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Dockside In Situ Measurements on SQS-26 Sonar Transducer with NRL Large Nearfield Calibration Array

[Unclassified Title]

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(U) The results of dockside in situ source level, sensitivity, transmit beam pattern and receive beam pattern measurements with the large Naval Research Laboratory (NRL) Nearfield Calibration Array (NFCA) on the SQS-26 CX sonar transducer as installed on the USS BLAKELY (1072) are described. These nearfield technique measurements are compared with computed farfield results and with classical farfield technique measurements performed on the same type sonar transducers reported by other authors. On the whole, the comparison agreement is fair

(Continues)

20. Abstract (Continued)

for source level, sensitivity and receive beam pattern measurements. However, the comparison of the transmit beam patterns are in sharp contrast. Some previously reported results and some unpublished measurements with the NFCA on large experimental transducers and on a quarter sector section of the BQS-6 submarine sonar transducer are included in Appendix B that show experimental verification of the nearfield calibration technique as applied with the NFCA.

CONTENTS

DOCKSIDE IN SITU MEASUREMENTS ON SQS-26 SONAR TRANSDUCER WITH NRL LARGE NEARFIELD CALIBRATION ARRAY

[Unclassified Title]

INTRODUCTION

(U) When the radiation frequencies of sonar transducers were 10 kHz or greater, the physical dimensions of the array apertures were small. The classical farfield measurement techniques produced meaningful results for the transducer performance characteristics in small volumes of water, such as acoustic tanks, small lakes and sheltered harbors. However, present-day, large low frequency sonar transducer arrays, such as the SQS-26 and the BQS-13 installed on destroyers and submarines respectively, require water depths in excess of 100 feet and distances between source and the farfield measuring hydrophone in excess of 200 feet. These greater depths and distances generated new problems both in establishing adequate facilities and by introducing anomalies in the measurements due to media inhomogeneities inherent in larger volumes of water. The interest in these problems has produced considerable effort to determine farfield radiation characteristics of underwater transducers from measurements made in the nearfield or Fresnel zone. The analytical treatment of the interzonal relationship is given in the literature [1-4]. A combination measurement-computation approach to the problem was developed by Horton and Baker of the Defense Research Laboratory (DRL), renamed the Applied Research Laboratories of the University of Texas. A more direct nearfield measurement technique that obeys the reciprocity principle was conceived and developed by W. James Trott of the Naval Underwater Sound Reference Laboratory. This laboratory has since merged with the Naval Research Laboratory (NRL) as the Underwater Sound Reference Division. R.J. Bobber [5] outlines a comprehensive comparison of the two approaches.

(U) The DRL method [5-7] computes the farfield pressure source level and distribution from nearfield measurements of pressure amplitude and phase in a numerical integration of a formulation of the Helmholtz integral equation over a closed surface surrounding the transducer source in its nearfield region. The pressure gradient term in the Helmholtz integral equation is approximated by the plane wave expression for the pressure gradient on the surface of integration. The measured data of pressure amplitude and phase are taken at discrete points spaced less than 0.8 of a wavelength apart over the surface of integration. This method is not reciprocal in the sense that it does not produce the receive sensitivity and beam pattern of a sonar transducer.

Note: Manuscript submitted January 31, 1975.

(U) The method developed by Trott [8-10] provided a practical solution in the form of the Nearfield Calibration Array (NFCA) whose direct response, when placed in the immediate proximity of a source, is proportional to the farfield pressure of the source in the direction normal to the place of the NFCA. The NFCA is reciprocal. That is, when used as a source in the immediate proximity of a receiver, the system response is proportional to the receiver free-field voltage sensitivity in the direction normal to the plane of the NFCA. Rotation of the transducer as a source or receiver about its own axis or rotation of the NFCA around the transducer will produce the transmit or receive beam pattern of the transducer. The first experimental model [9, 10] of the Trott NFCA concept was constructed as a plane circular array about 5 feet in diameter with a nearly uniform pressure amplitude region about 2.5 feet in diameter with an axial length of 5 feet along the principal normal to the plane of the array. Its useful frequency range was 4 to 12 kHz. The second experimental model [11,12] was constructed as a rectangular plane array about 10 feet by 7.5 feet with a useful plane wave volume about 5 feet by 3.5 feet and 12 feet along the principal normal to the array in the frequency range of 2 to 10 kHz.

(U) In order to develop experimental results to validate the nearfield calibration technique for the large sonar transducers such as the destroyer type SQS-26 and submarine type BQS-6 or BQS-13, a Large NRL NFCA was designed, constructed and evaluated [13-17]. This NFCA, shaded according to the Trott concept, consists of 2500 piezoceramic cylinders (3/4 inch dia. x 3/4 inch long with 1/8 inch walls) on 8 inch spacing in a 50 x 50 square matrix to form a 33 feet x 33 feet plane aperture with a useful plane wave volume about 18 feet in diameter centered on the principal normal and more than 40 feet long in the frequency range of 1 to 6 kHz. Its weight including the structural support frame is 4 tons. The overall dimensions are 40 feet x 38 feet x 1 foot. The construction details appear in Appendix A and some of the evaluation results [15] are repeated in Appendix B. In addition, a more rigorous derivation of the NFCA reciprocity principle based on the Helmholtz integral formulation with a numerical method for producing optimum shading coefficients for any distribution configuration of the point sources in the NFCA, both plane and conformal, was reported by Van Buren [18]. Additional measurements to experimentally verify the theory of the NFCA reciprocity principle were reported by Van Buren [19] in a paper presented to the Meeting of the Acoustical Society of America in April 1974 in New York City, N.Y.

(U) The response of the NFCA on both reception and transmission is directionally selective in that the response level outside the uniform pressure amplitude volume falls off with a sharp gradient to less than -20 dB. This property could be used to advantage in restrictive water volume regions such as exist at docking facilities for Naval vessels. Consequently, plans were made to use the NFCA in such an environment. This report discusses the application of the Large NRL NFCA to in situ, dockside acoustic measurements of the SQS-26 sonar transducer on a destroyer, the USS BLAKELY. The main objective of this effort was to determine feasibility of the nearfield calibration technique in the dockside environment at a typical Naval home port. In this dockside circumstance the water volume is small and the sources of reflections for multipath propagation are abundant. The Charleston S.C. Naval Station was chosen for these measurements because it is the only station on the East Coast with at least 40 feet of water depth at dockside to completely submerge the NFCA. It was anticipated that successful acoustic measurements of at least the source level of a ship's large sonar transducer in this environment would establish feasibility of the nearfield calibration technique sufficient to encourage its application as an added capability to the Sensor Accuracy Check Site (SACS) Facilities, particularly for depress beam calibration. These facilities are currently under development for in situ calibration of ship's sonar transducers. A pilot model is operational at Long Beach, California. Future plans envision establishment of a SACS Facility at each shipyard.

PREPARATION FOR MEASUREMENTS

(U) The Large NRL NFCA is shown in Fig. 1 supported in the vertical at the assembly and storage site alongside the wall of Building No. 53 at the Charleston, S.C. Naval Station. The 2500 piezoceramic point sources in the array are enclosed in 50 oil-filled tubular housings with 50 elements in each. These enclosures are concentric teflon and polyvinyl chloride tubes that are supported in expanded metal troughs oriented vertically prestressed axially and secured at twelve horizontal levels by prestressed flexible cables. This combination of stresses maintains the tubes in a plane and the prescribed spacing between them. The intersections of the twelve steel cables with the 50 support troughs provide 600 points for spacing adjustments as well as monitoring points across the face of the array to determine the position of each piezoceramic element with respect to a plane of reference and to each other. The adjustment tolerance allowance at each monitoring point was less than one-quarter of an inch.

(U) The NFCA was transferred in the vertical by a mobile crane from the assembly and storage site over a distance of several thousand feet to a floating crane at a docking area as shown in Fig. 2. The floating crane transported the NFCA to the destroyer docking pier. The floating crane was oriented normal to and at the end of the pier in position to lower the NFCA immediately in front of the bow of the USS BLAKELY as shown in Fig. 3. The floating crane suspended the NFCA in the water as shown in Fig. 4 with the center of the array in line on the horizontal with the ship's sonar transducer with approximately 22 feet of separation between. The ship's sonar transducer, the SQS-26, is a 15 foot diameter cylindrical array of 72 vertical staves about 6 feet long with 8 transducer elements in each stave. It is mounted in a dome at the bow at keel level of the ship at about 17 feet below the water surface. A rather gross method consisting of tie lines attached to the NFCA frame, was used to align and maintain the plane of the NFCA aperture normal to the ship's center line. Initially, the floating crane hoist cable assembly was rigged such that the NFCA was closer to the floating crane barge than to the ship's bow at the water line. This placed the center of the NFCA about 32 feet from the center of the ship's sonar transducer. Subsequently, the floating crane crew installed a hoist cable assembly that cleared the ship's bow, to allow positioning the NFCA right up against the ship's bow at the water line. This placed NFCA 22 feet from the sonar transducer and about 20 feet from the floating crane barge. This position of the NFCA relative to floating crane barge reduced the response to reflections from the floating barge to a neglible value as compared to the error of about 2 dB due to reflections for the previous position.

(U) Equipment for voice communications, sonar trigger pulse signals and sonar transducers receive signals, was installed between the ship's sonar control room and the measurement instrumentation housed in a shelter located on the end of the pier convenient to the bow of the ship and the NFCA. The calibrated measurement instrumentation had the capability of responding to and recording the pulsed sonar transmit signals picked up by the NFCA. These output signals from the NFCA were calibrated to directly measure the farfield pressure produced by the ship's sonar transducer. The measurement instrumentation also had the capability to insonify the ship's sonar transducer with a calibrated sound field pressure and to directly measure the sonar transducer receive signal to determine its receive sensitivity and receive beam pattern.

(U) The water current velocity at the end of the docking piers was dependent on the ebb and flow of the tides. The maximum velocities exceeded two knots, however for each tide cycle the flow currents during the tide turn-around was less than two tenths of a knot for about two hours. Since the handling facilities for maintaining stable orientation of the NFCA, while in the water at the bow of the ship were adequate in two tenths knot flow, the one week scheduled for this effort was arranged such that the tide turn-around occurred during regular working hours. The first and last days of the week were used for transferring the NFCA to and from the docking pier site. That left three two-hour periods for the in situ dockside acoustic measurements on the sonar transducer of the USS BLAKELY.

MEASUREMENTS

(C) Source level measurements, transit beam pattern data, receive sensitivity measurements and receive beam pattern data were obtained for the SQS-26 CX sonar transducer on the USS BLAKELY. The depression angle controls were set for zero depression angle for all modes of operation both transmit and receive. The source level measurements were obtained for the Omni Directional Transmit (ODT) and Bottom Bounce Track (BB/T) modes and transmit beam pattern data was taken for only the BB/T Mode and at five degree intervals through 180 degrees of bearing from 30 degrees through 00 degrees to 210 degrees. A casualty in the transmitter electronic driver precluded both repeat and additional transmit modes of operation. In the transmit modes the transmitter drive was operated at full power with triggered 500 ms pulse length of the continuous wave signal set at the f_2 (3.556 kHz) operational frequency at a repetition rate of one pulse per five seconds. The shorter 10 ms operational pulse length was not used because its control was not functioning properly.

(U) The receive sensitivity and receive beam pattern data were measured with the sonar transducer operating in the Bottom Bounce (BB) Variable Depression Receive Mode. The measurement for sensitivity was made on the main response axis of the VDR beam pattern. For these measurements the sonar transducer was insonified by the NFCA with a calibrated sound field of uniform pressure amplitude of 18.8 dB re one microbar at 3.550 kHz. The receive beam pattern data was obtained using the same sound field amplitude except that for the side lobe structure of the pattern, the sound level was increased 10 dB to keep the receive signal level within the dynamic range of the instrumentation system used for measuring and recording the data. The data points for the beam pattern were taken at one degree increments of bearing for the main beam and five degree increments for the side lobe structure for a total scan of 180 degrees from 30 degrees through zero degree to 210 degrees.

(U) The receive and transmit beam pattern data points through the 180 degree scan were obtained by rotating the sonar transducer main beam axis in incremental steps with the sonar system electrical scanning switch while the plane of the NFCA was fixed immediately at the ship's bow and normal to its center line. The controls in the sonar system electrical scanning switch for the BB/T transmit mode accomplished the beam steering by switching an adjacent stave (vertical array of eight transducer elements) into the advancing end of the transducer 24 stave aperture while switching out a stave at the receding end of the aperture. The consequence of this sequence of switching is an effective rotation of the main beam, side lobe structure and back radiation of the directivity pattern through 360 degrees in increments of one stave which corresponds to five degrees, since there are 72 staves on the sonar transducer cylindrical array. The sonar system scanning controls provide for indefinite dwell at any five degree increment of bearing through a complete rotation. The scanning controls for steering the main beam in the VDR mode are similar to those in the transmit mode except that beam-forming network in the BDR mode has higher resolution and provides steering in increments of one degree.

MEASUREMENTS RESULTS

(C) The source level and receive sensitivity measurements obtained with the NFCA on the SQS-26CX sonar transducer of the USS BLAKELY at dockside are compared in Table I with a computed value [20] for a mathematical model of the SQS-26CX sonar transducer and measurements made with the classical farfield technique [21-24]. The computed value listed in the table is a product of the normalized result 122.6 dB re 1 microbar per volt at 1 yard) from reference [20], Table A-VI, page A-16, midfrequency, zero depression angle and the full power voltage (15.8 dB re 1 volt) from reference [21], Appendix I, page 18. The measured comparison values taken from reference [21-23] are for the SQS-26CX type sonar transducers installed aboard the USS HEBRON, KIRK and PEARY respectively. Those from reference [24] are for an SQS-26AXR on the USS BRONSTEIN. The USS HEBRON values for the "electrical steering" case were taken from reference [21], Table 6 (Fig. 57), Table 8 (Fig. 75), and Table 20 (Fig. 123) for the BB/T BB/T (repeat) and VDR modes respectively. For the "hydrophone positioning" case, the values are from the same reference, Table I (Fig. 12), Table I (Fig. 3), Table 2 (Fig. 15), Table II (Fig. 96), and Table 12 (Fig. 99) for the ODT, BB/T, BB/T (repeat), VDR and VDR (repeat) modes respectively. The terms, "electrical steering" and "hydrophone positioning" are used to distinguish the two methods for acquiring the pressure amplitude distribution in a plane as a function of bearing. In one case the pressure measuring sensor is fixed in position while the sound source's directional beam is given an angular displacement about a fixed center of rotation by electrically switching the source array elements in and out sequentially. In the other case the equivalent is accomplished by angular positioning of the sensor around the sound source. The data from reference [22-24] was obtained by the "hydrophone positioning" method. The measured results for the USS KIRK and the specification standard values listed in Table I were taken from reference [22], page 6, paragraph 2.2.9 for the ODT and BB/T modes and page 4, paragraph 2.2.5 for the VDR mode. Corresponding data for the sonar transducer on the USS PEARY is from reference [23], page 6, paragraph 2.2.9 for the ODT and BB/T modes and page 4, paragraph 2.2.5 for the VDR mode. The data in Table I for the SQS-26AXR sonar transducer on the USS BRONSTEIN was taken from reference [24], page 3, paragraph E for the ODT and BB/T modes, and page 3, paragraph F for the VDR mode. Corresponding standard specification data in footnote (7) of Table I is on page 3, paragraphs E and F in the same reference.

(C) TABLE I
SOURCE LEVEL AND RECEIVE SENSITIVITY

	Transmit Modes			Receive Mode	
	dB re 1 microbar at 1 yard			dB re 1 Volt per microbar	
	ODT	BB/T	BB/T*	VDR	VDR*
USS BLAKELY-NFCA-NRL	131.3	145.7	145.6	-23.8	- -
Computed-Tracor (1)	- -	138.4	- -	- -	- -
USS HEBRON-NUSC/NL (2)	- -	142.8	144.8	-26.8	- -
USS HEBRON-NUSC/NL (3)	128.5	144.4	142.8	-25.4	-23.9
USS KIRK-NELC-SACS (4)	128.5	140.8	- -	-24.1	- -
USS PEARY-NELC-SACS (5)	128.9	140.1	- -	-25.7	- -
SQS-26CX Spec. Std. Values (6)	129	143	- -	-24	- -
USS BRONSTEIN-NELC-SACS (7)	125.8	140.4	- -	-25.1	- -

*REPEAT MEASUREMENTS

(1) From Ref. [20]

(2) From Ref. [21] - "electrical steering"

(3) From Ref. [21] - "hydrophone positioning"

(4) From Ref. [22]

(5) From Ref. [23]

(6) From Ref. [22]

(7) From Ref. [24] - SQS-26AXR Std. Values are 129 dB for ODT Mode, 144 dB for BB/T Mode and -24 dB for VDR Mode.

