NEAR FIELD TECHNIQUES AND APPLICATION AS AN IN SITU PERFORMANCE MONITOR/TRAINING DEVICE

MR. PAUL J. O'BRIEN
Electro-Acoustic Systems Laboratory
Hazeltine Corporation

Conventionally, all acoustic transducer parameters are measured in the far-field or Fraunhofer region. This is undesirable for some of the larger sonar systems, since very long test distances are required as well as elaborate calibration test sites. As a result, an extensive "down time" of the system is necessary. The capability of measuring the parameters of the AN/AQS-10 system, while in the Fresnel or near-field region, is valuable since it eliminates a great many of these problem areas. This capability is made feasible through utilization of a relatively new method of near-field transducer measurement.

To measure any transducer in the near field, a test array must be designed which will provide a constant pressure volume at the desired frequencies over the active face of the transducer under test. The design parameters of this array are, therefore, the operating frequency range and the test dimensions of the transducer. Also, the stave construction inherent to the measuring array should be such that the test array will in effect be acoustically transparent over the entire operating frequency range. W. J. Trott[1] of USRL has formulated the basic design principles of a test array which incorporate these measurement features. Since design features of this array have been well documented by Trott and others, I will not spend time reiterating them here.

Since prior effort in the formulation of this measuring techniques was concentrated on the development of planar arrays, the next logical extension of the near-field technique of transducer measurement was to include the formulation of arrays other than planar. With the encouragement of Trott and with the aid of F. R. Hill and others, an analysis was conducted which indicated that a cylindrically-configured near-field array was feasible, and that such a system could provide an accurate measure of the operating parameters of the AN/AQS-10 Sonar System. The original test array which was designed for the system was first verified by use of a computer and was subsequently fabricated and subjected to an extensive experimental program. The computer verification was possible through the use of a program written by the Laboratory which enables the computation of the complex pressure field developed by the test array at any point in space relative to it. Excellent agreement between near and far-field data was achieved.

These tests validated the basic measurement technique and formulated the design procedure for a conformal near-field array performance test set for the AN/AQS-10 Sonar System.

SYSTEM FEASIBILITY

In order to fully check out the system design prior to mounting the test array in a tank environment, a complete series of feasibility measurements were made at Hazeltine's Open-Water Test Site at Quincy, Massachusetts. These measurements were conducted in order to detect any deviation from normal far-field test results that may result due to the utilization of the near-field technique.

The test geometry that was utilized is shown in Figure 9. The water depth to the center of the test array was eight feet, with a sensor separation of four inches. The four-inch separation was established by mounting the test array staves in a cylindrical configuration on a 24-inch diameter. Since the diameter of the AN/AQS-10 transducer array is 16 inches, this resulted in a four-inch stand-off distance. All far-field measurements were taken at a distance of 11 feet. The nominal operating frequency for the sonar system was used to record the receiving beam patterns. Measurements were also made above and below the nominal frequency to establish operational modes. All measurements were made using a pulsed signal to avoid any interference due to reflections.

