root pen motion versus recorder input voltage, logarithmic pen motion versus recorder input voltage. The recorder will respond to an 80-dB dynamic range of input signal over an 80-dB logarithmic scale when fed from a linear detector and a 40-dB dynamic range of input signal when fed from a square-law detector.

To permit operation from a detector receiving an audio-modulated carrier, the recorder is furnished with a narrowband, crystal-bolometer amplifier. When using this amplifier, the recorder and the detector constitute a sensitive video detection receiving system.

For operation from a dc input signal, the crystal-bolometer amplifier may be replaced by an optional dc-chopper preamplifier. This permits direct recording from the output of a transducer or a detector receiving an unmodulated signal.

The chart servosystem positions the chart in response to the angular position of a remote synchro transmitter which is normally mechanically linked to the device being tested. A frequency-tracking servo provides chart positioning proportional to frequency for calibrated frequency response recordings.

The polar pattern recorder shown in Fig. 9 is used to plot beam patterns for transducers or arrays when polar-coordinate presentation is desired. The recorder is constructed to provide maximum circuit accessibility to facilitate maintenance and adjustments while providing adequate electrostatic and magnetic shielding between sensitive circuits and sources of electric and magnetic fields. Particular attention has been given to the interconnecting of ground circuits to prevent interunit coupling caused by ground loops.

Both the sensitive preamplifier and the pen function amplifier are plug-in units housed in a shielded rack-mounted assembly when in position. They are supplied with regulated dc filament and B+ voltages fro... the power supply and servoamplifier unit.

The balance potentiometers used with the pen system are housed in self-aligning, plug-in cases that allow rapid replacement without the necessity of adjustment.

The plug-in preamplifier furnished with the polar recorder may be either a crystal-bolometer amplifier, a dc-chopper preamplifier, or both. The crystal-bolometer amplifier permits the recorder pen system to be directly driven from an audio voltage or from a crystal or bolometer detector receiving an audio-modulated rf carrier. For operation from a crystal detector receiving an unmodulated rf carrier, or from a direct dc input, the dc-chopper preamplifier must be used. This amplifier employs a mechanical chopper to convert an input dc voltage to a 400-Hz carrier. The carrier is fed through a narrow-band amplifier to provide noise rejection.

The pen function amplifier is a plug-in unit that provides the necessary amplification and switching to generate one or more recorder pen functions. Five models of this unit are available, permitting a wide selection of pen function combinations.

The principles of operation of the rectangular recorder and the polar coordinate recorder are similar. The principal use of the latter is to plot polar acoustic beam patterns for a transducer array. Polar plots or beam patterns obtained in the NRL tank indicate acoustic pressure differences sensed by a fixed hydrophone as an array is rotated through 360 degrees. Synchronism between the chart turntable and the array rotating mechanism is maintained by a servosystem.

Signals from the hydrophone shown in Fig. 14 have been traced to the two recorders. The oscilloscope shown below the recorders is a Tektronix Type RM 561A oscilloscope equipped with a series of plug-in units that extend its operational flexibility. Interconnections between the measurements console and the scope make it possible to observe voltage or current signals anywhere in the circuit of the block diagram. Principal usage of the scope is to observe the transmitter and receive gate pulsed signal shapes and to adjust the delays so that the gating, during which measurements are made, occurs at a flat or stable portion of the pulse, particularly in cases where the amplitude of the pulse is irregular.

The operational characteristics of Tektronix scopes and plug-in units will not be discussed because of the voluminous amount of technical information readily available to users of these scopes.

Special Items

New instrumentation designed specially for the NRL Acoustic Research Tank includes the following:

1. A hydrophone positioning and scanning system;

2. An automatic, multiaxial, underwater rotator (for obtaining transducer array beam patterns) combined with a directivity index computer;

3. A vector component computer for pulsed (or cw) measurements of complex impedance, admittance, transfer function, or power.

A description of the above items will be given to complete the information on measurements instrumentation.

Hydrophone Positioning and Scanning System — A carriage-mounted, triaxial, hydrophone positioning and scanning system made to NRL specifications is shown at the right in Fig. 5. Although the system is excellent for many experimental applications, it was designed primarily for the study of pressure variations in the sound field of multielement transducer arrays in which there are unfavorable acoustic interactions between transducer elements. A simplified sketch of the carriage is shown in Fig. 15. The triaxial hydrophone positioning directions in relation to the tank tracks and test transducer or array are indicated by the x, y, and z axes. In the xz plane, the maximum area that can be scanned is limited to a 5-ft square by the mechanical gearing operating in the vertical or z direction and by the dimensions of the tank well in the horizontal or x direction. However, positioning or scanning along the y direction is limited only by the dimensions of the tank.