The farfield azimuth transmit beam pattern determined from NFCA nearfield measurements of the SQS-26CX sonar transducer on the USS BLAKELY at dockside is compared with computed [25] farfield patterns in figures 5, 6 and 7, and with other measured [21, 24] farfield beam patterns in figures 8 and 9. To show the degree of dispersion of measured data on the SQS-26 type sonar transducers from other sources (22, 23, 26, 27), the NFCA data, data from reference [21] and one computed [25] pattern are repeated in Fig. 10.

(U) In Figure 5 the measured NFCA beam pattern data taken in 5 degree increments by "electrical steering" from 30 degree bearing through 0 degrees to 210 degrees at the f_2 (3.556 kHz) frequency and zero degree depression angle settings in the BB/T transmit mode is compared to the computer pattern from reference [25], page 78. This computed pattern was based on a mathematical model of the SQS-26CX sonar transducer operating at the f_2 frequency setting in the narrow (BB/T) beam transmit mode with zero depression angle. The comparison of the NFCA data in Fig. 6 is with a computed pattern from reference [25], page 74 based on the same conditions as the computed pattern in Fig. 5, except that the operating frequency is f_1 (3.212 kHz). At this frequency the computed pattern has a more narrow main lobe. The NFCA data in Fig. 7 is compared to a computed pattern from reference [25], page 15, which again is based on the same imposed conditions as the one in Fig. 5, except for depression angle setting of 30 degrees. This computed pattern also is more narrow than the one in Fig. 5. In the depression angle control settings other than zero, the sonar system electrical circuitry, introduces a straight line slope of relative phase differences of drive between the eight transducer elements in each of the 24 vertical staves in the working aperture of the SQS-26 cylindrical sonar transducer array. This phasing produces an effective downward steering of the beam pattern. According to reference [20], the azimuth relative phasing of the staves in the aperture to a plane array equivalence is the same for all depression angle and frequency settings and is chosen to be optimum for the 30 degree depression angle setting.

(U) The same NFCA measured transmit beam pattern data is compared in Figures 8 and 9 to the measured results [21, 24] obtained by the classical farfield technique under the same sonar system operational control settings with respect to frequency, depression angle and narrow transit (BB/T) mode. In figure 8 the comparison is with the results for the SQS-26CX sonar transducer on the USS HEBRON acquired at a farfield separation distance of 212 feet by the "electrical steering" method [21], Fig. 57 and by the "hydrophone positioning" method [21], Fig. 3. In Fig. 9, the comparison is with measured results for the SQS-26 AXR sonar transducer on the USS BRONSTEIN [24], Fig. III-13, which were obtained by the "hydrophone positioning" method at a farfield separation distance of 170 feet, less than the 200 feet minimum distance for farfield measurements.

(U) The comparison shown in Fig. 10 for the NFCA data with a computed pattern and several measured beam patterns gives some indication of the variations in measured results relative to the computed pattern. The computed pattern [25], page 78, is a repeat of the one in Fig. 5. The measured patterns the USS HEBRON from reference [21] are repeats of those in Fig. 8. The other measured patterns are from references [22], Fig. 3.15.2, page 50; [23], Fig. 3.15.1, page 40; [26], Fig. 3.11, page 33; [27], Fig. 3.17.1, page 42. The latter four patterns are for the same type (SQS-26CX) sonar transducer as the USS BLAKELY has and operated at the same f_2 frequency and zero depression angle control setting in the BB/T transmit mode with data acquired by the "hydrophone positioning" method but at a farfield separation distance of 120 feet as compared to 212 feet used for results in reference [21].

(U)The farfield azimuth Variable Depression Receive (VDR) beam pattern obtained with the NFCA nearfield measurements for the SQS-26CX sonar transducer on the USS BLAKELY at dockside is compared with computed [25] farfield VDR beam pattern in Fig. 11, and with measured [21-24] VDR beam patterns in Figures 12 through 16. To show the degree of dispersion of measured data for VDR beam patterns for the SQS-26CX type sonar transducer as compared to the computed pattern, the measured results from the NFCA data and those from the several sources [21-23] are repeated in Fig. 17.

(U)In the comparison shown in Fig. 11, the measured NFCA data was acquired by the "electrical steering" method through 180 degrees of bearing for channel number 7 with the sonar transducer operating in the bottom bounce VDR mode at the f_2 frequency and zero depression angle settings. The basis for the computed [25] page 366 pattern is a mathematical model of a typical channel of an SQS-26CX sonar transducer operating in the bottom bounce VDR mode at the f_2 frequency and zero depression angle settings. The NFCA VDR pattern data is repeated in Figures 12 and 13 for comparison with measured farfield beam patterns from reference [21] Figs. 123 and 99 respectively for VDR channel 6 of the SQS-26CX sonar transducer on the USS HEBRON. The operating mode and sonar system control settings were the same as those for acquiring the NFCA data on the USS BLAKELY. The USS HEBRON data in Fig. 12 was obtained by "electrical steering" to effect spatial bearing displacement and by "hydrophone positioning" for the data in Fig. 13. In both cases the classical farfield measuring technique was used with a farfield separation distance of 212 feet. In Fig. 14 the NFCA data is again repeated for comparison to the measured pattern from reference [24], Fig. III-11 for the VDR channel 6 of the SQS-26 AXR sonar transducer on the USS BRONSTEIN which was operated in the bottom bounce VDR mode at the f_2 frequency and zero depression angle settings with data acquisition by the "hydrophone positioning" method using the classical farfield measuring technique at a separation distance of 120 feet. The NFCA data is also repeated in Fig. 15 and 16 for comparison to measured receive patterns from reference [23], Fig. 3.11.3 for an SQS-26CX sonar transducer on the USS PEARY and reference [22], Fig. 3.11.7 for an SQS-26CX sonar transducer on the USS KIRK respectively. The operating mode (bottom bounce VDR), frequency (f_2) and depression angle (zero) settings, data acquisition by "hydrophone positioning" using the classical farfield measuring technique at 120-foot farfield separation distance, and VDR channel number (6) were the same for both the PEARY and KIRK. The NFCA VDR pattern data for the USS BLAKELY, HEBRON, PEARY and KIRK are repeated in Fig. 17 to show the scatter of the measured results relative to the computed [25], page 366, VDR beam pattern for the SQS-26CX sonar transducer.

DISCUSSION

(U) The comparison in Table I of NFCA source level and receive sensitivity measurements of the SQS-26CX sonar transducer on the USS BLAKELY with measurements by the classical farfield technique performed on the SQS-26CX sonar transducers installed on the several destroyers shows significant variations. However, when consideration is given to the innumerable suspected influence factors and anomolies that are not under continuous experimental control, particularly with respect to the equipment in the complex circuitry of the sonar system, these variations lose an appreciable degree of their significance.

(C) The largest difference in Table I is relative to the computed source level for the BB/T mode. Part of this difference may be due to an incorrect assumption for the driving voltage for full acoustic power output for the SQS-26CX sonar transducer. Reference [20] gives the computed source level normalized to one volt and the value of 138.4 dB in Table I is a product of the normalized value and the full power voltage applied to the SQS-26CX transducer for the measurements reported in reference [21]. The next order of significant difference, 2.8 dB, is for the ODT mode between the NFCA value. The only further reasoning for these two discrepancies and for the significant difference between the specification standard value for the SQS-26 AXR sonar transducer on the USS BRONSTEIN is resort to anomolous causes. The comparison of the NFCA source levels for the BB/T mode with the values for the SQS-26CX transducer on the USS HEBRON is in fair agreement when variations among repeated measurements is taken into consideration. For example, comparing the NFCA value of 145.6 dB with 144.8 dB for the repeat measurement on the USS HEBRON transducer, the difference is less than 1 dB. A similar comparison of an extreme value for the measured receive sensitivity of the SQS-26CX transducer on the USS HEBRON with the corresponding NFCA value also shows an insignificant difference (0.1 dB).

(U) Table I also shows significant differences in comparison of both the NFCA source level values and those by NUSC/NL for the BB/T mode with the NELC-SACS values for the same mode. The reason advanced as an explanation is that the NELC-SACS measurements were made at a short (120 feet) separation distance before the Fraunhofer sound field of the transducer was fully developed, i.e., the proximity criteria was not satisfied. However, some detraction from this reasoning is apparent when comparing the less significant differences in the corresponding receive sensitivities, because reciprocity theory requires the same proximity criteria when the roles of transducers as between hydrophone and projector are interchanged. Consequently, there is left only resort to unknown anomolies as an explanation for portions of these variations among the measured values of source level and receive sensitivities for the several SQS-26CX sonar transducers chosen for comparison with the NFCA measurements.

(U) The transmit beam pattern data obtained with the NFCA on the SQS-26CX sonar transducer on the USS BLAKELY at dockside while operating in the BB/T mode at the f_2 (3.556 kHz) frequency and zero depression angle control setting is compared with three computed beam patterns in Figures 5, 6 and 7 taken from reference [25]. The lack of agreement of the NFCA data with the main beam of the computed pattern in Fig. 5 for the BB/T mode at the f_2 frequency and zero depression angle control settings of a typical SQS-26 CX sonar transducer is obvious. The agreement in symmetry with respect to the main beam axis is fair as is the agreement for the side lobe structure beyond the first three side lobes. Because of this poor comparison agreement, as shown in Fig. 5, and some uncertainty about several factors that were not independently measured, such as the driving frequency and the phasing for both azimuth and vertical beam pattern formation which depends on the depression angle control settings, the NFCA transmit beam pattern data is compared in Fig. 6 with the computed pattern from reference [25] for the f_1 (3.212 kHz) and zero depression angle setting, and in Fig. 7 with the computed pattern from the same reference for the f_2 frequency but 30 degree depression angle setting. With respect to the Fig. 5 comparison, the agreement in both Fig. 6 and 7 is better and best in Fig. 7. According to reference [20], the combination of vertical and azimuth phasing is optimized in the BB/T transmit mode for the f_2 frequency and 30 degree depression angle setting. It is assumed that optimum means a beam pattern with narrowest main beam and lowest side lobe structure. The NFCA data fits this optimum better as is evidenced in Fig. 7 than the computed patterns in Figs. 5 and 6. The importance of making independent measurements to minimize uncertainties is obvious.

(U) The comparison of the NFCA data in Fig. 8 with the measured results from reference [21] for the SQS-26CX sonar transducer on the USS HEBRON for the BB/T transmit mode with the f_2 frequency and zero depression angle control settings by both the "electrical steering" and "hydrophone positioning" methods of data acquisition shows nearly the same disagreement for the main beam as with the computed pattern in Fig. 5. The side lobe structure, particularly for the right side of the patterns, is in fair agreement.

(U) Fairly good agreement of the NFCA data is evident in Fig. 9 with the measured results from reference [24] for the SQS-26AXR sonar transducer on the USS BRONSTEIN obtained by the classical farfield technique with the separation distance of 120 feet at the NELC SACS Facility with the f_2 frequency and zero depression angle settings in the BB/T transmit mode. The nominal azimuth relative phasing in electrical degrees for the SQS-26AXR sonar transducer 24 stave aperture transmitting in the BB/T Mode is 0, 15, 45, 90, 149, 222, 308, 407, 520, 670, 770 and 912 as compared to 0, 19, 39, 82, 128, 198, 272, 360, 463, 571, 689, and 810 for the SQS-26CX transducer. This relative phasing for the SQS-26AXR is considered optimum at the f_2 frequency and zero depression angle setting, whereas for the SQS-26CX the optimum is at the f_2 frequency but at the 30 degree depression angle setting which introduces additional relative phasing to depress the beam pattern downwards by 30 degrees. This accounts for the reported BB/T mode azimuth beam pattern differences as between the SQS-26AXR and SQS-26CX sonar transducer systems. These comparisons lend credence to the suspected uncertainty of the depression angle sonar system control settings when the NFCA data on the sonar transducer of the USS BLAKELY was taken. This again emphasizes the importance of independent measurements of the sonar system parameters for the different operational sonar system control settings for which measurements are made. The preferred alternative approach for direct comparison is simultaneous measurements on the same sonar transducer by the nearfield and the classical farfield calibration techniques as was done for the transmit measurements reported in reference [15] some of which are reproduced in Appendix B. This approach is anticipated for future comparisons of the two techniques at the SACS Facility by NELC.

(U) In Fig. 10 the scattering of the measured beam pattern data from various sources relative to the computed pattern for the SQS-26CX sonar transducer is outside the region defined by the computed pattern except the NFCA data which, of course, shows a narrower beam as it does in Fig. 5. It is significant that the measured results obtained at the NELC-SACS Facility have a broader main beam as compared to the NUSC data, because the farfield separation distance was nearly half that for the NUSC data and, therefore, more nearly in the nearfield region of the sound field. Although the NUSC data was taken at a 212 feet separation distance, it still shows a slightly broader pattern than the computer pattern which suggests that the 212-foot separation distance may still be short of the Fraunhofer region of the sound field.

(U) As shown in Fig. 11, the NFCA measured receive data for the BB mode, zero depression angle and f_2 frequency settings, VDR Channel #7 beam pattern for the SQS-26CX sonar transducer on the USS BLAKELY at dockside compares favorably with the corresponding computed [25] pattern within the -4 dB down points and then diverges significantly along the skirts of the main lobe and with respect to the first portion of the side lobe structure. But, then again it falls fairly well within the remaining portion of the side lobe structure and the reported portion of the back lobe structure.

(U) The NFCA receive beam pattern data is in fair agreement with the receive pattern measurements taken by the classical farfield technique, as shown in Figs. 12 through 17. In Fig. 12 the apparent discrepancies as the result of assymmetry. The NUSC data for the SQS-26CX transducer on the USS HEBRON shows a slightly greater degree of assymmetry as compared to the NFCA data. Both sets of data were acquired by the electrical steering procedure. In Fig. 13 the NUSC data was acquired by the "hydrophone positioning" method and shows a sharper departure from symmetry as compared to the NFCA data along the -10 dB to -20 dB right hand skirt portion of the main lobe of the beam pattern.

(U) The NFCA receive beam pattern data for the SQS-26CX sonar transducer on the USS BLAKELY is compared in Fig. 14 with corresponding NELC-SACS Facility measurements on the SQS-26AXR sonar transducer on the USS BRONSTEIN. The agreement is fairly good overall except for the assymmetry of the SQS-26AXR beam pattern in the region of the -4 or -5 dB down points and a significant narrowing of its main lobe skirts below the -10 dB down points.

(U) The comparison of the NFCA receive data with the NELC-SACS VDR receive measurements on the SQS-26CX transducers on the USS PEARY and USS KIRK in Figs. 15 and 16 respectively is in about as fair agreement as the comparisons in Figs. 12 and 13 with the SQS-26CX sonar transducer on the USS HEBRON.

(U) Figure 17 shows the scatter of the measured VDR receive beam pattern data for the SQS-26CX sonar transducers on several destroyers, including the NFCA data relative to the computed receive pattern for a mathematical model of an SQS-26CX sonar transducer. All of the measured data falls on or outside of the main lobe of the computed pattern and the NFCA data appears close to the mean of all the measured results. With respect to the side lobe structure of the computed beam pattern, the NFCA data on the whole compares more favorably than the data measured by the classical farfield technique. This is a consequence of the characteristic capability of the NFCA to reject most of the multipath propagation signals that influence the resultant reception signal obtained with the classical farfield calibration technique in media that contain complex boundaries such as may exist at dockside. It is emphasized that on reception as well as on transmission, the comparison of different measurement techniques would be much more conclusive if accomplished by the alternate approach of simultaneous measurements of the same sonar transducer as was done in obtaining the results from reference [15] reproduced in Appendix B.