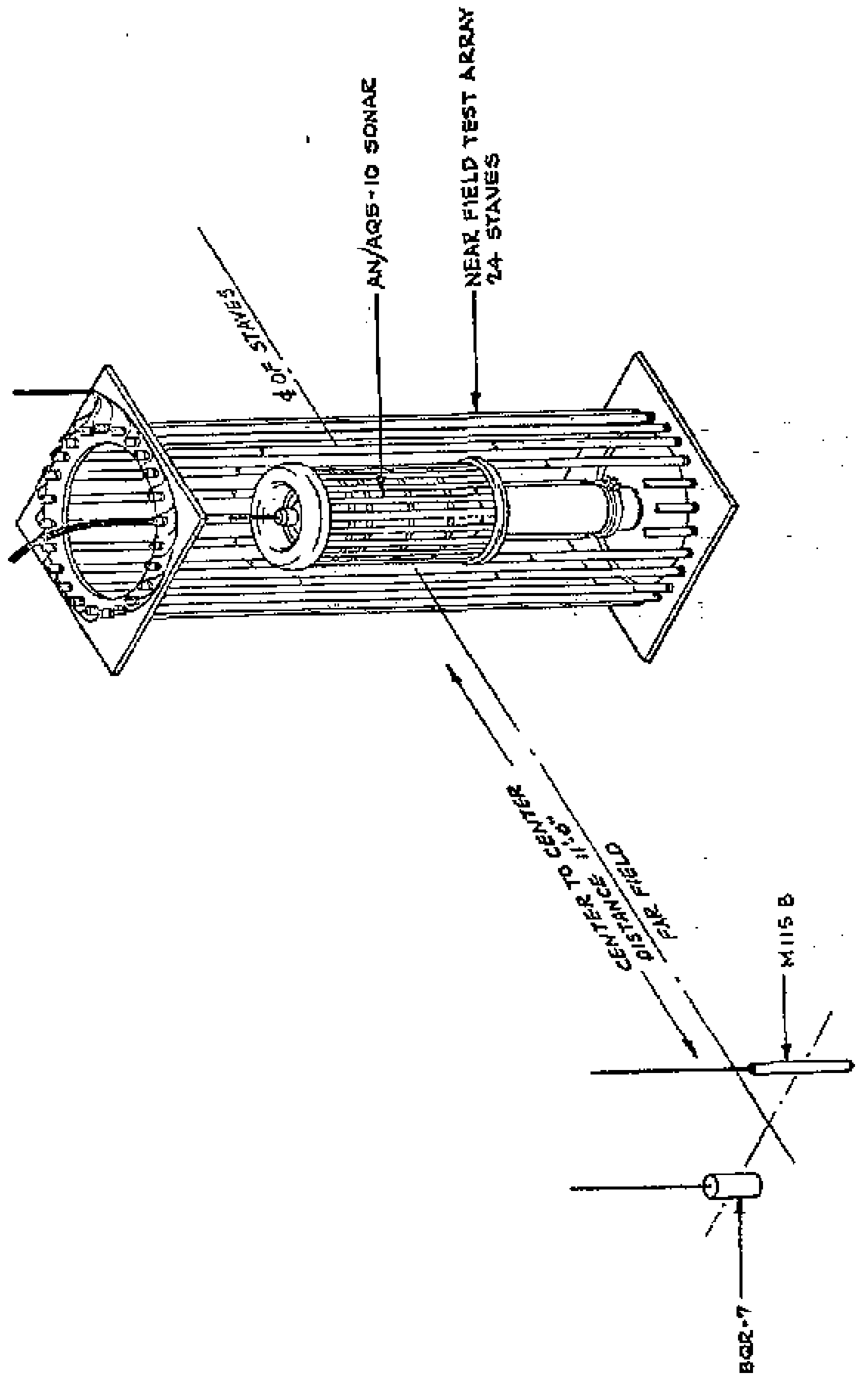

Figure 9. Near-and Far-Field Feasibility Test Configuration

The AN/AQS-10 was rotated through in the field to achieve a complete azimuthal far-field beam pattern. Figures 10, 11 and 12.

Based on these significantly encouraging results, a decision was made to proceed with the fabrication of the tank system.

As mentioned previously, the near-field array consists of 24 staves, each of which contains 19 small ceramic transducer elements spaced four inches apart. There are a total of 456 elements in the test array. These elements are PZT-4 ceramic cylinders measuring 1/2 inch by 1/4 inch by 1/8 inch and are sealed with glass-to-metal end caps. Amplitude shading of the elements is accomplished by a combination of series-connected capacitors and etching of the element conductive surface. The elements are connected in parallel and inserted into a test array stave. The stave is a hollow neoprene tube which is evacuated, oil filled and capped at each end after the element has been inserted (Figure 13). The staves are horizontally shaded and phased before being connected in parallel to form the integral test array. A set of ten staves is in operation at any one time (135-degree arc segment). The 24 staves are equally spaced on a 24-inch diameter circle located concentrically about the AN/AQS-10 transducer. This results in a four-inch stand-off distance between arrays and a clearance from the tank walls of approximately eight inches.

The cylindrical test tank is fabricated from 0.25-inch steel. The outside diameter is 40.5 inches and the height is 92.25 inches. The interior surface of the test tank is lined with sound absorbing rubber (SAPERT) which is cemented to the tank. This lining is 0.28 inch thick and results in a moderate reduction in the intensity of the acoustic reflection.