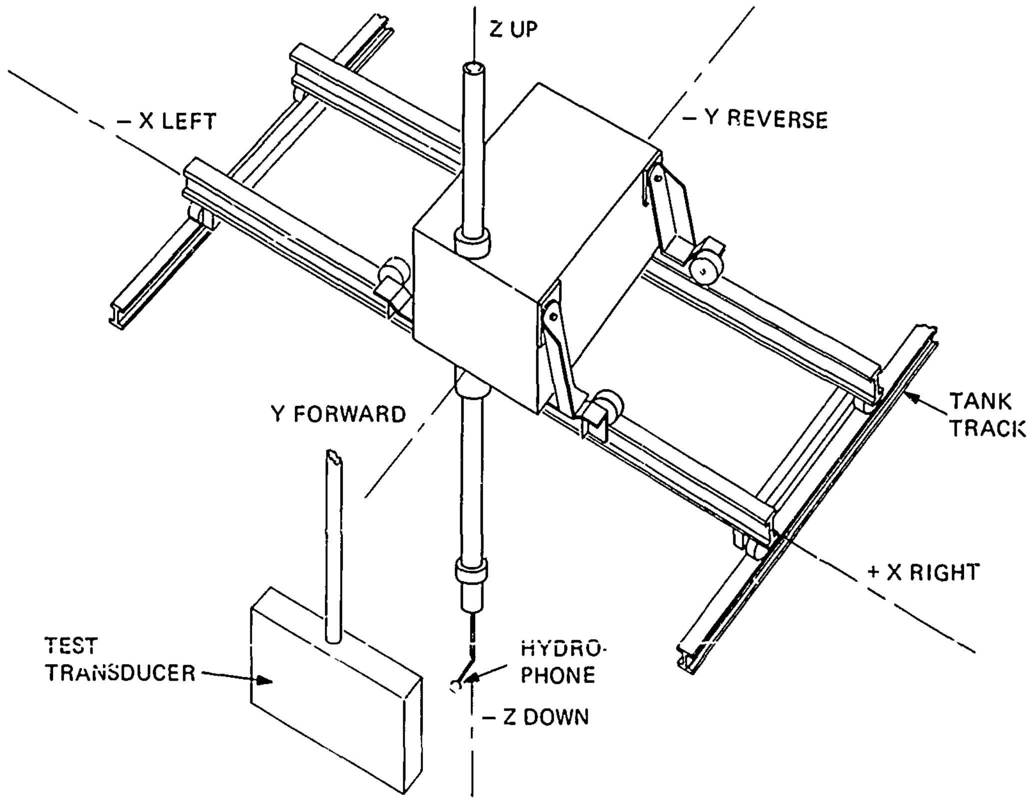


Fig. 15 - Simplified sketch of automatic scanning and triaxial probe positioning system

Carriage Details — The carriage at the right in Fig. 5 is supplied with four precision wheels. A three-point cam roller assembly is used in conjunction with the aluminum guide bar on one track to maintain straight-line motion in the range (y) direction. Motive power is supplied to one of the four wheels through a motor-worm gear box combination for variable speed operation along the range (y) axis. Adjustable limit switches located at the front and rear of the carriage are activated by a transducer mount located on the same track and by limit stops located on the track. The positioner is equipped with two precision levels for use during the carriage leveling procedure.

A secondary or x-axis carriage is supported and guided by two precision ground rails attached to the main carriage as shown in Figs. 5 and 15. The carriage rides on a three-point friction bushing support rather than on ball bushings to maintain minimum mechanical noise levels. Motion along the x axis is provided by a precision ball-nut, lead-screw assembly. Drive power is applied to one end of the lead screw by a worm gear box, while synchro position data are taken at the other end. The z-axis probe assembly is mounted on the x-axis carriage. Motion along the z-axis is provided by a motor-driven gear mechanism. The probe assembly is equipped with a hinged joint to allow the vertical axis to be tilted 90 degrees for ease of probe changes.

Controls for Hydrophone Positioning and Scanning — Operation of the positioning and scanning system may best be explained by referring to the block diagram (Fig. 16) of the principal components. As shown in the diagram, two position control units are provided. The Model 4114 is a dual-axis, dual-speed control for operation of the x-z axis. With this unit, independent speed control of each axis allows slow index rates on the x axis for greater accuracy and, at the same time, rapid scanning rates on the z axis for minimizing total measurement time. The Model 4111 is a single-axis control, without an indicator, that provides variable speed operation of the range (y) axis.

The positioner programmer may be set to permit manual operation or programmed for automatic operation. In the manual operating mode, any axis can be operated independently and simultaneously with the two position control units. The positioner is equipped with mechanical limit switches to prevent accidental overtravel. Probe position can be read directly with a resolution of 0.01 in. on the Model 4422-66 indicator for the x and z axis. A scale fixed to the track and a pointer fixed to the carriage provide visual indication of the y (range) position of the carriage.

Both of the position control units have open-loop, Variac speed controls with provisions for dynamic braking of dc motors. The braking is accomplished by placing a braking resistor across the motor by relay when the speed control knob is returned to the zero speed position or when a scanning limit switch is actuated.

The motors for all three axes of the positioner have sufficient excess power to give smooth control of speed over the whole range without appreciable overshoot in the normal operating ranges of scanning and indexing speeds. The scanning speed will normally be approximately in the range 0.5 to 6 ips because of limitations imposed by the dynamic errors of the recorder, pulse repetition rate in pulse operation, maximum typing rate of the RDP unit, etc.

For automatic operation, the programmer is set to control scanning over a selected area in the xz plane at a given y-axis distance in the near or far field of a transducer array. The hydrophone moves at a constant speed in the vertical (z-axis) direction between preset limits, which may be varied from ±1 to ±30 in. from a zero point located at an approximately 11-ft water depth in the tank. At the end of a scanning run, the hydrophone is automatically indexed, or moved along the x axis, preparatory to making another scanning run. Fixed, selectable, indexing distances between scan lines are 0.1, 0.4, 1.0, and 2.0 in. in the NRL unit. The scanning sequence continues until manually terminated or until a positioning limit switch is actuated. Maximum scanning speed is 6 ips; hydrophone positioning accuracy is ±0.05 in.

A view of the control panel for hydrophone positioning and scanning is shown at the left in Fig. 13. The panel includes the recorder control unit, the x- and y-axis meters for indicating hydrophone position, the positioner programmer, the dual positioner control unit, and the positioner control unit. At the right in Fig. 13 is a radiation distribution printer (RDP) and an IBM automatic typewriter.

Signal Recording for the Scanning System — In the circuitry of Fig. 16, signals from the test hydrophone located on the probe of the positioner are processed in a normal manner through the transducer calibration portion of the system. The output of the receiver signal gate is passed through the Scientific Atlantic Model 82143A recorder control unit to the input of the rectangular recorder shown in Fig. 9. The rectangular recorder has been modified by adding an encoder to the pen system. This encoder generates a gray code representing the level of the recorder signal, and this code is used to control the keyboard of the radiation distribution printer's electric typewriter. The chart of the rectangular recorder is driven by the z axis of the positioner, so that the signal recorded is signal amplitude versus probe position along the z axis. To keep subsequent recordings from falling on top of each other, the recorder control unit can be used to insert 1 dB of attenuation in the signal path each time the probe indexes along the x axis. Each time the x axis indexes, the recorder control unit can modulate the pen of the recorder with four different codes that occur sequentially (as the attenuator moves). The modulation of the pen repeats itself every fifth step, but there will be a 4-dB level difference between similar modulation codes. The recorder control unit can also advance the recorder chart one cycle at every index of the x axis if this operation is desired to prevent overlapping of recordings.