CONCLUSION

(U) The principal objective of this experiment, to demonstrate the feasibility of the Large NRL NFCA for dockside in situ source level measurements on the Navy large low frequency sonar transducer with little or no interference from multipath signal propagation, was accomplished. The secondary objective of increasing confidence level in the nearfield calibration technique was accomplished sufficiently to justify comparison experiments for the nearfield and classical farfield calibration techniques by NELC of the Long Beach California SACS Facility. The ultimate objective of NELC is to incorporate the nearfield calibration technique to extend the capability of the SACS Facility to in situ calibration of the downward directed or depressed beam of the sonar transducers. The existing water depths (50 feet) at the Long Beach SACS Facility, and at other planned shipyard sites for this facility, is not adequate without periodic prohibitively costly dredging to minimize multipath signal interference in the measurements of the depressed transducer beam by the classical farfield technique. Because the nearfield technique does not require the long separation distances between the sound projector and the measuring hydrophone, the direct signal is measured before it is reflected by the bottom and surface interfaces. Consequently, the nearfield technique will not only extend the SACS Facility capability to measurement of the transducer depressed beam but will reduce the size and, therefore, the cost of the planned facilities at other sites.

(U) The experience with this experiment has emphasized the advisability of making independent measurements of the various parameters of the sonar system including the sonar transducer, such as azimuth and vertical phasing networks on transmission and reception, transmitter drive level, transducer element impedance, linearity behavior with drive level, etc., including stability of these parameters with time. The alternative approach of simultaneous acoustic measurements on the sonar transducer of the same ship or submarine for comparison of two or more calibration methods, such as the nearfield and classical farfield calibration techniques, would preclude the need for extensive sonar system parameter measurements.

ACKNOWLEDGEMENTS

(U) The authors wish to express appreciation to Delfus Dorsey for assistance in the handling, assembly and dimensional alignment to a nominal plane of the 2500 acoustic sensor element in the frame of the NFCA in preparation for the dockside in situ measurements. Thanks is also gratefully expressed to Josephus Neeley for assistance in preparation and operation of the instrumentation system for the electrical and acoustical measurements for the experiment. Grateful appreciation is extended to the Commander, Cruiser-Destroyer Force, U.S. Atlantic Fleet, Newport, Rhode Island, for authorizing use of the USS BLAKELY for acoustic measurement on its SQS-26CX sonar transducer, as well as assistance in the numerous arrangement details by the Commander's Maintenance Representative and his SCAT Team at the Charleston Naval Shipyard. Special appreciation is directed to the Commanding Officer of the Charleston Naval Station and units under his Command, particularly, to the Station's Shipyard Liaison and Public Work Officer, LT Ken Bell, the SeaBee Unit under LT W.C. Fisher, and the Port Services Group commanded by CDR G. Fondron, for their gracious hospitality generously sprinkled with patience for our shortcomings and for the almost endless series of small and large tasks accomplished with dispatch and interest in success of the experiment.

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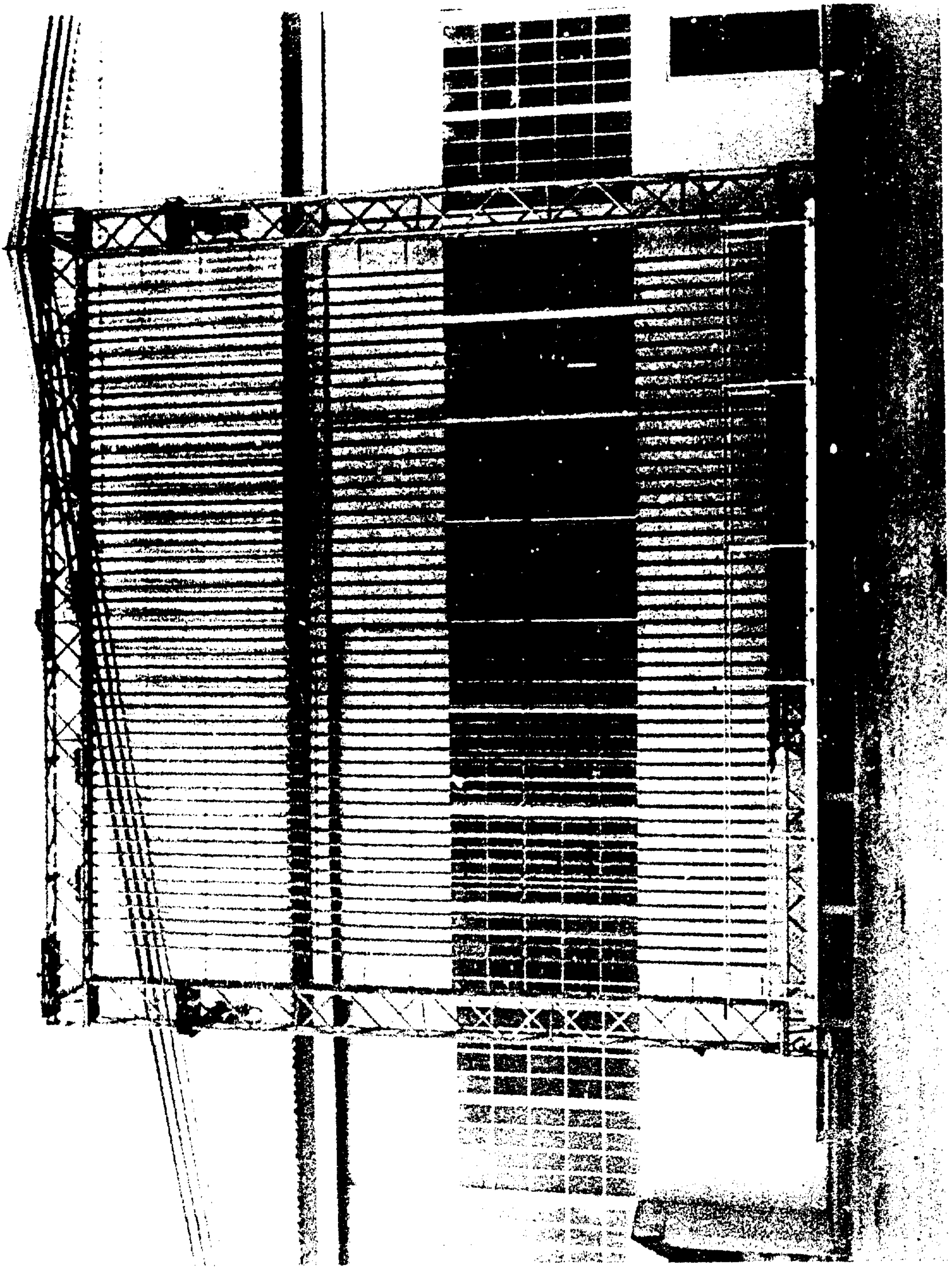
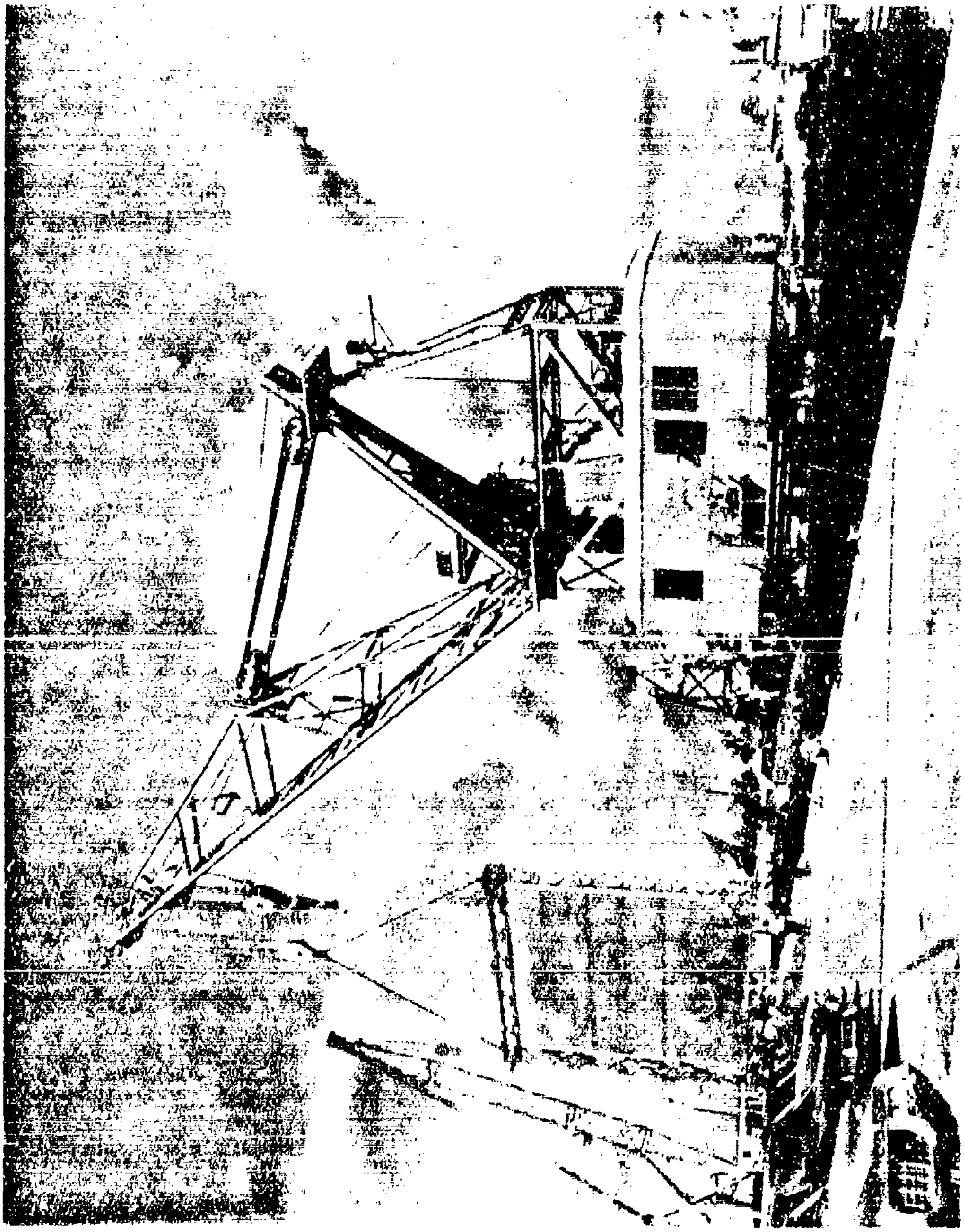
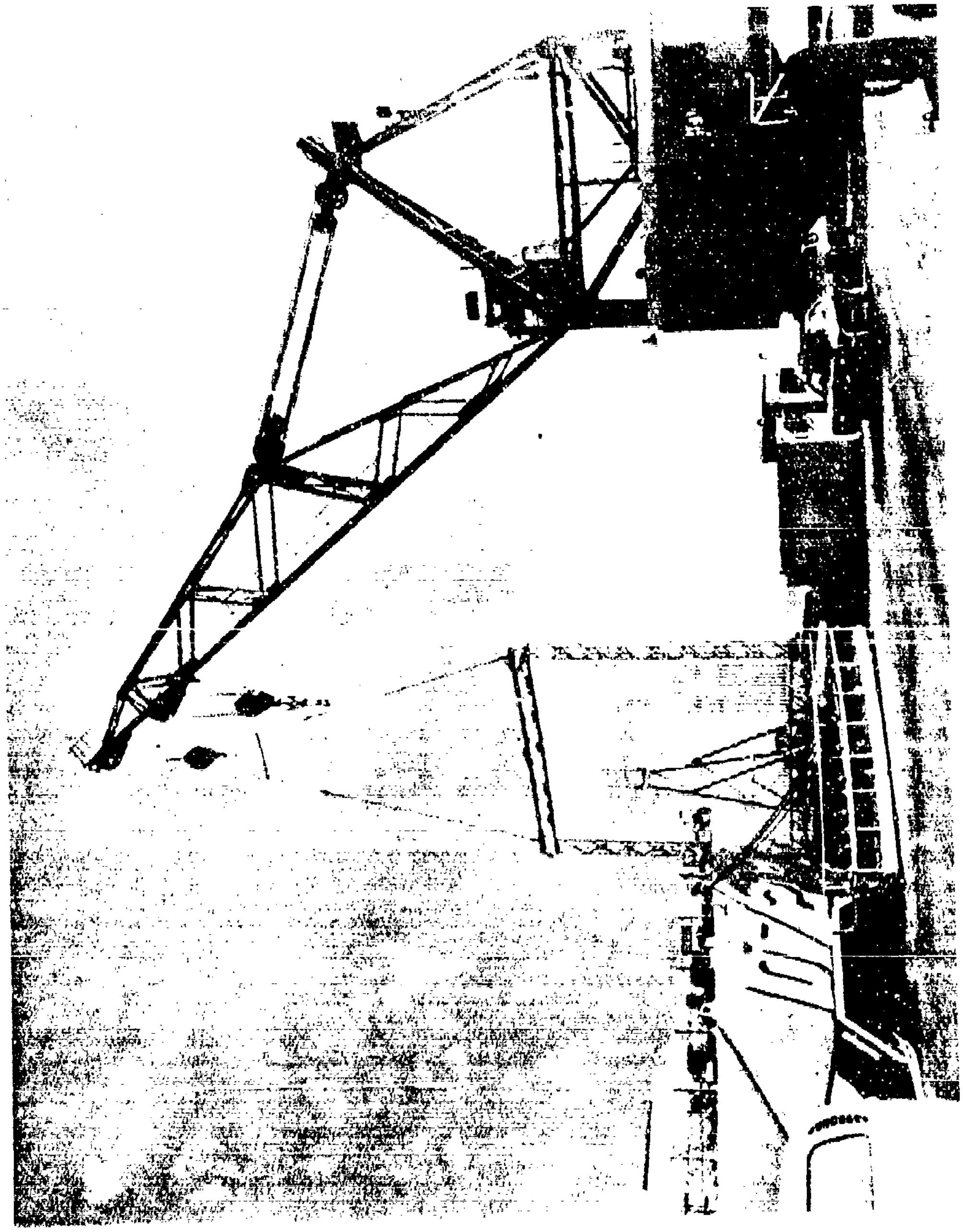


(U) Fig. 1 — Photo of NFCA at assembly-storage site — Charleston Naval Station (CNS)