A. ELECTRO-ACOUSTICAL DESCRIPTION

The element-to-element spacing of four inches, as well as element size, assures transparency of the array at the operating frequency. The horizontal and vertical shading coefficients for the test array were derived by projecting the relative stave position in the array onto a modified Gaussian shading function which is obtained by using the binomial expansion coefficients. Figure 14 illustrates the shading function that was employed for the AN/AQS-10 test array. Also presented is the phase shift introduced into each stave, the amount of which is determined by its relative distance from a plane drawn tangent to the surface of the array. The resulting array exhibits a response similar to that of a comparable near-field planar array. This can be verified empirically by calculating the sound pressure and phase at various points within the field.

In order to simplify the calculation of the field point sound pressures, interactions between elements of the test array are neglected. This is a reasonable assumption for this array because of the chosen element-to-element spacing and element size. The resultant sound pressure at a given field point is the sum of the contributions from all the elements of the array.

where: a_j = shading coefficient for the j^{th} element
r_j = distance from j^{th} element to field joint
$k = 2\pi/\lambda$
kd_j = phase of the voltage applied to the j^{th} element.

The computer program evaluates the equation at each field point.

The acoustic field developed by the array, as read out by the computer, is plotted as a pressure contour variation in Figure 15. By inspection of this figure, it is apparent that a sufficient plane wave volume is present to enclose the sensitive receiving face of the AN/AQS-10 transducer and therefore, a Fraunhofer effort is obtained in the Fresnel region.

To test the AN/AQS-10 receiving hydrophone, a transmit signal is generated in the test set and is used to drive the test array staves. The hydrophone output signal is returned to

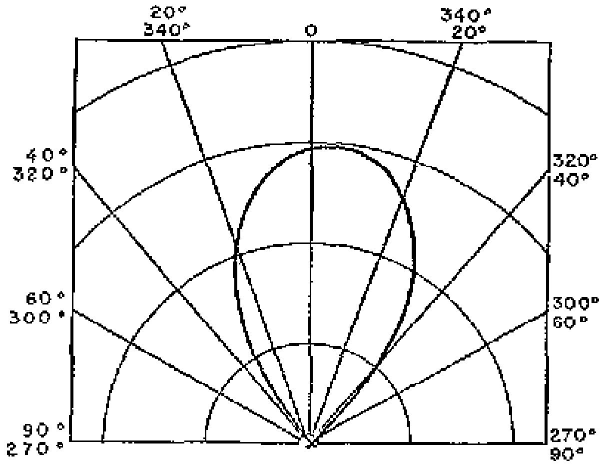

Figure 10. AQS-10 Beam Pattern, Far-Field Test Distance = 11 Feet

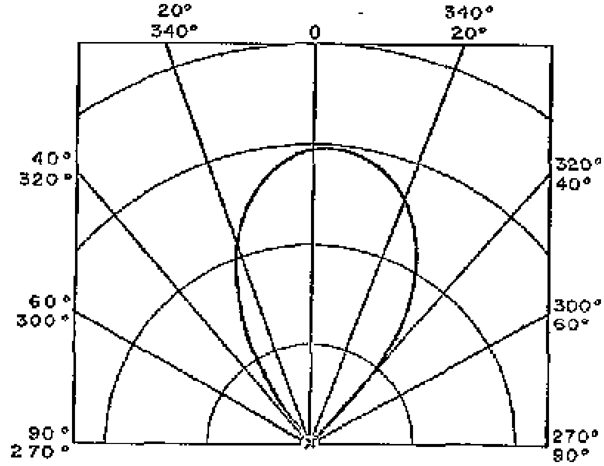

Figure 11. AQS-10 Beam Pattern, Near Field, Array Staves No. 1-10 Test Distance = 4 Inches