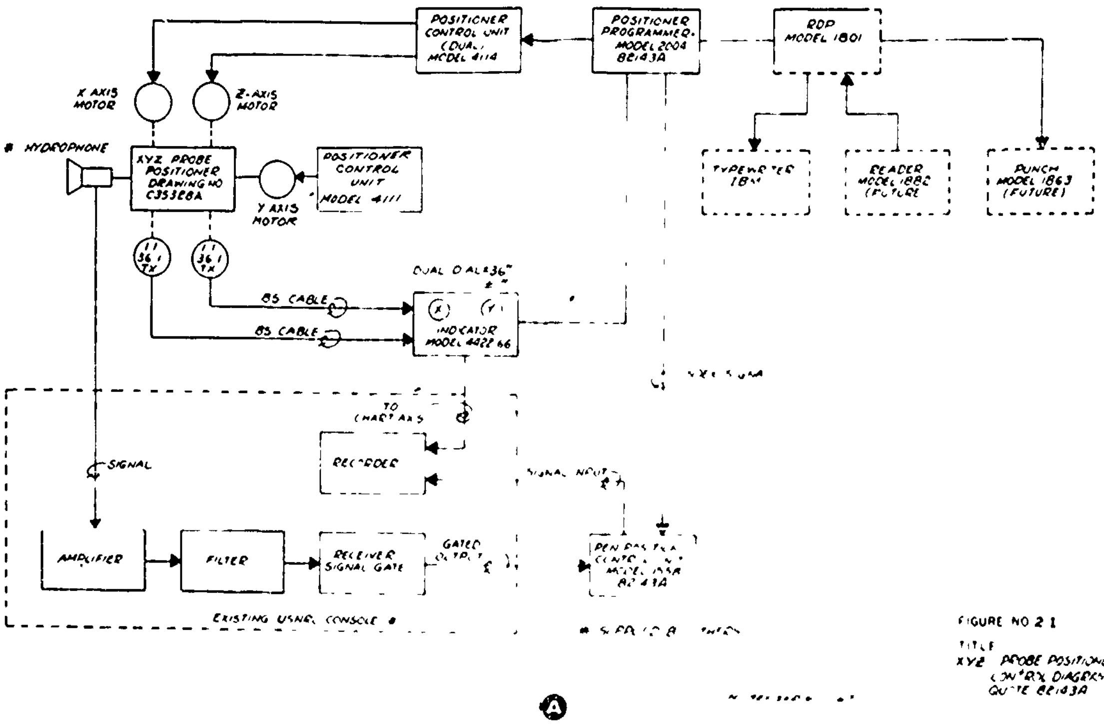


Fig. 16 - Block diagram of xyz probe positioner

The function of the recorder control unit is to control the chart and pen of the rectangular recorder and to provide signal information for the RDP system. In Fig. 13, the control unit is below the Moseley recorder. This close-up view clearly shows the operating dials, which will now be discussed.

The AUTO CHART CYCLE switch is used to advance the chart of the recorder one cycle (20 in.) every time the positioner goes through one scanning cycle in automatic operation. The FORWARD position runs paper out of the recorder, and the REVERSE position runs paper into the recorder. The OFF position disables the automatic advance feature, and the recorder chart operates normally. The chart advance has an inhibit circuit that prevents the positioner from starting a new scan until the chart cycle has completed. This prevents the scan from starting before the recorder chart is in position. The ATTENUATION STEP swirch is used to insert attenuation in the signal line into the recorder pen input. The CW position makes the attenuator step 1 dB clockwise at the end of each scan cycle of the positioner. The CCW position makes the attenuator step 1 dB counterclockwise at the end of each scan cycle. The OFF position disables the automatic stepping of the attenuator.

Attenuation in the signal line is controlled by the ATTENUATION DB switch. The switch can be rotated manually at any time to position it to the desired setting. When the switch is on the 22 position, the LIMIT light comes on and indicates that no more attenuation is available. The 23 position is not used, and the signal is completely disconnected from the recorder input. The switch has no stops and will rotate continuously.

A modulation code is available for the pen so that multiple recordings on one piece of paper can be identified. The code is recorded by periodically lifting the pen from the recording paper. Four codes are available, and these are determined by the position of the attenuator switch. The 0-dB position code is for continuous recording; the 1-dB position code is a long on, short off, code; the 2-dB position code is an equal on-off code; the 3-dB position code is a short on, long off, code. At the 4-dB position, the code starts repeating itself and continues to repeat itself every fifth step. The code is turned on by placing the PEN MOD switch in the ON position. The MOD RATE controls the rate of the code to compensate for different chart speeds on the recorder. In the down position, the PEN MOD switch disables the code and the pen writes continuously. In the center position, the pen is lifted.

The gray code from the rectangular recorder is used to provide the RDP unit with signal-level information. At the start of a scan of the probe, the typewriter carriage will be at the left and the carriage will move toward the right as the probe scans. Each time the signal level is within the limits of the selected increment of signal level, the typewriter will print the level of the signal. When the probe reaches the end of its scan, the typewriter will hit the right-hand margin, and the carriage will return. The paper will also be advanced one line. This process will repeat until the end of the scanning cycle.

The Scientific Atlanta Series 1800 radiation distribution printer, combined with a Model 2004 positioner programmer and an IBM typewriter provides an automatically typed numerical chart in decibel values that represent the acoustic pressure variations sensed by a miniature hydrophone as it scans an area in front of the radiating face of a transducer. The numerical values printed by the RDP unit are determined from coded signals received from a logarithmic pen servo in the rectangular recorder. The RDP unit processes the coded signals and feeds them to a decoder that drives the individual key solenoids in the IBM typewriter. A special set of type slugs is provided for numerals 0 through 40. The numerals correspond to the recorder chart reading to the nearest decibel.