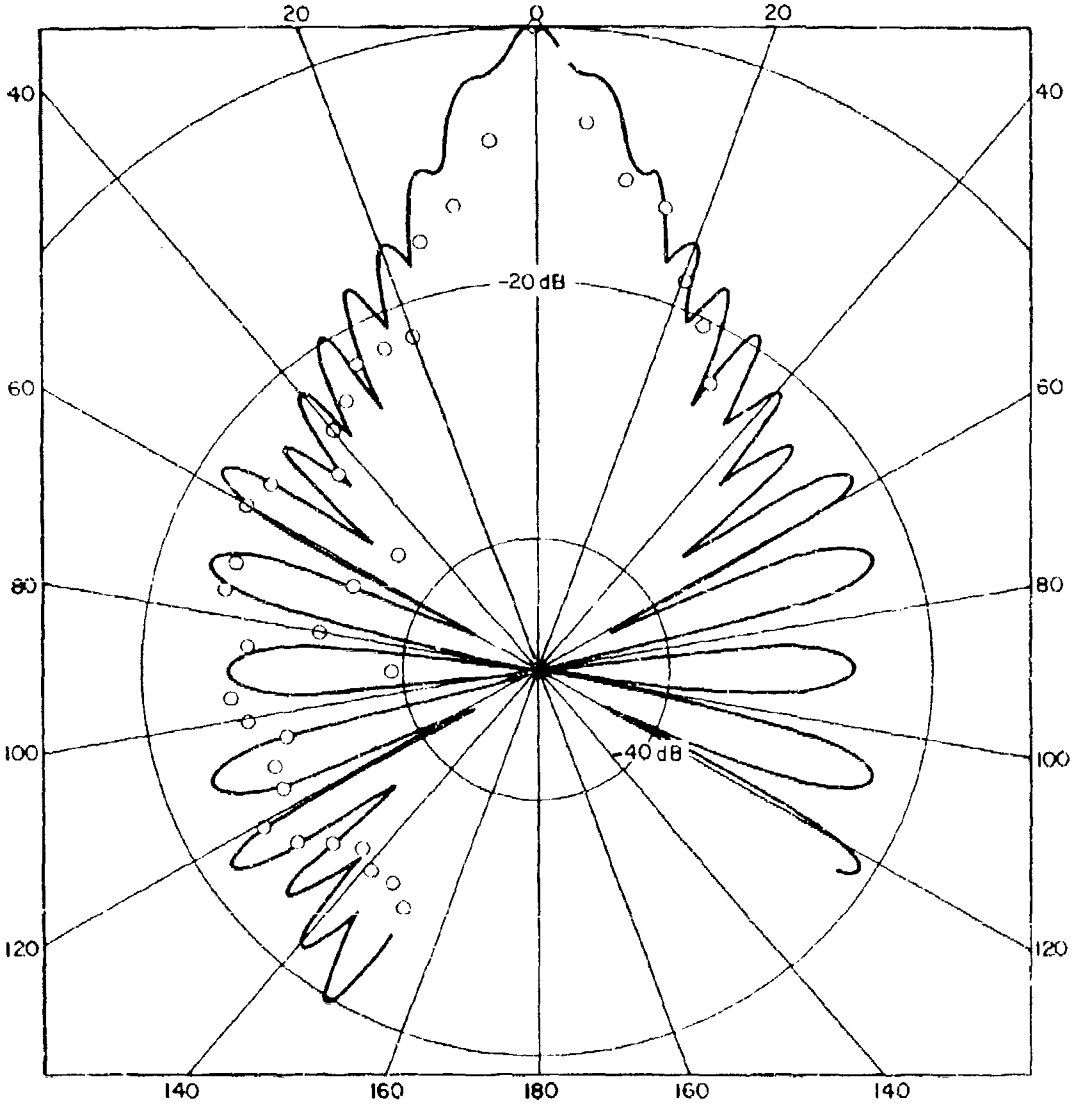


(U) Fig. 2 — Photo of NFCA at quay wall-transfer from mobile crane to floating crane



(U) Fig. 3 – Photo of NFCA at docking pier at bow of USS BLAKELY

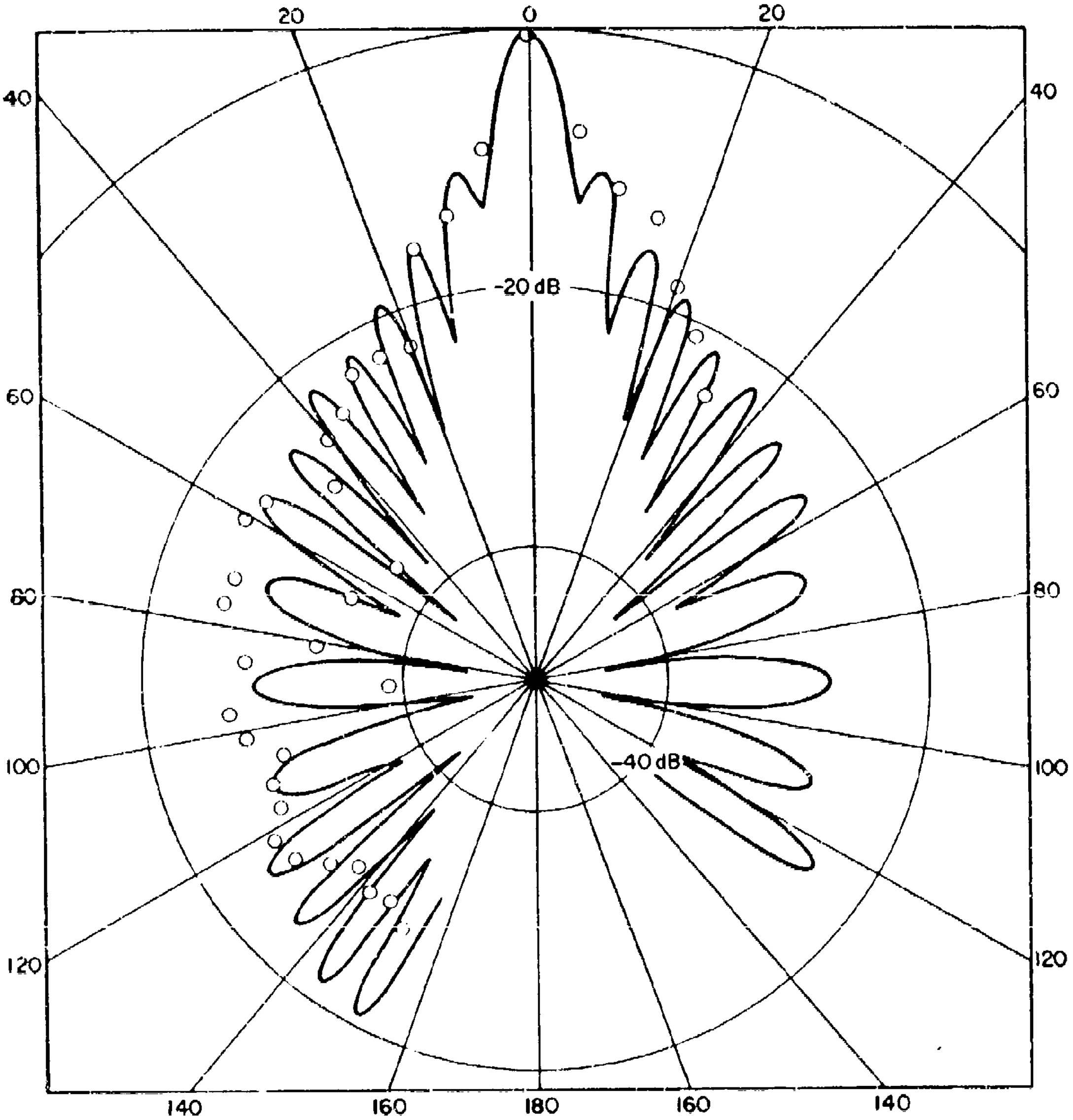
(U) Fig. 4 - Photo of NFCA in water at bow of USS BLAKELY



(C) Fig. 5 — Farfield azimuth transmit beam pattern — BB/T mode — SQS26CX

—— Computed by Kunz [25] page 78 - zero depression-3.556 kHz

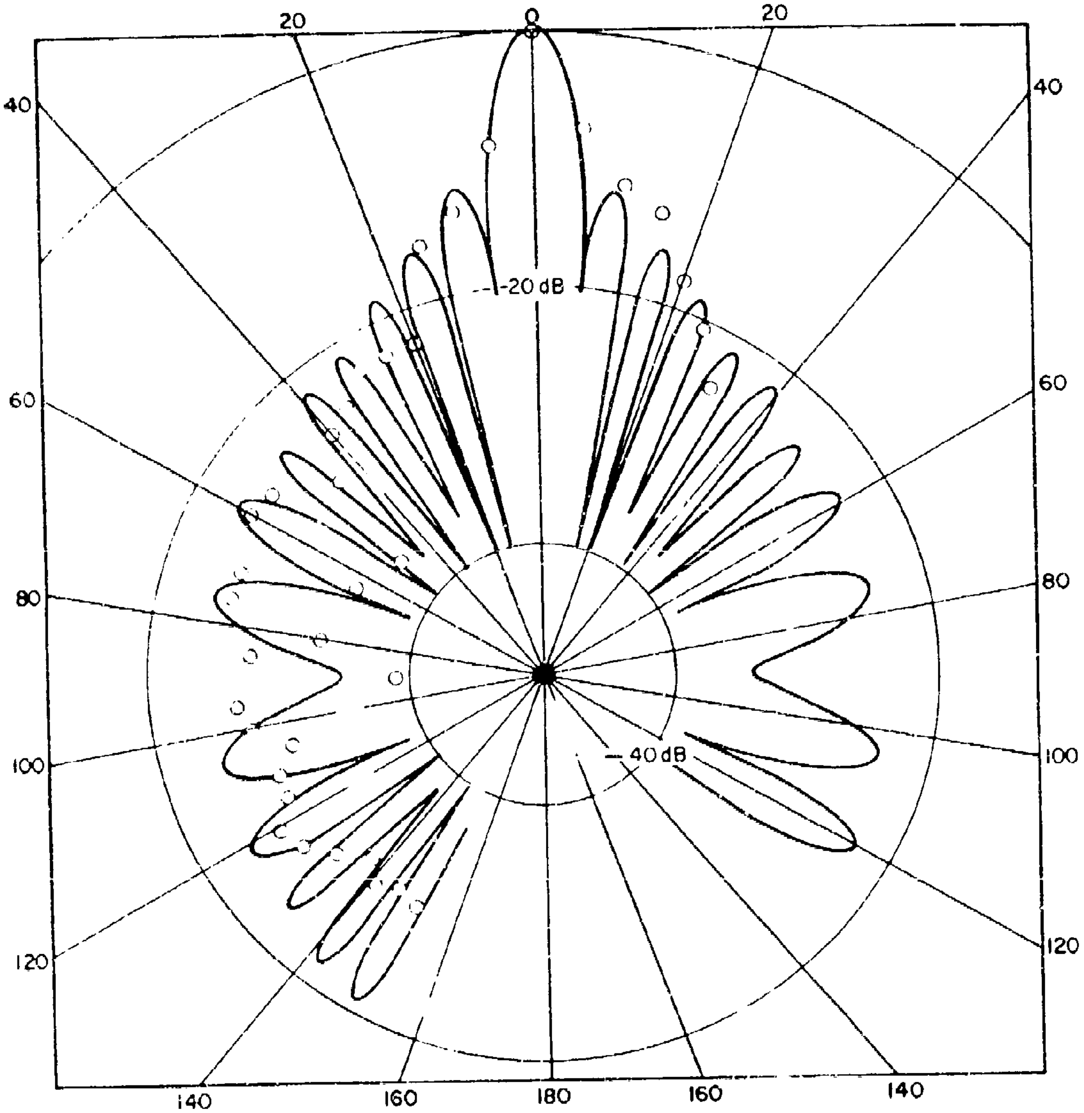
O Measured with NFCA-USS BLAKELY - electrical steering-zero depression - 3.556 kHz



(C) Fig. 6 — Farfield azimuth transmit beam pattern — BB/T mode — SQS26CX

—— Computed by Kunz [25] page 74 - zero depression - 3.212 kHz

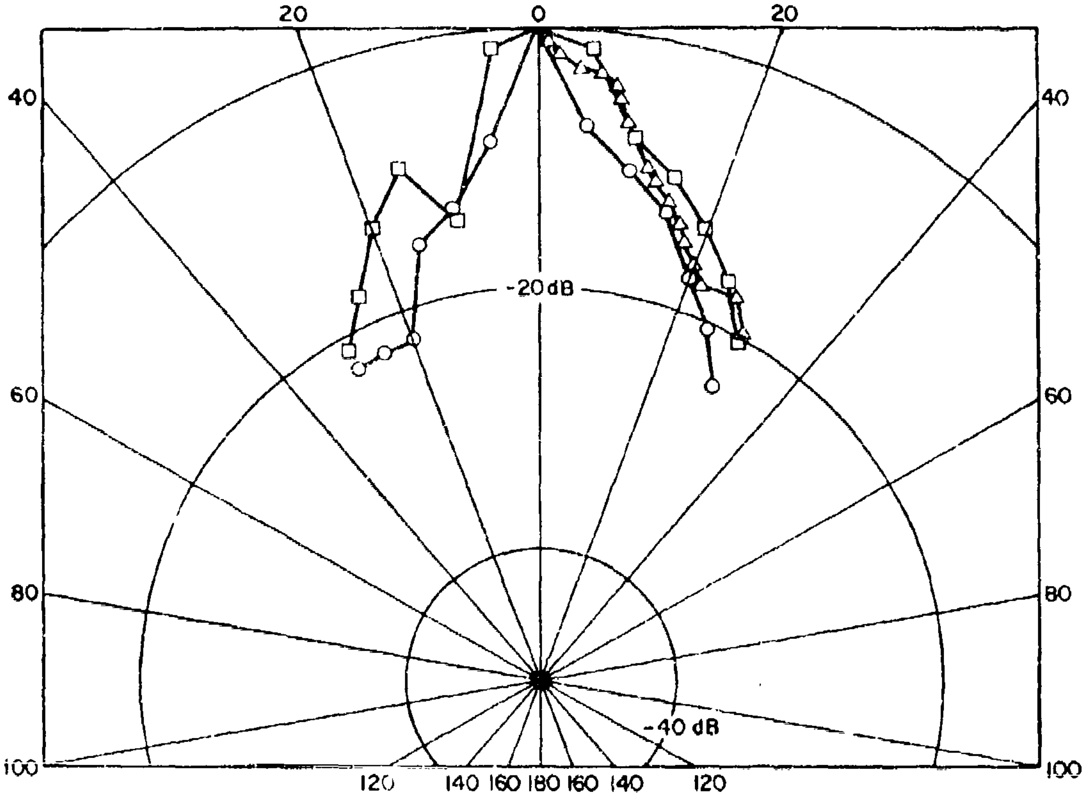
0 Measured with NFCA -- USS BLAKELY - Electrical Steering - zero depression -- 3.556 kHz



(C) Fig. 7 — Farfield azimuth transmit beam pattern -- BB/T mode — SQS26CX

—— Computed by Kunz [25] page 150 - 30 degree depression -3.556 kHz

○ Measured with NFCA -- USS BLAKELY - electrical steering - zero depression - 3.556 kHz

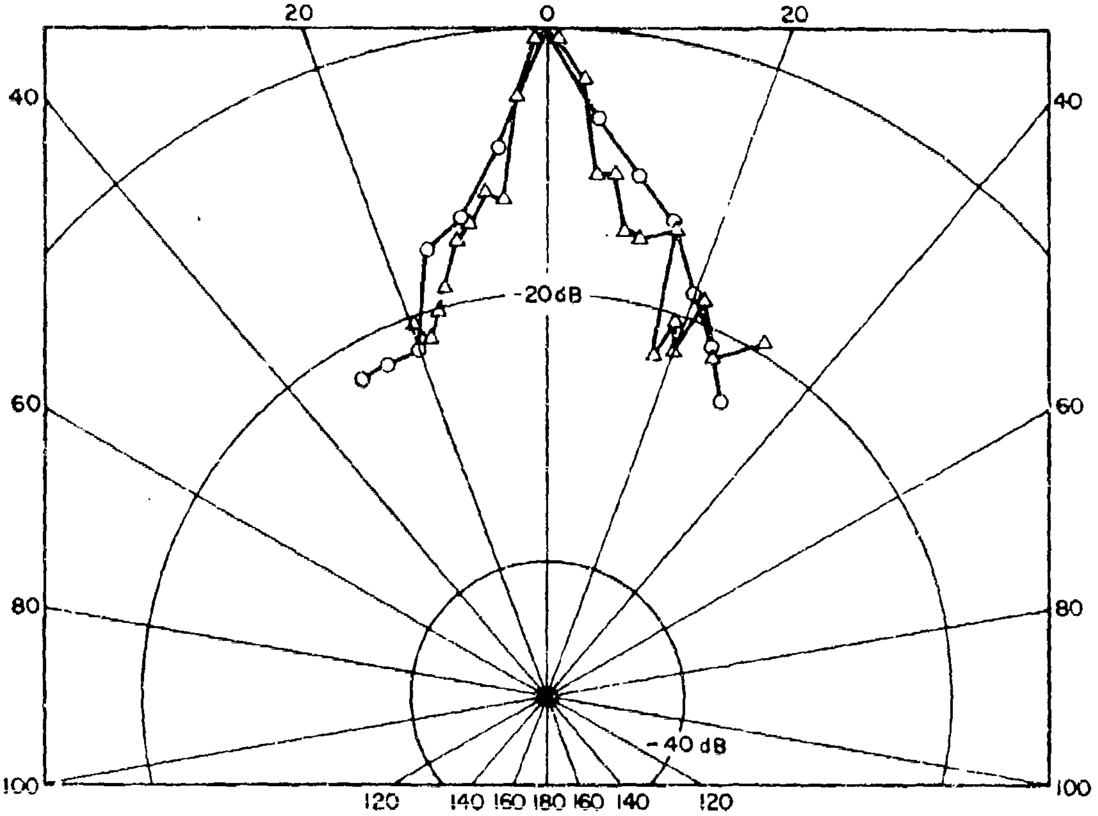


(C) Fig. 8 — Farfield azimuth transmit beam pattern — BB/T mode-zero depression — 3.556 kHz — SQS26CX