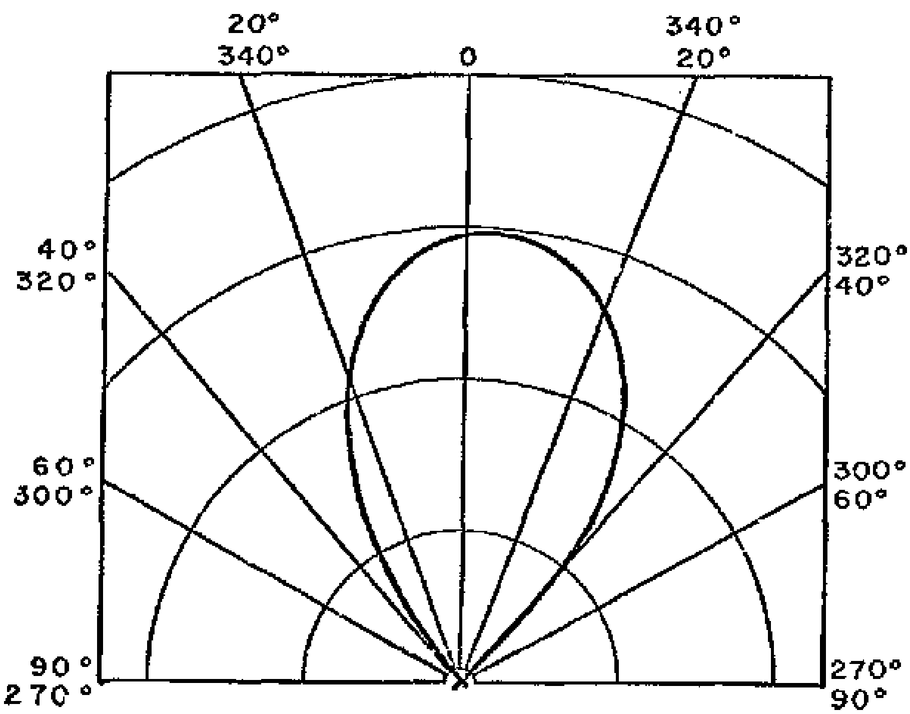

Figure 12. AQS-10 Beam Pattern, Near Field, Array Staves No. 11-20 Test Distance = 4 Inches