A torque receiver connected to a 36:1 synchro transmitter on the z axis of the hydrophone positioner drives a photoelectric commutator to generate a sample pulse for every 0.1 or 0.4 in. of hydrophone travel. The binary code established by the sample pulse is stored in a memory circuit to prevent a change of code during writer output operation. The binary code is then fed to a relay decoder, which pulses one of the typewriter key solenoids to initiate the typing action. To print only the numerals at 1-, 2-, 3-, or 6-dB intervals for making less detailed plots, only the appropriate key solenoids are switched to the decoder. If the decoder selects a line that is not connected, a circuit will cause the typewriter to space. The carriage return is controlled by a switch actuated at the end of the writing line. A program interlock circuit will stop the program if the typing speed is too fast or if the positioner does not stop at the proper position upon the completion of each scan run.

Special features of the IBM typewriter are as follows:

1. Writing speed — 8 characters per second, maximum

2. Selectable amplitude increments — 1, 2, 3, or 6 dB

3. Accuracy — recorder pen position sensed within ±0.1 dB and printed within ±0 5 dB.

4. Dynamic range — 40 dB for all amplitude increments

5. Format — Chart writing area is 9 by 18 in. A total of 180 sampled values can be recorded in the z coordinate and 90 sampled values in the x coordinate.

Of the two methods described for recording signal information from the scanning hydrophone, the typed numerical charts are far superior. Illustrative examples of numerical charts are presented in Figs. 17 through 22. The first four charts represent cross sections of acoustic pressure fields obtained for scanned areas 3 in., 5 in., 3 ft, and 12 ft in front of an 18-in.-diameter, multielement, planar transducer array resonating at 12.5 kHz. In Fig. 17, the scanned area is a 3-ft square, the separation distance between hydrophone and radiating face of the array is 3 in., and the index distance between scan lines is 0.4 in. The zeros in the center of the pattern represent the highest reference pressure. All other numbers are minus dB values and show how the pressures fall in an outward direction from the center. Pattern recognition is enhanced by programming the printer to type only even decibel values, thus leaving blank spaces where consecutive odd numbers would otherwise have been printed. Asymmetries at the quadrants of the circular portion of the pattern are probably due to the method of clamping the transducer elements in the circular case. In Fig. 18, the separation distance between the array and the hydrophone is 5 in. instead of 3 in. The pattern is just slightly different. However, more differences may be noted in the pattern of Fig. 19, where the separation distance between the hydrophone and the array radiating face was increased to 3 ft. Some of the difference is because the scanned area was increased to a 5-ft square and the index axis was foreshortened to fit on the graph paper used in the IBM typewriter. The pattern would have retained a square appearance if the index distance setting of 0.4 in. had been retained. Figure 20 shows what the cross section of the acoustic beam looks like in the far field, where the separation distance between the hydrophone and the array radiating face is 12 ft. The pattern of Fig. 21 is for two horizontal lines of eight transducers each. The array was driven at the resonant frequency of 14 kHz. The separation distance between the array radiating face and the hydrophone was 3 in. Variations in the pattern indicate that the transducer elements at one end of the two-line array were different from those at the other end. A final pattern for a model biplanar array of free-flooded ring transducers is shown in Fig. 22. The operating frequency was 30 kHz, and the separation distance between the hydrophone and the radiating face was 3 in. Pattern