O——O Measured with NFCA - USS BLAKELY - electrical steering

Measured by farfield technique by NUSC [21]
Fig. 57 - USS HEBRON - electrical steering

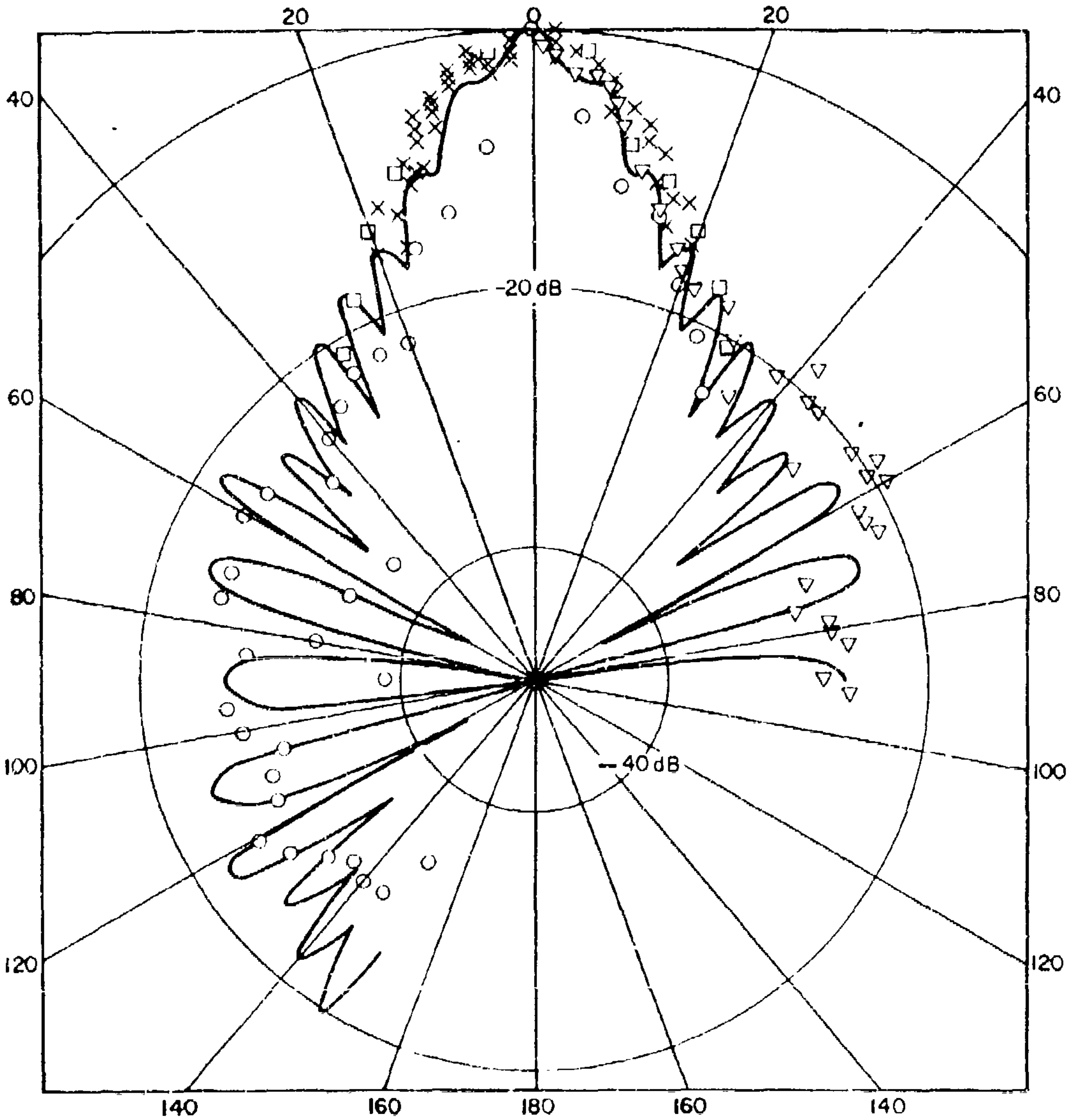
Δ——Δ Measured by farfield technique by NUSC [21]
Fig 3 - USS HEBRON - hydrophone positioning



(C) Fig. 9 — Farfield azimuth transmit beam pattern — BB/T mode — zero depression — 3.556 kHz

O—O Measured with NFCA - USS BLAKELY - SQS26CX - electrical steering

Δ—Δ Measured by farfield technique by NELC-SACS[24], Fig. III 13 - USS BRONSTEIN - SQS26AX - hydrophone positioning



(C) Fig. 10 — Farfield azimuth transmit beam pattern — BB/T mode — zero depression — 3.556 kHz — SQS26CX

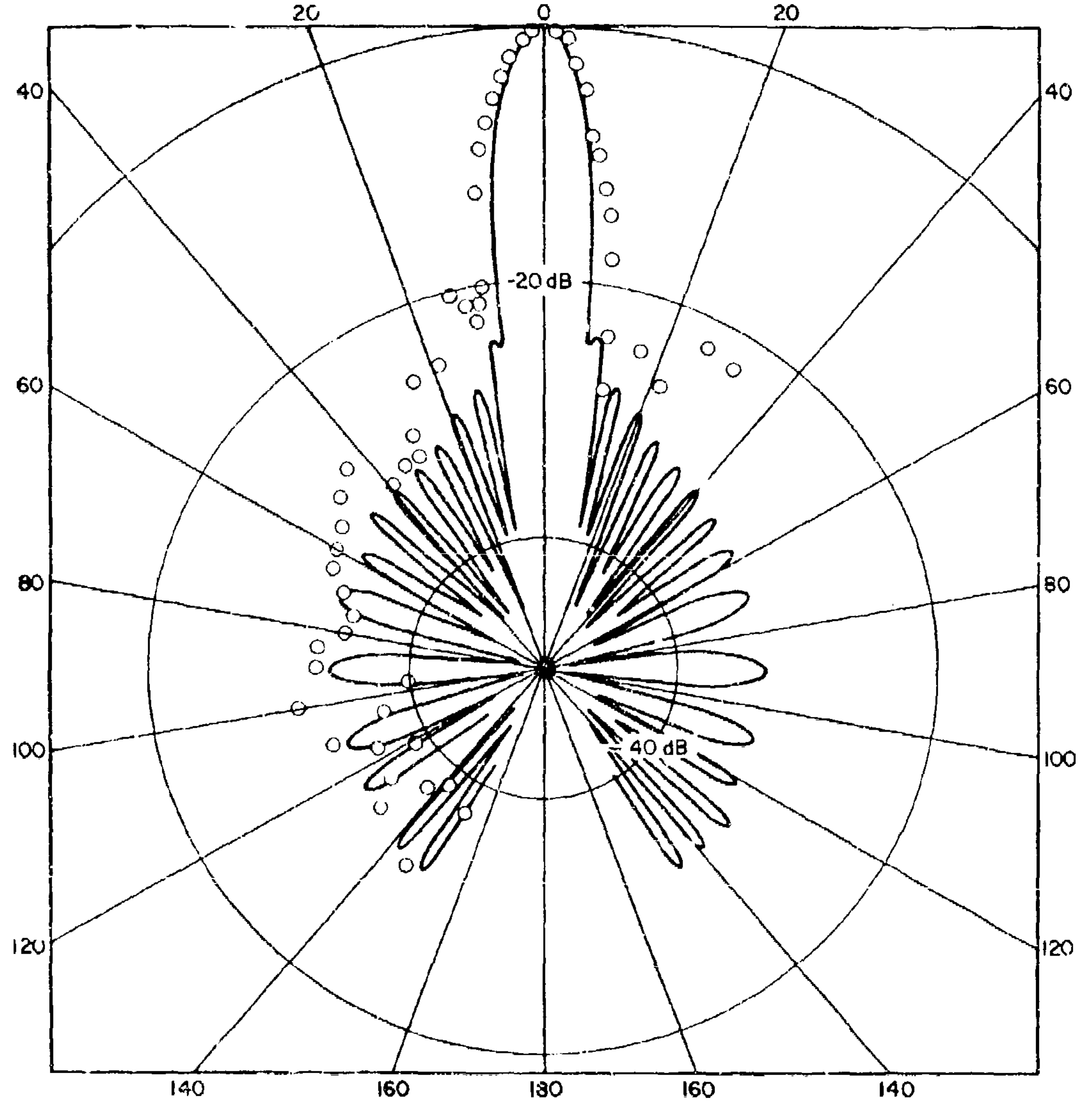
—— Computed by Kunz [25] page 78

O Measured with NFCA - USS BLAKELY - electrical steering

Measured by farfield technique by NUSC [21] Fig. 57- USS HEBRON - electrical steering

Δ Measured by farfield technique by NUSC [21] Fig. 3 - USS HEBRON - hydrophone positioning

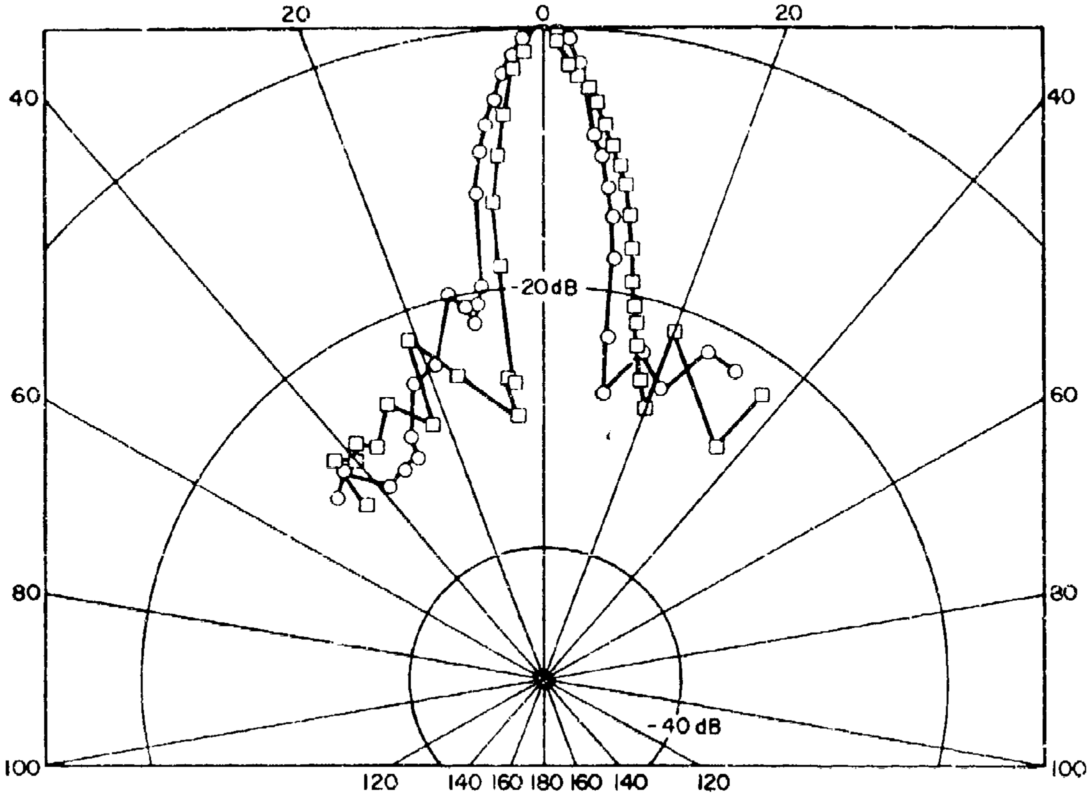
X Measured by farfield technique by NELC - SACS - USS KIRK [22] Fig. 3.15.2, page 50, USS PEARY, [23], Fig. 3.15.1, page 40; USS FANNING [26], Fig. 3.11, page 33; USS HOLT [27], Fig. 3.17.1 page 42 - hydrophone positioning



(C) Fig. 11 — Farfield azimuth receive beam pattern — BB mode — zero depression — variable depression receiver — 3.556 kHz — SQS26CX

—— Computed by Kunz [25] page 366

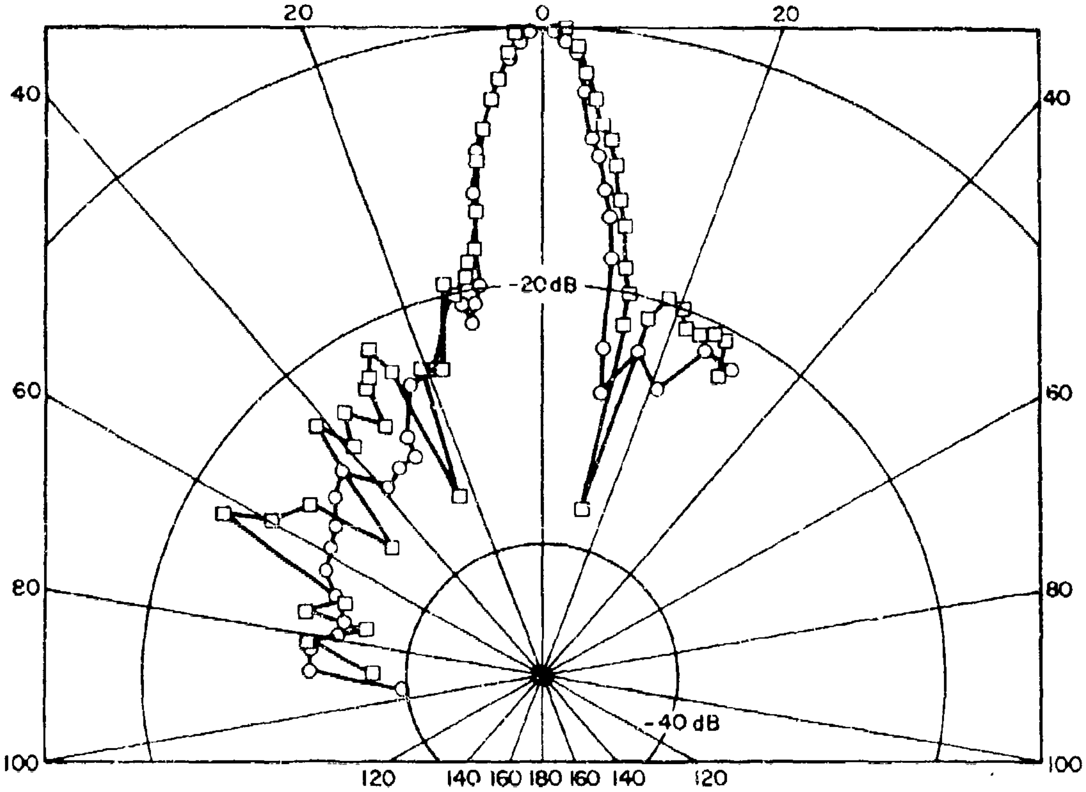
0 Measured with NFCA - electrical steering - channel #7



(C) Fig. 12 — Farfield azimuth receive beam pattern — BB mode — zero depression — variable depression receiver — 3.556 kHz — SQS26CX