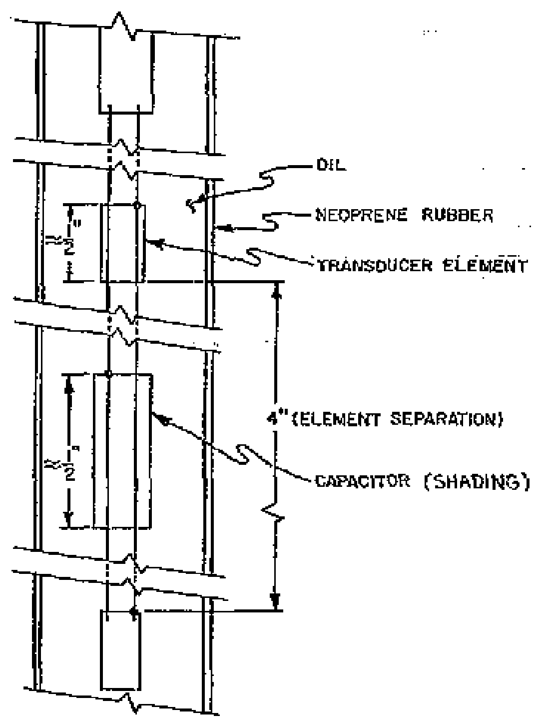

Figure 13. Typical Stave for Test Tank System

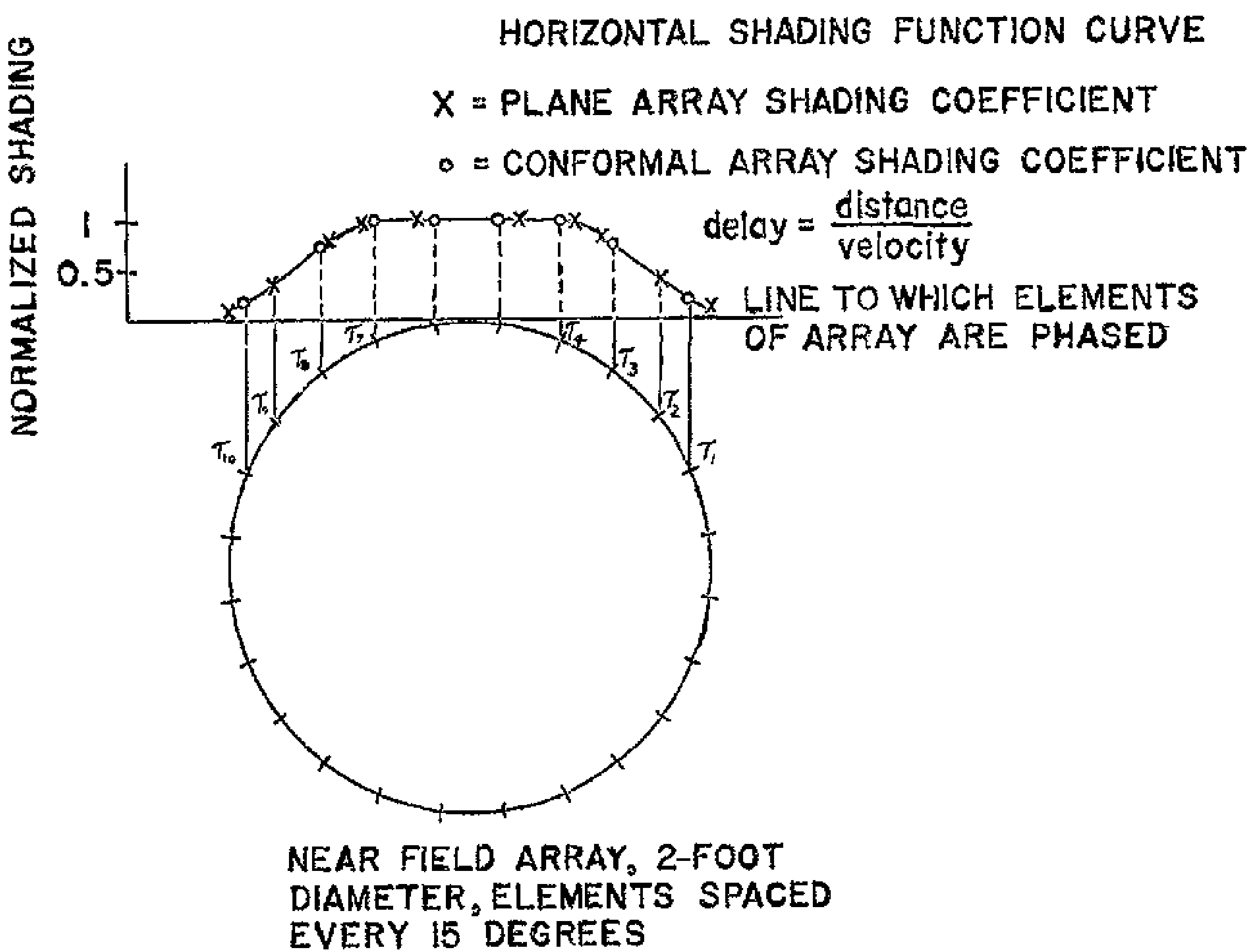

Figure 14. Shading Coefficients and Phasing for a 10 Stave Section of the Near-Field Array