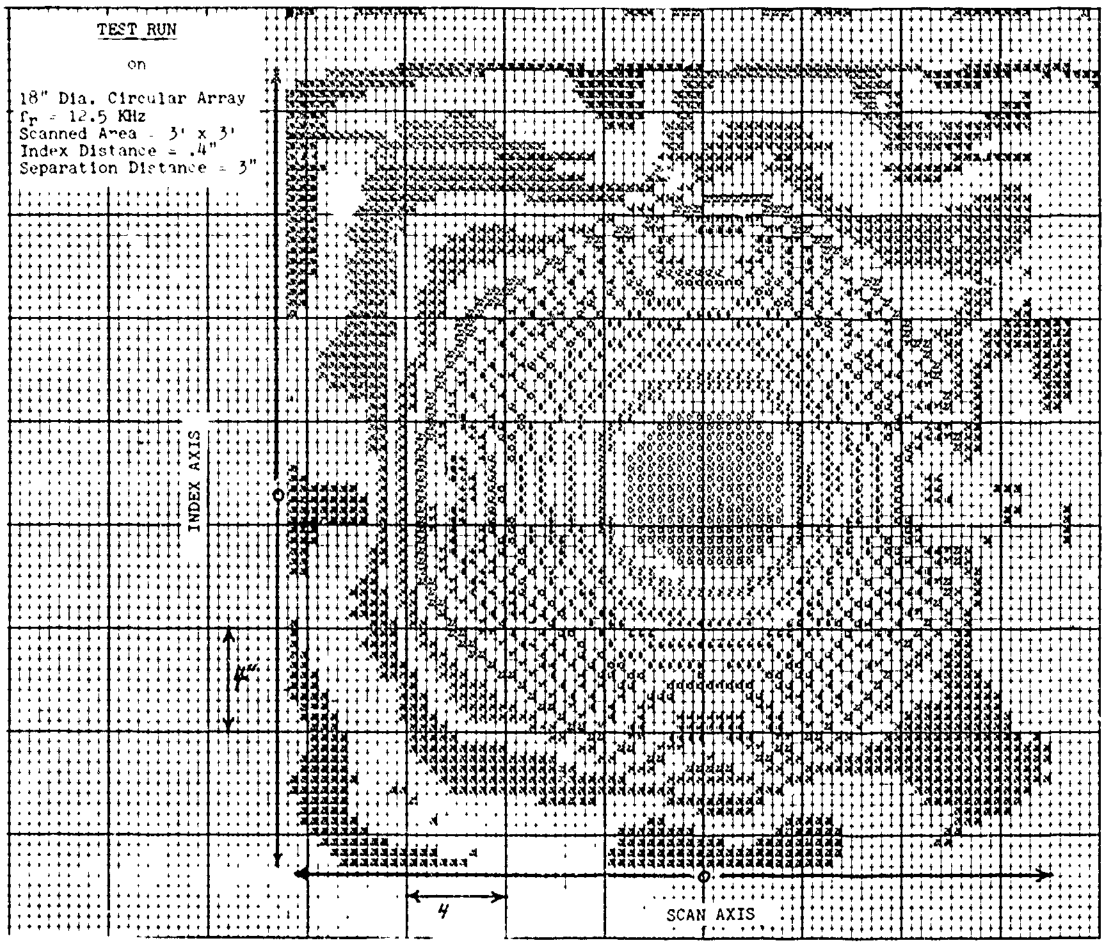


Fig. 17 - Pattern taken by automatic scanner

recognition is more difficult in charts representing complex pressure fields; however, recognition can be improved by use of a coloring scheme in which all numbers of the same value have an assigned color.

Directivity Index Computer System — Principal parts of the computer system are (1) an additional transducer rotating mechanism for obtaining the multiplanar beam patterns required to compute accurate directivity indexes when the acoustic beam patterns are complex, (2) a control panel (similar to the control unit in Fig. 12) for rotating a transducer array and plotting beam patterns at angles necessary to reconstruct a complex acoustic field, and (3) a directivity index computer located on the control panel, consisting of a pattern integrator and a spherical integrator converter unit.

The pattern integrator is normally used to measure the directivity of beam patterns for symmetrical acoustic fields but may also be used to measure the area under a curve plotted in rectangular coordinates. The integrator operates either independently or simultaneously with either a polar or a rectangular beam pattern recorder, since its output signals are obtained directly from a bolometer amplifier and a transducer array positioner. A synchro signal from the array positioner sets a synchro receiver in the

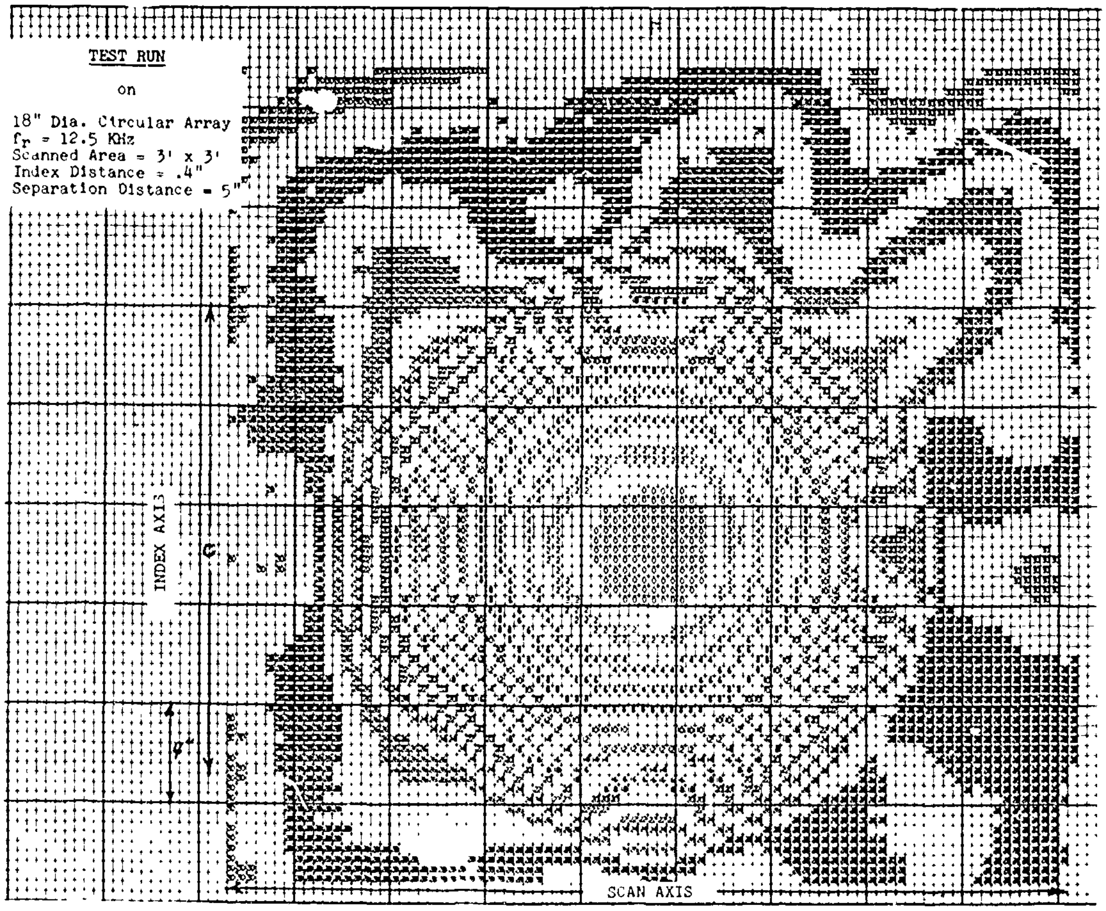


Fig. 18 - Pattern taken by automatic scanner

integrator which, in conjunction with a light source, photocell, and disk, forms a sample-pulse generator. This generator furnishes 1000 sampling pulses per revolution of the array positioner when operating from the 36:1 synchro in the positioner.

Each sampling pulse initiates a sweep gate which in turn triggers a linear sweep generator. The positive-going sawtooth of the sweep generator, starting with negative polarity, is coupled to both a zero comparator and an amplitude comparator. When the sweep voltage reaches zero potential, the zero comparator opens the counter gate, and when the sweep voltage reaches a magnitude equivalent to the input dc signal voltage, the amplitude comparator turns off the counter gate and resets the sweep gate and sweep generator. For each sampling pulse, the counter gate is open for a time interval proportional to the magnitude of the input signal voltage.