○——○ Measured with NFCA - electrical steering - USS BLAKELY - channel #7

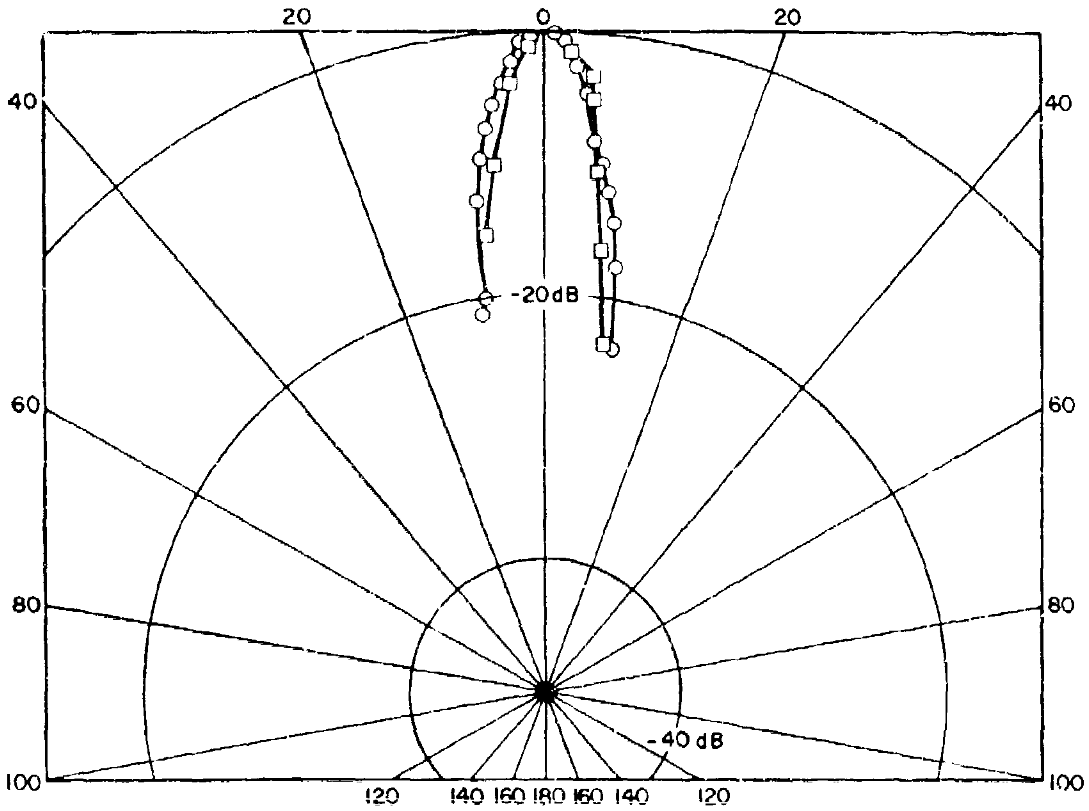
Measured by farfield technique with electrical steering by NUSC [21] Fig. 123 - USS HEBRON - channel #6



(C) Fig. 13 — Farfield azimuth receive beam pattern — BB mode — zero depression — variable depression receiver — 3.556 kHz — SQS26CX

0——0 Measured with NFCA - electrical steering - USS BLAKELY - channel #7

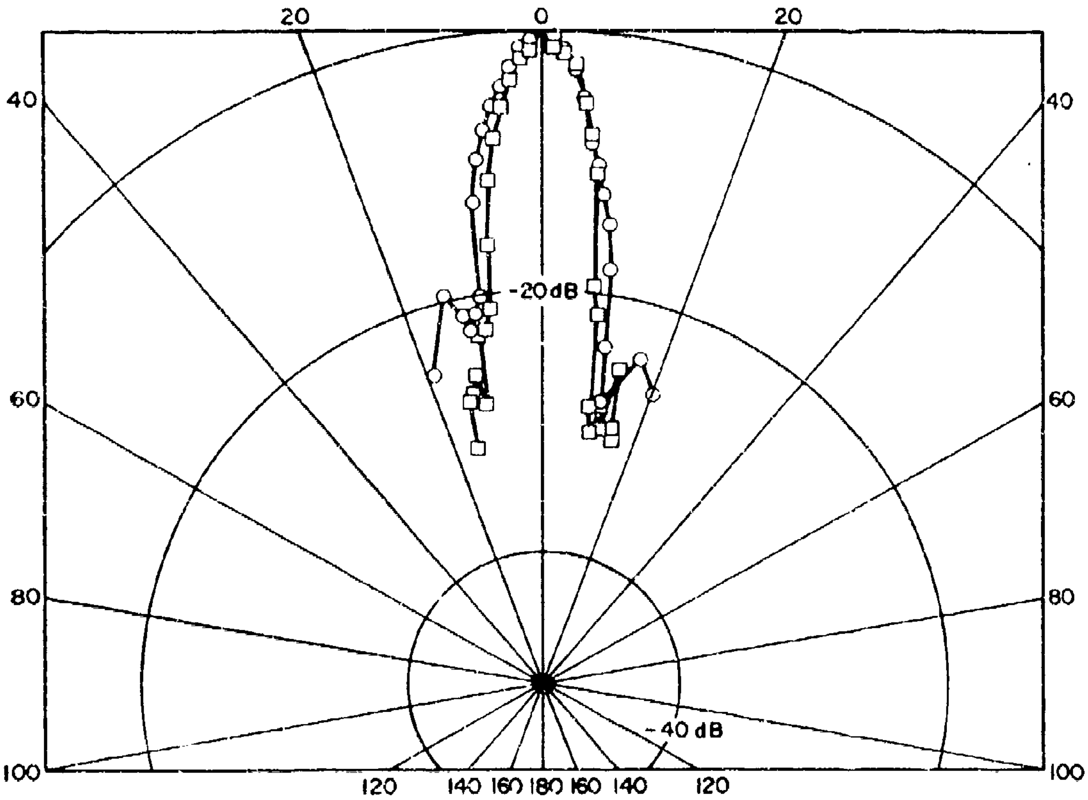
Measured by farfield technique with hydrophone positioning by NUSC [21] Fig. 99 - USS HEBRON - channel #6



(C) Fig. 14 — Farfield azimuth receive beam pattern — BB mode — zero depression — variable depression receiver — 3.556 kHz

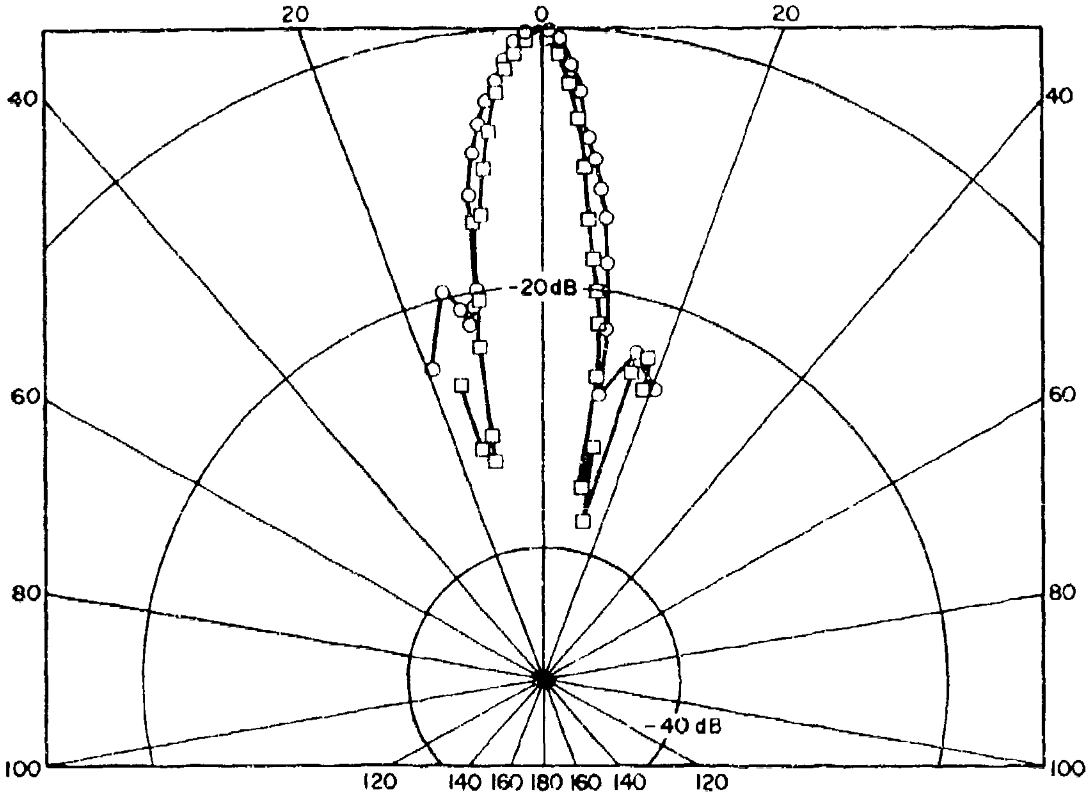
O—O Measured with NFCA - electrical steering - USS BLAKELY - channel #7 - SQS26CX

Measured by farfield technique with hydrophone positioning by NELC-SACS [24] Fig. III 11 - USS BRONSTEIN - channel #6 - SQS26AXR



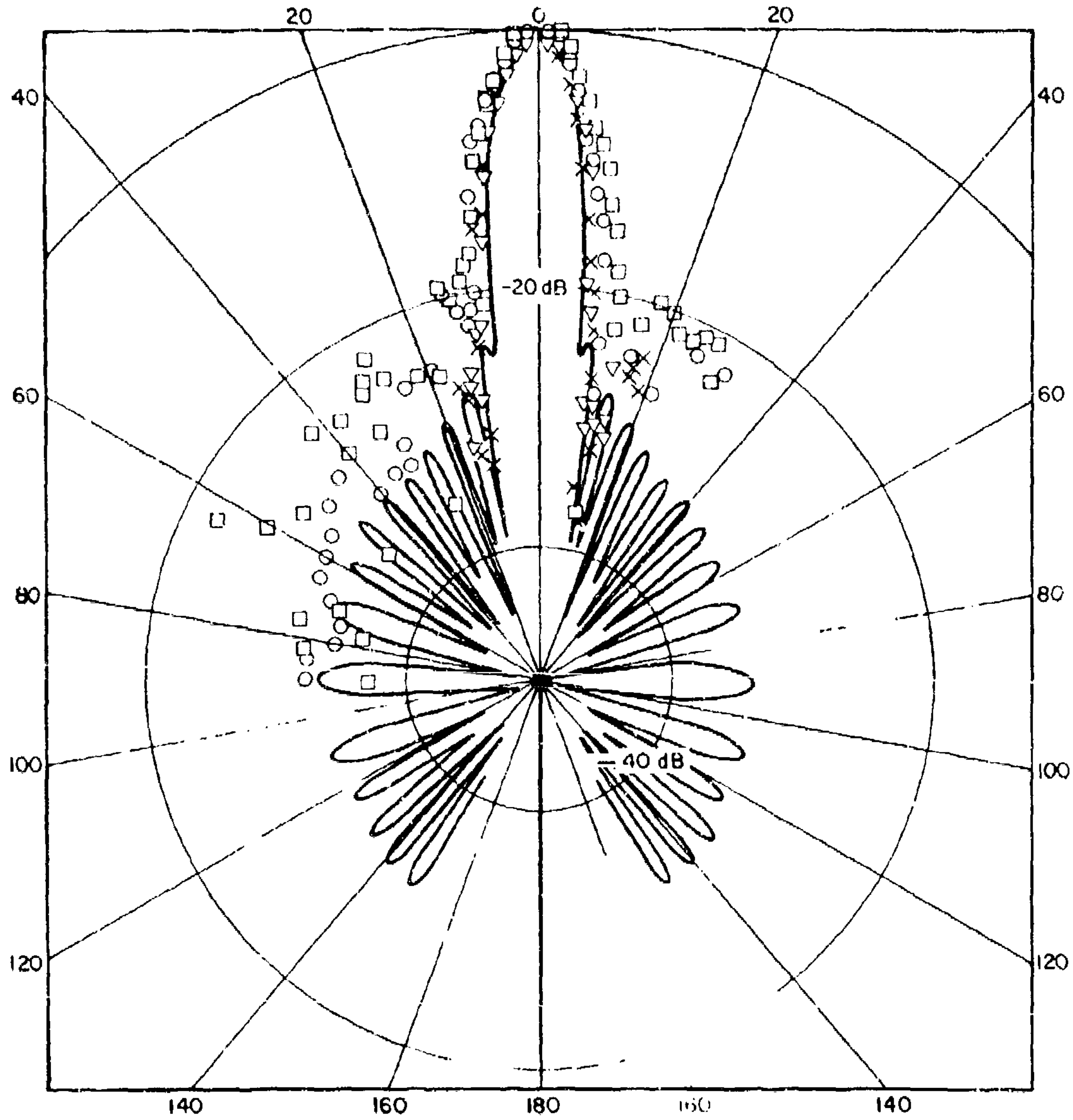
(C) Fig. 15 — Farfield azimuth receive beam pattern — BB mode — zero depression — variable depression receiver — 3.556 kHz — SQS26CX

○——○ Measured with NFCA - USS BLAKELY - channel #7
Measured by farfield technique with hydrophone positioning by NELC-SACS [23] Fig. 3.11.3 - USS PEARY - channel #6



(C) Fig. 16 — Farfield azimuth receive beam pattern — BB mode — zero depression — variable depression receiver — 3.556 kHz — SQS26CX

O——O Measured with NFCA - USS BLAKELY - channel #7
Measured by farfield technique with hydrophone positioning by NELC-SACS [22] Fig. 3.11.7 - USS KIRK - channel #6



(C) Fig. 17 — **Farfield azimuth receive beam pattern — BB mode — zero depression — variable depression receiver — 3.556 kHz — SQS-26CX**

—— Computed by Kunz [25] page 366

0 Measured with NFCA - electrical steering - USS BLAKELY channel #7

Measured by farfield technique with hydrophone positioning by NUSC [21] Fig. 99 - USS HEBRON - channel #6

Δ Measured by farfield technique with hydrophone positioning by NELC - SACS [23] Fig. 3.11.3 - USS PEARY - channel #6

X Measured by farfield technique with hydrophone positioning by NELC - SACS [22] Fig. 3.11.7 - USS KIRK - channel #6

APPENDIX A

GENERAL DESCRIPTION OF NFCA

(U) The large NRL Nearfield Calibration Array (NFCA) consists of 2500 piezoceramic acoustic sensors in a 50 x 50 square matrix on 8-inch centers. They are physically housed in 50 shaded Nearfield Line (NRL) arrays with 50 sensor elements in each. The design concept for the housing and assembly of the acoustic sensors in the shaded NFL is essentially the same as described in Ref. A1, A2. The 50 NRL's are supported as shown in Fig. A1 in an aluminum structural frame 40 feet x 38 feet x 1 foot which together with cables and junction boxes weighs 4 tons. The position of these 50 shaded line arrays in the structural frame oriented in the vertical are maintained in a nominal plane to within about ±1/4 inch by axial tension of between 100 and 200 lbs. and by transverse flexible taut stainless steel cables at 12 levels.

(U) The 50 sensor elements in each NFL are strung together as indicated in Fig. A2. Each sensor element assembly shown in Fig. A3 consists of the 3/4 inch diameter piezoceramic cylinder 3/4 inch long with 1/4 inch thick walls, two glass-metal end cap seals and an end-looped wire for electrical and mechanical connection to adjacent sensors.

(U) The NFL housing consists of two concentric plastic tubes. The inner castor oil filled teflon tube with an electro-magnetic shield wrap contains the "bead string" of the 50 piezoceramic cylindrical sensors with their series shading condensers. The outer protective tube is of clear polyvinyl chloride with castor oil between it and the teflon tube. The housing assembly is terminated at each end in an "end fitting" and supported in an expanded stainless steel trough as shown in Fig. A4. The two "end fittings" are identical except that only one has the cover cap with the bulkhead electrical connector that is shown in Fig. A4. Fig. 5 shows a cross-sectional sketch representing the completed assembly of the NFL.

(U) The shading coefficients for the 50 sensor elements in each NFL and for the 50 NFL's in the NFCA are the same because the array is square. The values of these coefficients and the method of shading the individual sensors in each NFL are given in this Appendix under Details of Assembly of the Shaded NFL Array.