$$p = \sum_{j=1}^{N} \frac{a_j}{r_j} e^{i(kr_j + kd_j)}$$

Where: a_j = shading coefficient for the j^{th} element

r_j = distance from j^{th} element to field point

$k = 2\pi/\lambda$

kd_j = phase of the voltage applied to the j^{th} element

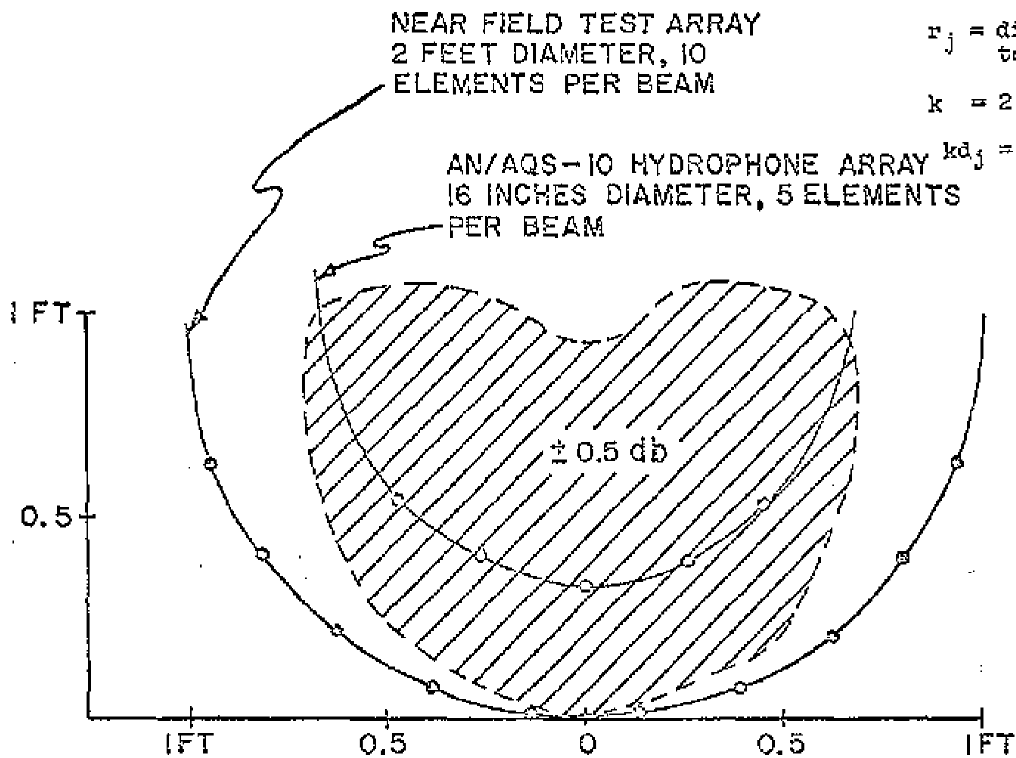

Figure 15. Computer Region of Nearly Constant Pressure in the Sound Field with Cylindrical Array

the test set and metered. By calibrating the test system before the monitoring operation, comparative results of AN/AQS-10 minimum detectable signal level and receiving beam-to-beam uniformity tests will be indicated on the test set meter. A complete system block diagram is presented in Figure 16.

Because of the test distances involved, an acoustic free field condition is present for approximately three transmit cycles. The received signal is therefore gated as well as being filtered and detected. The spacing of the test staves about the AN/AQS-10 is such that a receiver signal level may be monitored every 15 degrees. This is accomplished by switching a set of ten test staves one stave position at a time around the array. Points on the receiving beam may be metered on the MRA and on the MRA ± 15 degrees, ± 30 degrees, ± 45 degrees, etc. Uniformity among beams can thus be compared as well as a discrete representation of the true far-field beam pattern.

A typical receiving beam of the AN/AQS-10 as measured in the far field has already been shown. This pattern may be compared at discrete points to the response points which are obtainable by utilizing the beam uniformity test of the test tank system (Table 1). For this test the transmitting voltage was adjusted so that a convenient 100 volts on the MRA could be read on the test set meter. The first column of the table represents the position of the AN/AQS-10 beam in degrees, the second column is the output voltage and the third column is this voltage converted to decibels. It is apparent from this table that the points taken by the test array in the near field agree to within ± 1/2 db of the main lobe of the far-field beam pattern. Since minor lobes were not measured in the far field, no comparison was made in this region, however, it is quite apparent from the near-field data, that a secondary lobe structure is present in the receiving response. The dynamic range of the detector is the limiting factor when making measurements well down into the noise. By switching the AN/AQS-10 receiving beam, it is possible to obtain these points on all beams and thereby determine if any beam is malfunctioning. Any malfunction will manifest itself as incompatible output voltages and therefore, when compared to the true far-field pattern, can be traced to a particular beam.

The minimum detectable signal level for each receiving beam can be determined by utilization of a transmit signal level attenuator. By adjusting the signal level transmitted by the test staves until it is equal to the background noise inherent in the beam under test, an accurate measure of this system parameter can be made.

Similarly by reciprocity, the AN/AQS-10 transmitting response can be monitored at the various power levels of the AN/AQS-10 projector in the same manner as in the receiving response. Therefore, the transmitting beam pattern can be monitored every 15 degrees.

Also, by injecting into the test array a signal which is keyed to the AN/AQS-10 transmitter, system range and bearing accuracy can be checked every 15 degrees and at every range scale. This is accomplished by transmitting a 3.5—or 35-millisecond pulse with a repetition rate which is determined by the range scale selected on the AN/AQS-10 control set. A delay introduced by a variable adjustment on the test set is used to simulate a target range.

This system is representative of a first attempt to design, develop and fabricate a near-field type sonar performance monitoring system, and as such is not indicative of the optimum in system effectiveness. However, this system's performance is indicative of the results that can be attained through the utilization of a near-field measuring technique. A sonar system's operational performance has been completely described by a radically new type of monitoring system with results that completely substantiate the efficacy of the measuring approach.