The input signal is normally obtained from the output of a crystal-bolometer amplifier. In this case the audio signal is amplified and rectified before it is fed to the amplitude comparator. Alternatively, the input signal can be obtained from the linear balancing potentiometer in the beam pattern recorder. This dc signal, which varies between 0 and 100 V, is fed directly to the amplitude comparator.

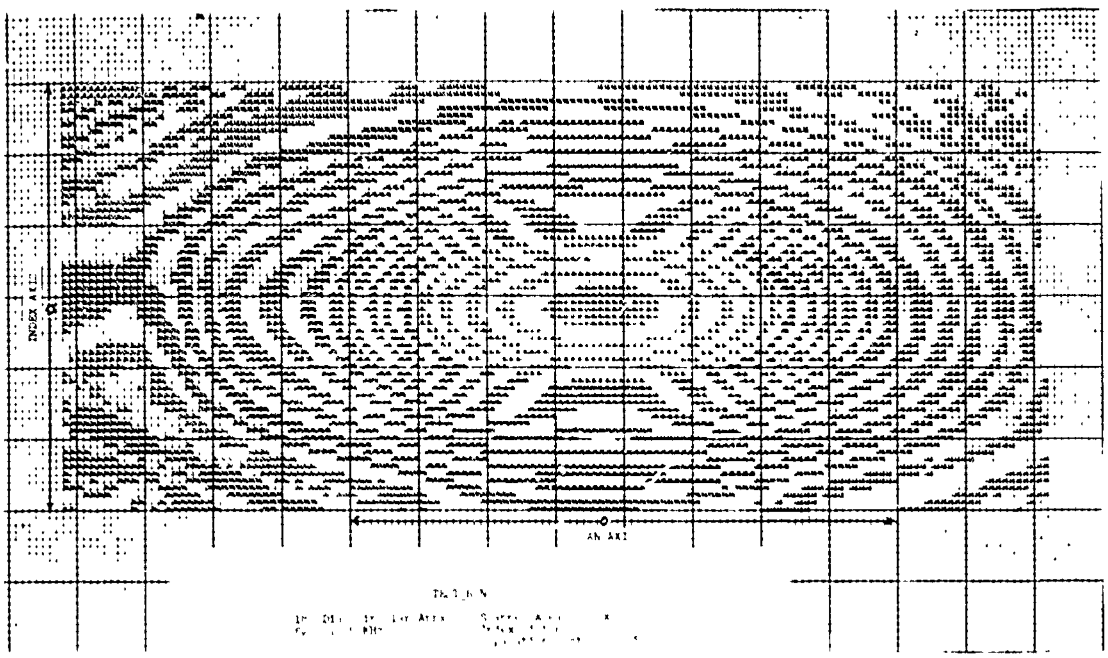


Fig. 19 - Pattern taken by automatic scanner

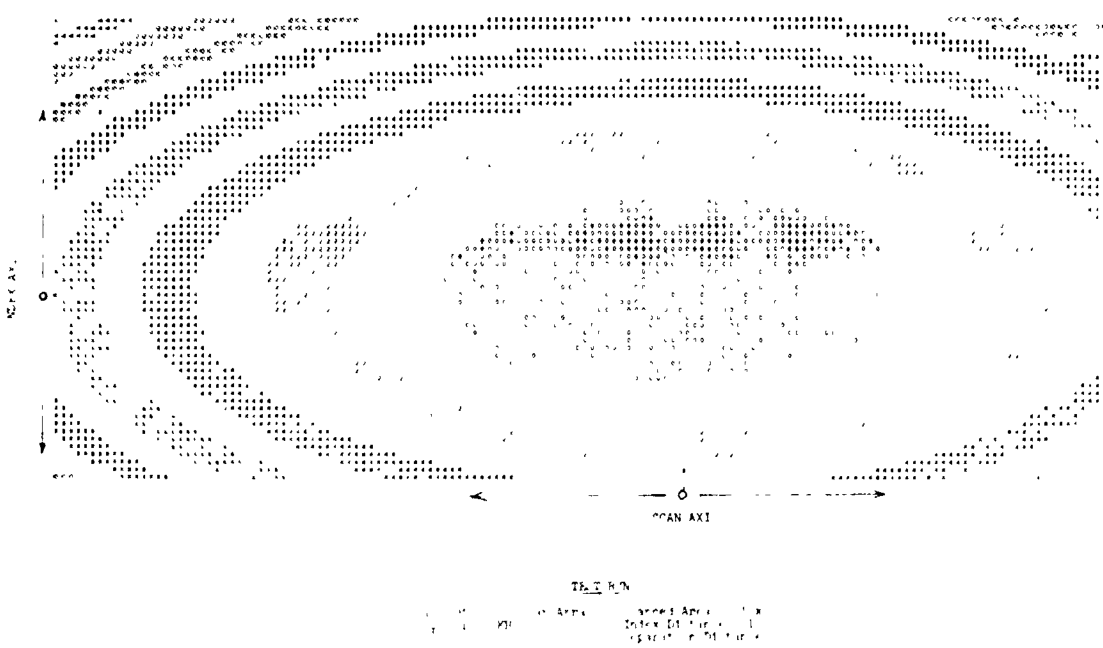
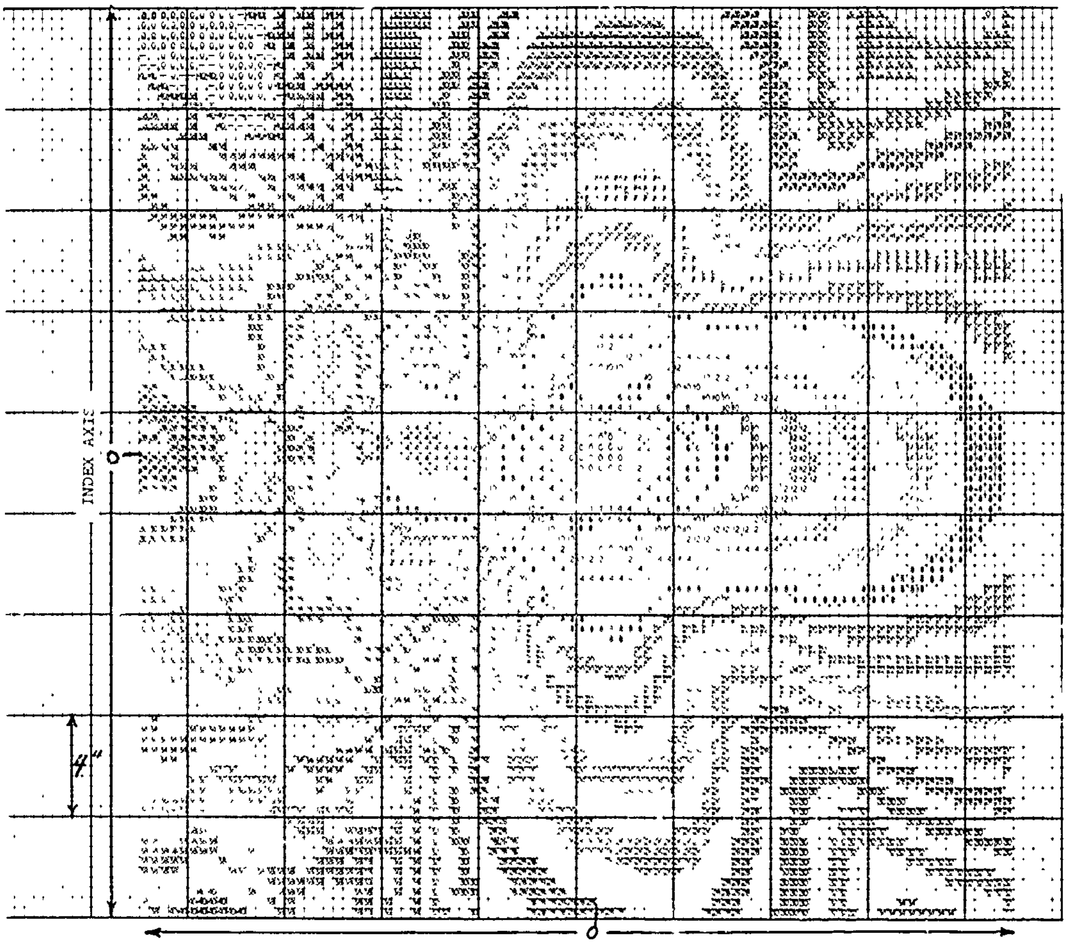