(U) The method of shading the NFL's relative to each other is by electrically connecting condensers in series with the NFL's except for those in the central region of the NFCA. In this center region the shading coefficients are unity for 18 NFL's and close enough to unity for 12 others that the difference fall within the variations of the product of capacitance and sensitivity (or transmitting current response) for the NFL's selected for this center region. Therefore, 30 of the 50 NFL's in the center region did not require series connected condensers. The values in microfarads of the series shading condensors for the 10 NFL's on the right side of the 30 in the center region starting with the NFL nearest the structural frame are:

0.0049, 0.0092, 0.0169, 0.026, 0.0372, 0.074, 0.112, 0.188, 0.283 and 0.368. The corresponding values for the left side are: 0.0049, 0.0093, 0.0165, 0.0272, 0.038, 0.0738, 0.118, 0.203, 0.237, and 0.346. The right side is defined not from the point of view of the observer but rather the right of the face of the plane of the NFCA. The face of the NFCA is identified as the open side of the expanded metal troughs supporting the NFL's. The values of capacitance for these series shading condensers were determined from the relationship: $S_\chi C_{\chi t} = (S_0 C_0)K$, where S_χ is the transmitting current response (TCR) for the specific NRL, $C_{\chi t}$ is the capacitance of the series combination of the capacitance of the specific NFL and the shading condenser selected, S_0 and C_0 are arbitrarily chosen reference values of TCR and NFL capacitance, and K is the assigned shading coefficient. The criterion for the $S_0 C_0$ product is to maximize the number of NFL's that will satisfy the shading requirements without use of series shading condensers. The reference product, $S_0 C_0$, chosen was -92.7 dB where the S_0 value was +46.5 dB re one microbar per ampere at one meter at 3kHz and the capacitance, C_0, was -139.2 dB re one farad.

DETAILS OF ASSEMBLY OF SHADED NEAR FIELD LINE ARRAY

(U)I. Procedural Requirements

A. Preparation of piezoceramic cylinders (lead zirconate titante)

3/4 inch O.D. x 3/4 inch long x 1/8 inch thick wall (Manuf: Channel, Clevite, Electra Scientific).

1. Make visual examination for:
    - a. Continuity of inner and outer silver electrode surface. if not continuous.
    - b. Pits, cracks, and other blemishes in ceramic walls. Reject if present.
    - c. Distortion. Reject if obviously distorted.
    - d. Adherence of silver electrode by applying and then pulling off plastic electrical adhesive tape. Reject if electrode peels off.
2. Check polarity of each cylinder using ohmmeter deflection when applying pressure with eraser end of pencil. All must have same polarity. Identify cylinders by manufacturer and some sort of number system.
3. Solder two wire leads, 0.011 inch tinned flexible voice coil wire No. 13400-53 (Lenz Electric Mfg. Co.) to the inside silver electrode of the cylinder. (Use 38-60-2 lead, tin, silver solder (DIVCO #233)). Use special soldering technique

for very thin silver electrodes, such as minimum heat, minimum amount of solder, etc. Space them 180 degrees apart and about 3/16 inch from each end of the cylinder. Clean area for soldering with eraser. Coil and insert the wires to clear end of cylinder in preparation for bonding the metal-glass hermetically sealed end caps.

4. Bond the 0.723SS-1/075 (Electrical Industries) hermetic seals to the cylinder ends, one end at a time. Check seals with 1000 volt megger. Insulation resistance should be greater than 2×10^9 ohms.

   a. Lap the end surface of the cylinder as well as the bonding surface of the cylinder as well as the bonding surface of the hermetic seal. Use Tri-n-ite 400-A grid paper with a figure "8" motion.

   b. Clean the surface with acetone, apply thin layer of Epoxy-Patch kit adhesive to both surfaces and set the seal onto the end of the cylinder with a twisting motion to spread the adhesive and center the seal after having passed the lead wire through the pin hole in the hermetic seal. Allow about 24 hours of drying time for curing at room temperature. Then repeat this procedure for the other end of the cylinder.

5. Insert a silver-plated phosphor bronze wire 0.040 inch diameter with a loop 3/16 inch to 1/4 inch mean diameter at one end through the pin hole of the hermetic seal, form a similar loop at the other end of the phosphor bronze wire and align the wire such that the center of the loops are about 1/2 inch from the end of the cylinder assembly. Then solder the voice coil wire and the phosphor bronze wire at the hermetic seal pin hole such as to assure 30 inch vacuum seal.

6. Perform a leak test on all assembled units in peanut oil media in a vacuum of 30 inches for about 5 minutes. Leaks, if any, appear as a continuous stream of air bubbles.

7. Measurements on completed assembly of piezoceramic cylinders.

   a. Check insulation resistance with 500 volt megger. Should be above 2×10^9 ohms between each silver electrode and "ground" (metal body of hermetic seal).

   b. Measure capacity C_X and conductance at 1 kc, 25 degrees centigrade and 50 percent relative humidity. Values of capacity are in order of 3000 to 4000 pf and conductance in order of 0.03 μ mhos. Precision of measurement should be in order of 0.1 percent.

c. Measure sensitivity M_X of each assembly using G19 calibrator with instrumentation and reference standard (LC32) for measuring sound field with a precision of about 1 percent.

8. Selection of the prepared piezoceramic assemblies for location in the shaded line.

a. The reference field strength for the unity shaded elements in the line of 50 elements is -279.24 dB, the product of M_0 and C_0, where M_0 has nominal value of -100.65 dB reference to one volt per μbar and C_0 has nominal value of 3000 pf or -178.59 dB reference to a farad. The choice of $(MC)_0$ is arbitrary. The criterion is to maximize the number of usable elements from a given lot.

b. Since the line is symmetrical, half of the 50 elements or 25 are shaded similarly to the other half.

c. Starting at the end of the line with numeral designation of 1 the shading coefficients $(MC)_x/(MC)_0$ follow:

25 - 1
24 - 1
23 - 1
22 - 1
21 - 1
20 - 1
19 - 1
18 - 1
17 - 1
16 - 0.995
15 - 0.989
14 - 0.978
13 - 0.957
12 - 0.924
11 - 0.874
10 - 0.804
9 - 0.716
8 - 0.612
7 - 0.500
6 - 0.388
5 - 0.284
4 - 0.196
3 - 0.126
2 - 0.0762
1 - 0.0427

Note: 1 - 8 are shaded by series connected condensers plus some etching to match the selected condenser.

9 - 16 are shaded by etching or otherwise removing outside electrode surface.

d. From measurements indicated in 7c and 7b compute the product $(MC)_X$ for each peizoceramic cylindrical element. For element position number 17 to 25 inclusive, select cylinders whose $(MC)_X$ product is within 0.1 dB of the reference product $(MC)_0$. Small adjustments can be made by removing outside electrode surface of the cylinder. For element position 9 to 16 inclusive, select piezoceramic cylinders whose product $(MC)_\chi$ after adjustment by removing element outside electrode surface is within 1 percent or 0.1 dB of the product of $(MC)_0$ and the appropriate element position shading coefficient. For example: $(MC)_\chi = 0.804\ (MC)_0$ to within 1 percent or 0.1 dB for element position 10.

e. For element position 1 to 8 inclusive select piezoceramic cylinders and condensers (Corning glass type) that are electrically in series with the capacitance of the piezoceramic cylinders, such that the product $(MC_s)_\chi$ is within 1 percent or 0.1 dB of the product of $(MC)_0$ and the appropriate element position shading coefficient. C_s is the value of the electrical series combination of the capacitance of the condenser and capacitance of the piezoceramic cylinder. Fine adjustments of capacitance can be made by judicious removal of outside electrode surface on the piezoceramic cylinders.

B. "Bead String" assembly of piezoceramic cylinders.

1. Assembly of 50 element line.

a. The piezoceramic cylinders, when prepared as indicated under A above, are arranged in a straight line on a jig. The jig fixes the cylinder on 8 inches ± 1/64 inch centers. No. 18 stranded teflon coated tinned copper wire of appropriate length is connected between the phosphor bronze loops provided on the cylinders by soldering. Connection between loops is accomplished with a nominal tension, about 5 pounds, just enough to assure that accumulated length of the string of 50 elements is 392 inches ± 1/4 inch measured between centers of the end elements of the string.

b. Each cylindrical element for element position number 9 to 25 is then soldered directly to a continuous length of bus wire No. 24 stranded (19 x 36) white silicone insulated wire (Markel Co.) at two points on the outside silver electrode surface. The distance between solder points is about 4 times the distance from each point to the edge of the silver electrode on the cylinder. The soldering technique shall be such as to leave the bond intact between the silver electrode and the piezoceramic surface of the cylindrical element. However, the soldering joints must be sufficiently intact to hold mechanically and maintain electrical contact under vibration at 3500 cps at amplitude of 4×10^{-3} inches (.1 g) for 10 hours.

c. For element positions 1 to 8 inclusive the selected series condenser is soldered between the white silicone insulated bus wire and the outer electrode surface of the piezoceramic cylinder. Both condenser leads are sleeved with teflon spaghetti. It is advisable to allow a generous excess of the bus wire at each end for connection to the electrical termination end fitting.

C. Assembly of double plastic housing consisting of (a) an inner teflon tube, (b) an outer polyvinyl chloride tube, (c) metal end fittings (one at each end of double housing, (d) a wrap of electromagnetic shielding around outside of the teflon tube, and (e) air free castor oil fill in and between the tubes.

1. Prepare the teflon tubes, 1 inch O.D. x 7/8 inch I.D. (1) Make visual examination for flaws that might impair impermeability to air and water. (2) Cut the tubes to length about 393 inches. (3) Clean inside and outside with acetone and allow to dry. (4) Stretch I.D. of end of tube for about 2 inches to 15/16 inch. (5) Etch inside surface of both ends of tube for distance of 1-1/2 inches from ends by dipping into Tetra-Etch (W.L. Gore & Assoc. 487 Paper Mill Rd., Newark, Del.) in preparation for epoxy bond to the end fittings. Slip teflon collar, 1 inch I.D. x 1-1/8 inches O.D. x 1/4 inch long, over one end of the teflon tube to serve as a shoulder stop for the electro-magnetic shielding wrap.

2. Insert the metal "end fitting" that has the electrical bulkhead in the end fitting connector into one end of the teflon tube. Before insertion, apply epoxy-patch kit cement to provide an adequate bond between the teflon tube and the inserted surface of the "end fitting." Secure the teflon tube onto the "end fitting" with punch lock strap 3/8 inch wide. Modify the strap by breaking off the turned back projection under the punch loop and solder broken edge to the punch loop. This reduces the thickness of the strap assembly.

3. Wrap the teflon tube with electro-magnetic shielding material, Conetic-AA, which is 2 mils thick, 4 inches wide and about 393 inches long. Shorter length may be used with overlapping soldered joints for electrical continutiy. This material is made by Precision Mica Corp. Wrapping technique can be facilitated by taping the long edge to the teflon tube using adhesive teflon tape, rolling the tube for the remainder of the wrap and tacking with silver solder at intervals along the seam to secure a good workmanship wrap free of wrinkles.

4. Solder a length of flexible lead wire identified as No. 24 stranded (19 x 36) white silicone insulated (Markel CO) to the shielding material about two inches from the end of the wrap for ground connection. This lead wire should be long enough for about 20 percent slack and should be sleeved with teflon spaghetti long enough to extend over the metal band on the teflon tube and with shrinkable spaghetti over end of teflon spaghetti to secure the teflon spaghetti well against the pin of the hermetically sealed metal-glass feed-thru. In the end fitting for the ground shield connection.

5. Prepare the 1-1/4 inches I.D. x 1-1/2 inches O.D. (PVC) polyvinyl chloride tubing (Excelon) by cleaning all surfaces with alcohol and cutting to 395 inches length. Slide the PVC tube (apply castor oil for easy sliding, if necessary) over the shield covered teflon tube and onto the shoulder of one "end fitting." Secure the end of the PVC tubing onto the "end fitting" with 30 mils dia. nylon lacing cord wrap (Mil.-T-713 Type P class C - Heminway and Bartlett). Coat the wrap with vulcalok (a rubber cement) and wrap with cotton tape (2 turns at least) and recoat to saturation with vulcalok.

6. Insert the "end fitting" without the electrical bulkhead connector into the other end of the teflon tube. Observe the bonding procedure used in setting the first "end fitting" into the teflon tube. Since the PVC tubing is longer than the teflon tube, it will be necessary to slide the PVC tubing back away from the end of the teflon tube to provide access to insert the "end fitting" into the teflon tube. For convenience a jig should be used to hold the PVC tubing in position temporarily. Then slide the PVC tubing over the "end fitting" and secure as in C-5.

7. Evacuate the air from between the teflon and PVC tube and fill with air free castor oil. To assure the absence of air, maintain 30 inch vacuum (about 0.1 micron pressure) on oil in the oil filled space until monitor indicates absence of air. Insert the "O" ring seal screws in the oil-fill holes and check for leaks.

D. Assembly of "bead string" into the Double Plastic Housing.

1. Make certain that the "bead string" and the inside surfaces of the Housing are clean and free of foreign matter.

2. Solder a generous length (4 to 6 inches) of the No. 22 silicone insulated wire (same kind as continuous bus wire

on "bead string" to the hermetically sealed feed-thru that is connected to the shielding material.

3. Securing the "bead string" to the housing "end fittings."

   a. Solder a 12 inch length of the No. 18 teflon covered stranded wire to the heel of the wire loop of the end sensor element for connection to the electrical bulkhead connector on the "end fitting." Also prepare 8 inch length of the No. 18 teflon covered stranded wire as used in Para. B-1-a by removal of the teflon insulation except for 1 inch length left in the center of the 8 inches length. Slip a sleeve of teflon spaghetti over the 1 inch length of the wire having the remaining insulation. Then thread this wire through the loop of the last cylindrical element at the end of the "bead string." Twist with one or more turns to assure adequate electrical insulation between loop and copper wire. Pass the two bare ends of the copper wire over the teflon spool on the 1/8 inch pin that will set in the pair of slots in the "end fitting." Twist the ends of the bare copper wire and adjust such that the axial dimension between center of the piezoceramic element and teflon spool pin is 1-3/4 inches ±1/16 inch. Sleeve the twisted ends with two layers of shrinkable silicone spaghetti.

   b. Proceed similarly with the last element at the other end of the "bead string" except that the dimension between the center of this element and the pin with the teflon spool in the other "end fitting" will be different from 1-3/4 inches at the bulkhead terminal and because of error allowances in length of both the "bead string" and the housing as well as some variation in stretch of the "bead string" and contraction of the housing when the "bead string" is pre-stressed with tension of 10 to 25 lbs.

4. Assembly of cover plates to the "end fittings."

   a. Insert "O" rings and electrical bulkhead connectors into the cover plate of one "end fitting" of housing section. For the other end of the housing use a cover plate with "O" ring buth without the bulkhead electrical connector.

   b. Make solder connections to the electrical bulkhead connector. Use shrinkable silicone spaghetti sleeving on each wire. These wire leads of the connector are identified with colored tabs. Connect the "red" lead to the feed through that is connected to the "Conetic" shield, the "white" lead to the wire connected to the inside silver electrode terminal at the heel of the phosphor bronze loop of the last cylinder and the "green" to the bus wire that connects the outside silver electrodes of the piezoceramic elements. The "black" wire is not used and should be folded and sleeved with shrinkable silicone spaghetti.

c. When making soldering connection, care must be exercised to insure that no solder particles, loose or attached, are left within the housings.

d. Check insulation resistance with 1000 volt meggar between each terminal and "ground." The insulation resistance should be greater than 2 x 10^9 ohms. Also check similarly between each pair of wire terminals.

5. Fill inner plastic (teflon) tubing with air-free castor oil.

   a. By means of oil-filled holes in each "end fitting" pump out the air to 0.1 micron of pressure.