The degree of resolution to which sonar system parameters can be measured is directly dependent on the design sophistication of the test system. Although the AN/AQS-10 test

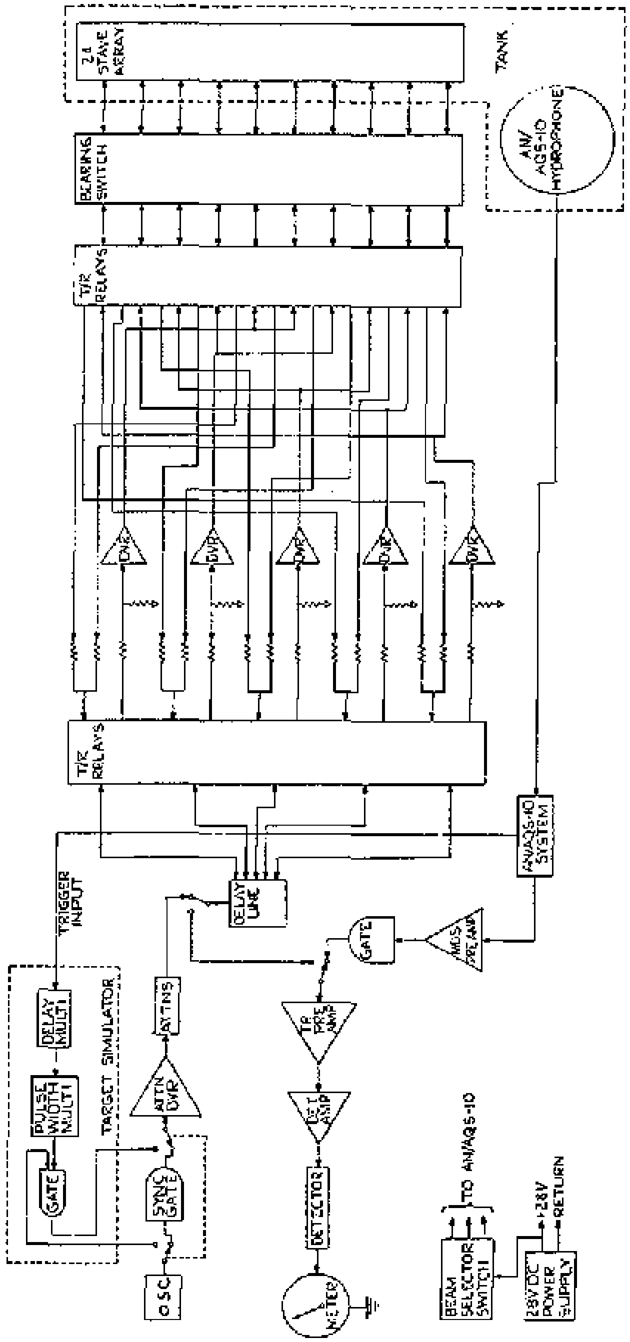

Figure 16. Test Tank System Block Diagram

system has achieved all the performance specification goals initially set forth, it is not possible to conclude that more rigid measurement requirements can be specified and, in turn, be attained by implementing slight improvements in design criteria. Based also on the experience derived from this design, it is possible to similarly conclude that some of the system design criteria may be relaxed.

As previously described, through simple modifications, the system could be adaptable to an operator training device. Such a system would provide an operator with the opportunity of training under actual operational acoustic conditions rather than in artificial, electrically-generated simulation conditions.

The next technological step in the development of the near-field program is to show the practicability of calibrating a sonar transducer with an array of acoustically transparent probes which are fixed with respect to ship's coordinates and located inside the sonar dome. This concept of a fixed, conformal, broadband near-field calibrated array is presently undergoing study and analysis with significantly encouraging results.

TABLE 1

Discreet Beam Pattern Test Points

Beam No. 1	Output Voltage	db re 100V
MRA	100V	0
-15	66V	-3.6
-30	24V	-12.5
-45	7.6V	-22.4
-60	4.5V	-27.0
-75	6.4V	-23.9
-90	8.0V	-21.9
-105	7.0V	-23.2
-120	4.8V	-26.4
-135	2.9V	-30.7
-150	2.2V	-33.1
-165	2.0V	-34.0
180	1.7V	-35.4
+165	1.9V	-34.4
+150	2.2V	-33.1
+135	2.8V	-31.0
+120	4.8V	-26.4
+105	7.0V	-23.2
+90	7.6V	-22.4
+75	6.0V	-24.4
+60	5.0V	-26.0
+45	8.2V	-21.7
+30	23.4V	-12.6
+15	65V	-3.6

References:

J. W. Trott, "Underwater-Sound Transducer Calibration from Near-Field Data," J. Acoust. Soc. Am. 36, pp. 1557-1558 (9 Aug, 1964)