Fig. 20 - Pattern taken by automatic scanner



2 Lines of 8 Model Transducers
f_r = 14 KHz
Scanned Area = 3' x 3'
Index Distance - .4"
Separation Distance = 3"

Fig. 21 - Pattern taken by automatic scanner

During the "on" time of the counter gate, the output of a 100-kHz clock oscillator is totaled in a set of six decade counters, of which the two least significant figures are not displayed. When the sampling pulse counter has counted 1000 sampling pulses (360 degrees of array rotation), the integrator is automatically shut off. Resetting is accomplished by use of a front panel switch that resets all counters and gates to their zero and closed position.

The Scientific Atlanta Model 2621 spherical integrator converter unit greatly simplifies beam pattern integration by accomplishing several calculations automatically. The converter unit adapts the pattern integrator to perform weighted spherical-coordinate integration by performing the following three functions: (1) each solid angle of the sphere of integration is automatically weighted equally, (2) constants used in calculating the directivity of an array are automatically taken into account for specified increments of integration, and (3) additional count storage is provided.

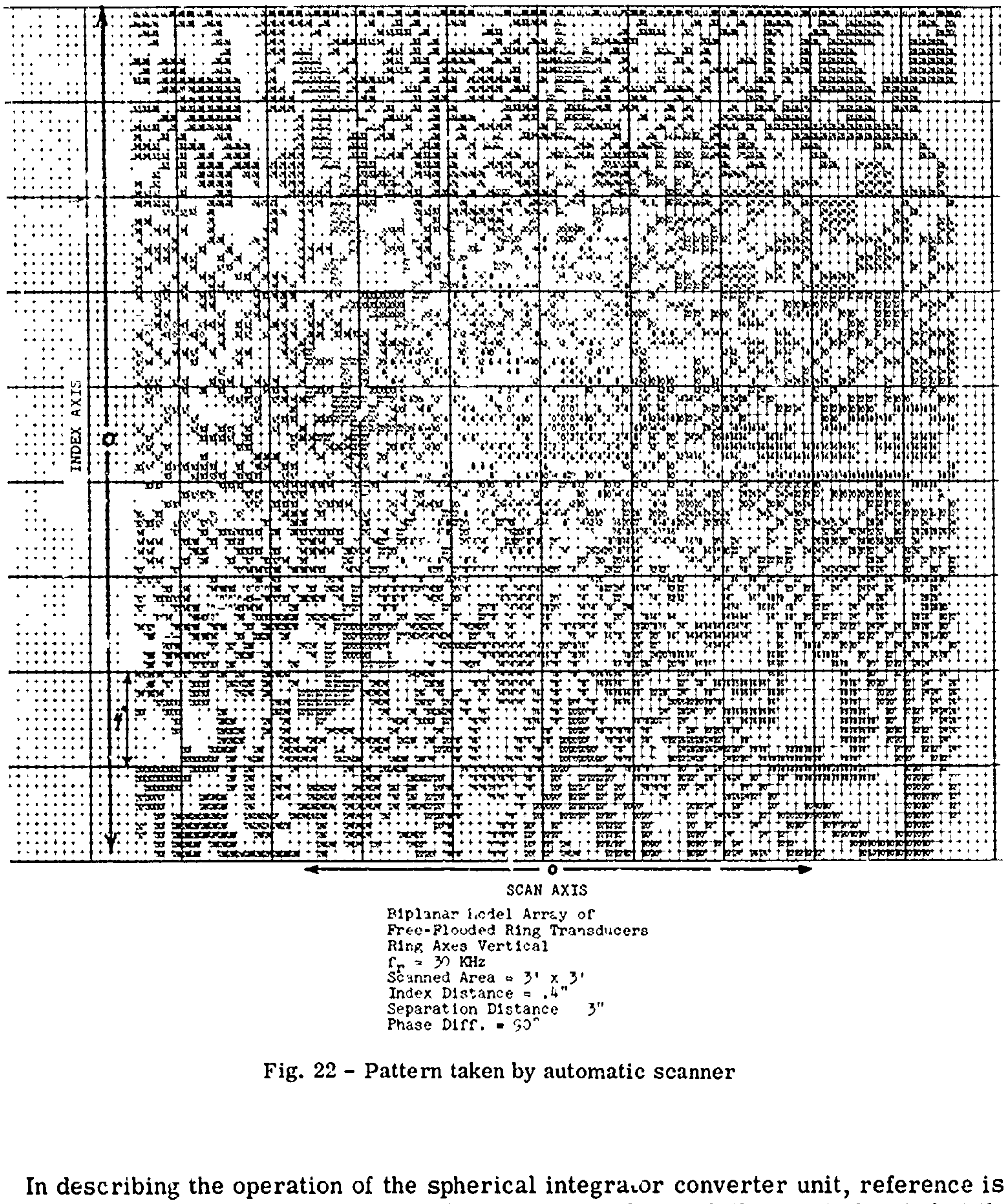


Fig. 22 - Pattern taken by automatic scanner

In describing the operation of the spherical integrator converter unit, reference is made to a sphere with rectangular coordinates x, y, and z, with the origin located at the center of the sphere, and two angles ϕ and θ located in the first octant. Angle ϕ is measured from x in the xy plane, and angle θ is measured from z in a sector which is ϕ degrees from x.

When the directivity of an array is measured through the use of the pattern integrator alone, ϕ number of cuts are taken at successive θ angles and the data for each cut are recorded individually. At the end of the integration process, the results for each ϕ cut must be weighted individually by multiplying the result by the sine of the θ angle at which the particular ϕ cut was made.

In weighted spherical-coordinate integration, the converter unit supplies the pattern integrator with a counting clock frequency which varies as the sine of θ, thereby weighting automatically. Use of the converter unit eliminates the calculations necessary when the pattern integrator is used alone. This is accomplished by making the calibration clock frequency differ by a selected amount and also by proper selection of the countdown ratio of the converter-unit counters. An auxiliary mode of operation allows the use of a variety of θ increments with only minor additional calculations.

Weighting by variation of the clock frequency permits introduction of the input signal to the integrator without attenuation, so that the full dynamic range of the analog-to-digital conversion circuitry is utilized at all angles of θ. Consequently, there is no magnification of the effect of zero-shift, or linearity, errors near the polar axis.

Vector Component Computer — A Dranetz Engineering Laboratories Model 202 vector component computer for pulsed or cw measurement of complex impedance, admittance, transfer function, or power is shown in the left panel of Fig. 9. This very important piece of equipment is not shown in the block diagram for the instrumentation console because it was not provided as a component of that system.

In the NRL acoustic tank measurements, the vector component computer, or VCC, is used in conjunction with a Moseley recorder, shown at the top left in Fig. 13, for plotting motional impedance or admittance circles, which provide a considerable amount of the information required to determine the operating characteristics of transducers and arrays.

Special features of the VCC are

1. Measurements for cw, gated cw, or single-tone burst signals

2. Wide frequency range — 50 Hz to 300 kHz

3. Selected sampling times — 0.5 to 500 msec

4. Dc outputs for direct readout or automatic recording — holding time up to 3 min for single burst.

5. Compatible with all Dranetz 100-PA series plug-ins and adapters

6. Completely transistorized

7. Auto-Correct circuits that eliminate errors due to variations in signal source level.

8. Internal delay to eliminate effects of transients.

Applications of the VCC are

1. Measurement of complex impedance and admittance of electroacoustical transducers under low or high power

2. Measurement of the real and imaginary input power

3. Plotting the transmitting and receiving response of projectors or hydrophones

4. Use as a phase-lock detector for low-level tone burst signals.

COMMENTS

The planned instrumentation for the Acoustic Research Tank facility is not yet 100% complete due to the delay in the delivery date for the directivity index computer. It is expected that the acqusition of newly developed or specialized instrumentation will continue throughout the life of the tank and be accelerated when new problems, requiring additional instrumentation, are assigned.

Results of reverberation measurements made in the NRL tank compare favorably with similar measurements made for a wooden tank of approximately the same size and reported by Klein and Baker.* Samples of the NRL measurements are given in the table below.

Table 3
Results of Reverberation Measurements

Frequency (kHz)	Reverberation Time (msec)	Reverberation Decay (dB/sec)	Absorption Coefficient
5	160	370	0.32
10	144	540	0.44
20	105	570	0.46

Various aspects of acoustic tank design, suitability for particular applications, and the relation between transducer parameters and tank size are not discussed because of the adequate coverage in the many reports cited in the Bibliography. Material covered in those reports may generally be identified by the title of the report.

*E. L. Klein and D. D. Baker, "Reverberation Measurements in Water Tanks," DRL Memo, BuShips Ser 689B-124, Defense Research Laboratory, Univ. Texas, Austin, Texas, June 22, 1962.

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13. ABSTRACT

A new Acoustic Research Tank facility designed for precise acoustic measurements on, and the study of, scaled models of sonar transducers, arrays, and related underwater devices has been installed at the Naval Research Laboratory.

The tank is constructed of cypress wood, is 30 ft in diameter and 22 ft deep, and is enclosed in a cinder block house, which contributes to the maintenance of the controlled environment necessary for accurate measurements.

Acoustic measurements are made using an electronic console designed to accommodate two channels of continuous-wave or pulsed-signal excitation. All components in the console are of the latest design and are matched and integrated to provide an accurate, highly flexible, and manually convenient measuring system. Three pieces of instrumentation specially designed for the NRL tank are (a) a triaxial hydrophone positioning and scanning system, (b) a multiaxial underwater rotator (for use with a directivity index computer), and (c) a vector component computer that operates on pulsed signals.

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