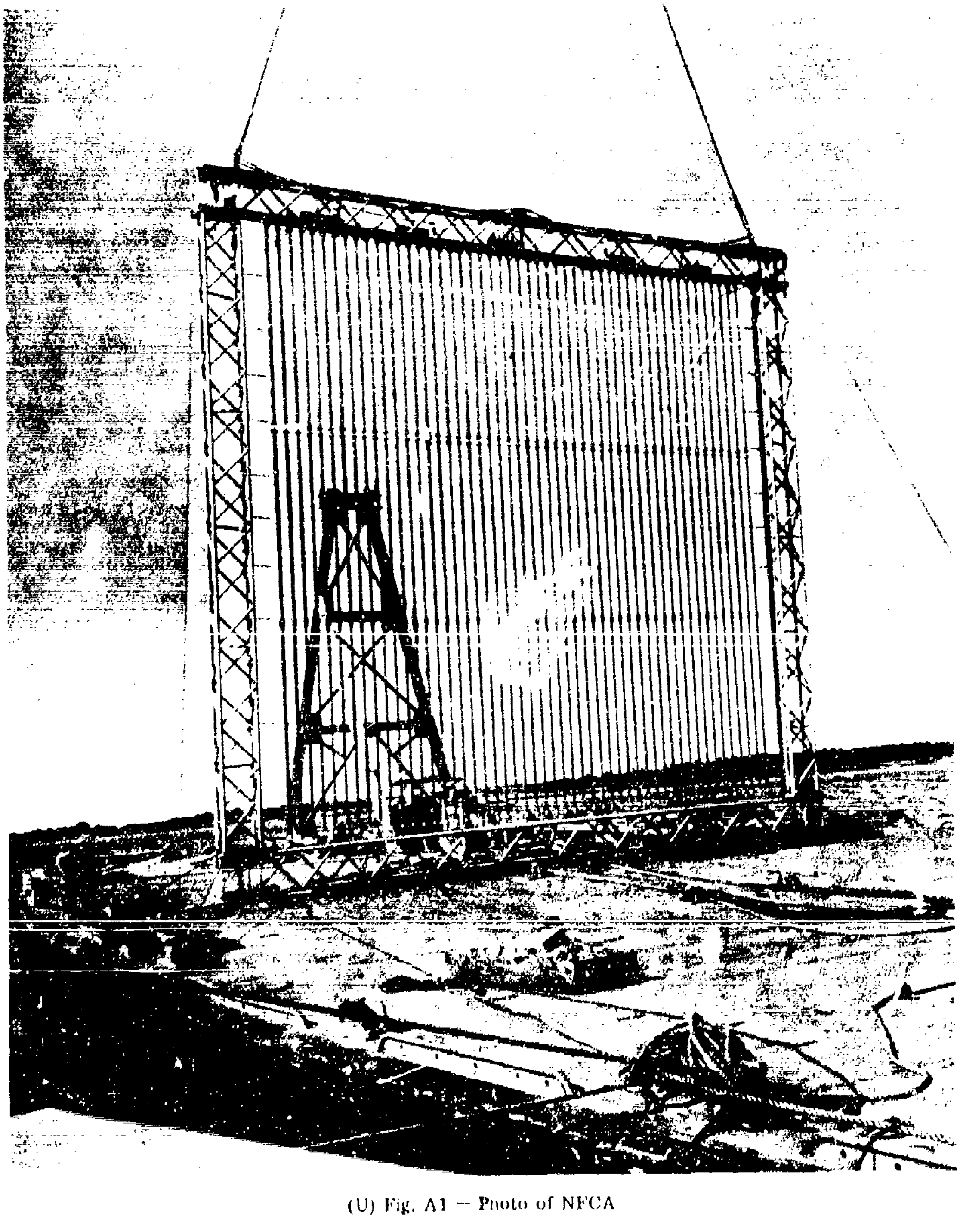
   b. With the housings in vertical position fill the teflon tube with air-free castor oil by way of the oil-filled hole in the bottom "end fitting."

   c. Make the insulation resistance checks again as in 4-d above and measure total capacity and conductance.

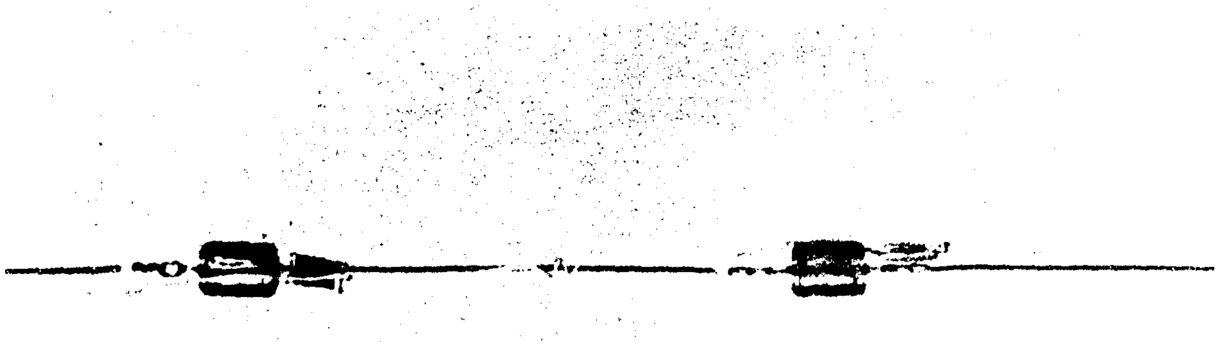
REFERENCES

A1. W. J. Trott and Ivor Groves, "Application of the Near-Field Array Technique to Sonar Evaluation," JUA (USN) 16, pp. 501-523 (July 1966) (CONFIDENTIAL)

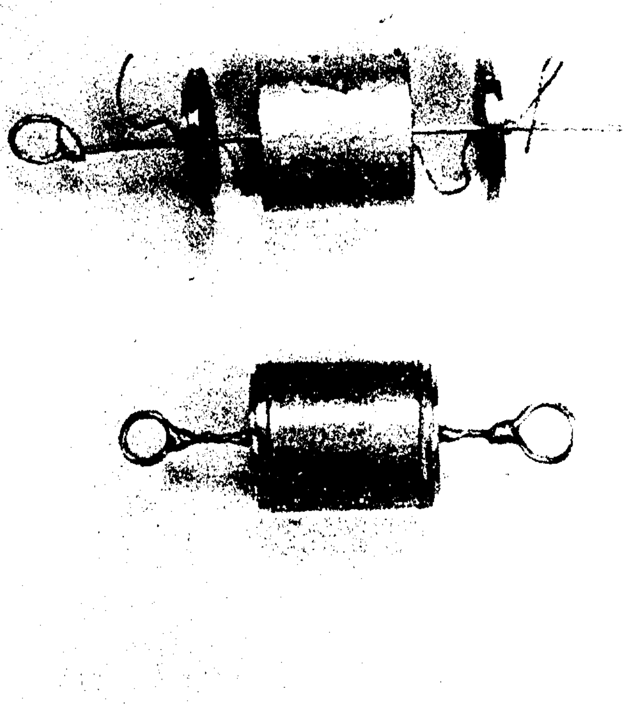
A2. W. J. Trott and Ivor Groves, "Application of the Near-Field Array Technique to Sonar Evaluation," NRL Report 6734 (May 1968) (UNCLASSIFIED)



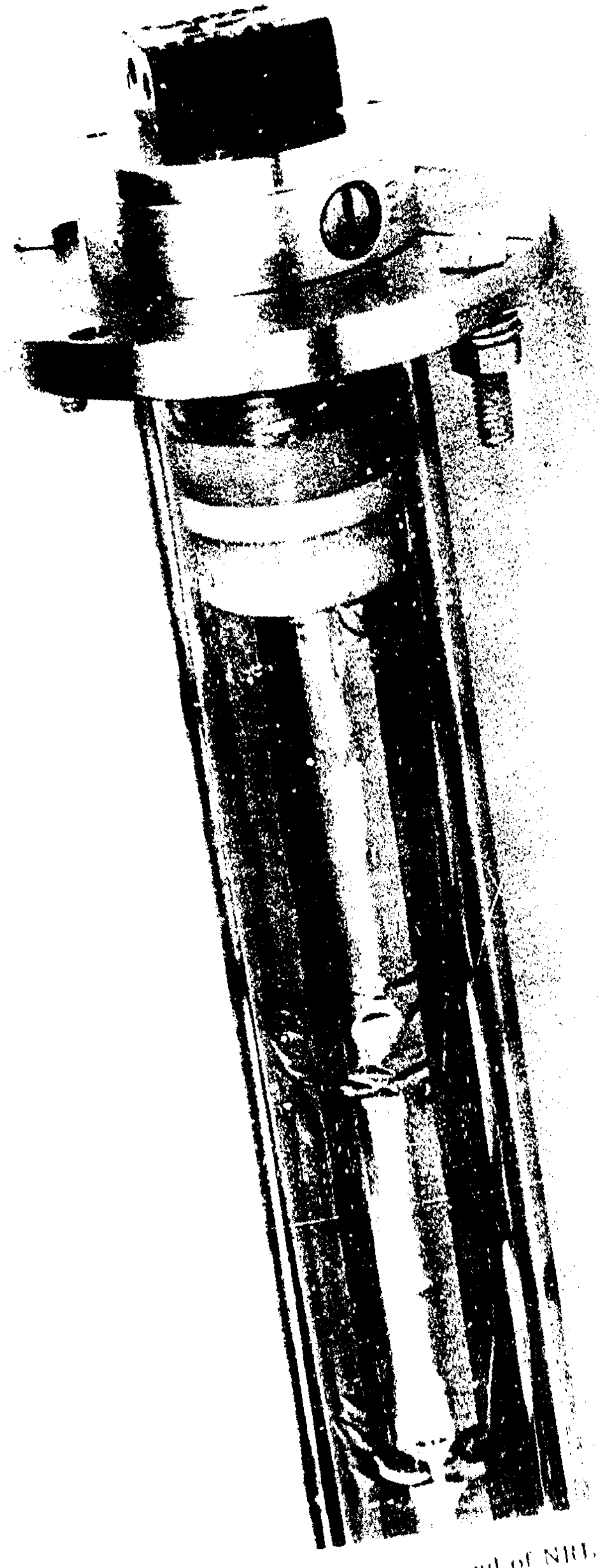
(U) Fig. A1 — Photo of NFCA



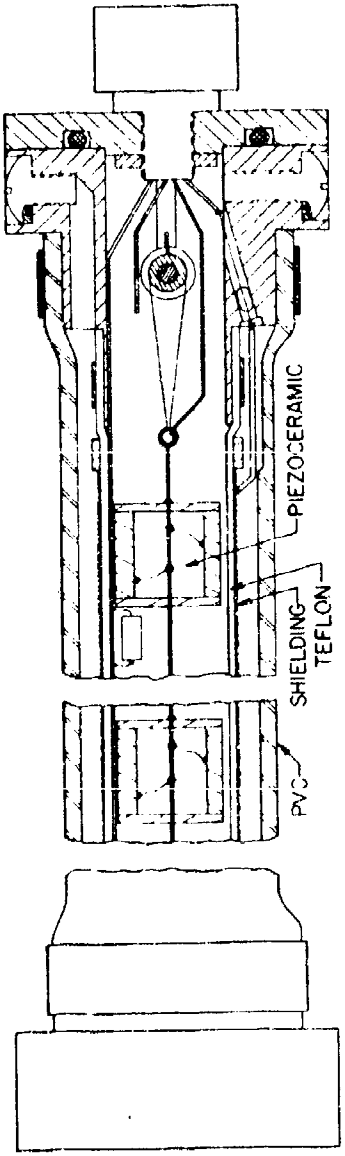
(U) Fig. A2 — Photo of portion of "bead string" of NFL sensor elements with series connected shading condensors



(U) Fig. A3 — Photo of NFL element sensor assembly



(U) Fig. A1 — Photo of one end of NRL housing assembly



(U) Fig. A5 — Photo of cross-sectional sketch of complete NFL assembly

APPENDIX B

(U)Some of the results of experimental measurements, reference [B1] (listed as reference [15] in the main text of this report), are repeated here to show validity of the nearfield calibration technique in a direct measure of the farfield beam pattern of large aperture transducers with the large NRL Nearfield Calibration Array (NFCA) by comparison to computed farfield beam patterns for the same transducer. In addition, the unpublished results from two separate experiments for beam pattern comparison obtained by simultaneous measurements on the same transducer by the classical farfield and the nearfield techniques are included to show direct experimental verification of the latter technique as designed into the large NRL NFCA.

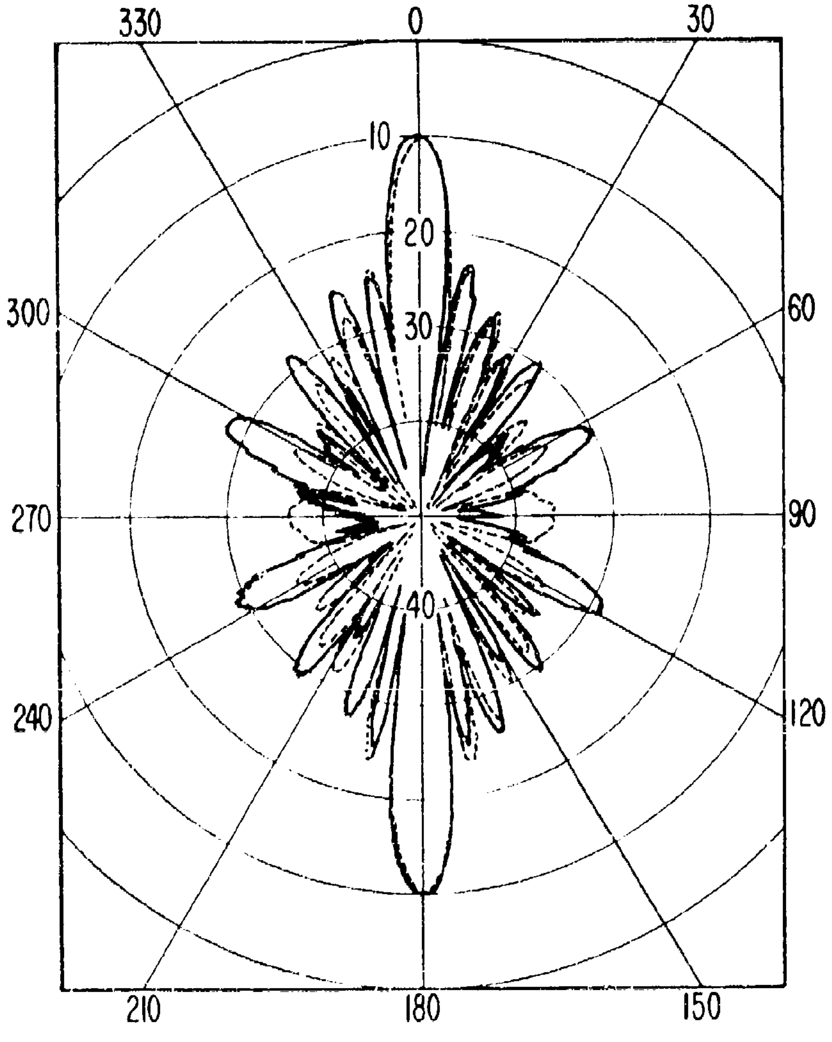
(C)The NFCA beam pattern results are compared to the computed farfield patterns in Figs. B1, B2 and B3. The comparisons appear in reference [B1] as Figs. 12, 14 and 18 respectively. In Fig. B1 the comparison is for an 18-foot experimental line array, and in Fig. B2 for an experimental plane array (Cruciform) formed by two 18-foot line arrays arranged as diagonals of a square 12.5 feet on the side. Figure B3 compares the NFCA measured beam pattern with the computed farfield beam pattern for a single aperture quarter sector of a BQS-6 submarine sonar transducer driven at the specification standard frequency of 3.5 kHz.

(U)The unpublished beam pattern measurements, shown in Figs. B4 and B5 for the same BQS-6 submarine sonar transducer, were obtained simultaneously by the nearfield calibration technique with the NFCA and by the classical farfield technique using a source-hydrophone separation distance of 220 feet. For the results, in Figure B4, the BQS-6 submarine transducer with its dome and the NFCA were suspended within 20 feet of each other directly from the barge platform at the Lake Seneca Calibration Facility and the farfield measuring hydrophone was suspended from a floating boom extending about 70 feet from the end of the 150-foot long barge platform. The suspension arrangement used to obtain the beam pattern measurements, shown in Fig. B5, were the same as above for the farfield measuring hydrophone. However, the BQS-6 submarine sonar transducer without its dome and the NFCA were suspended within a few feet of each other in a common structure, as shown in Fig. B6. This common structure suspended from the barge platform was provided with an azimuth positioner and gear box to rotate the BQS-6 relative to the NFCA and the farfield measuring hydrophone for simultaneous beam pattern measurements.

(U) The agreement of the NFCA measured beam patterns with the computed farfield pattern, and with the measured beam patterns obtained with the classical farfield technique, is very good for the main lobe in each comparison and is fairly good for the side lobe structure.

REFERENCES:

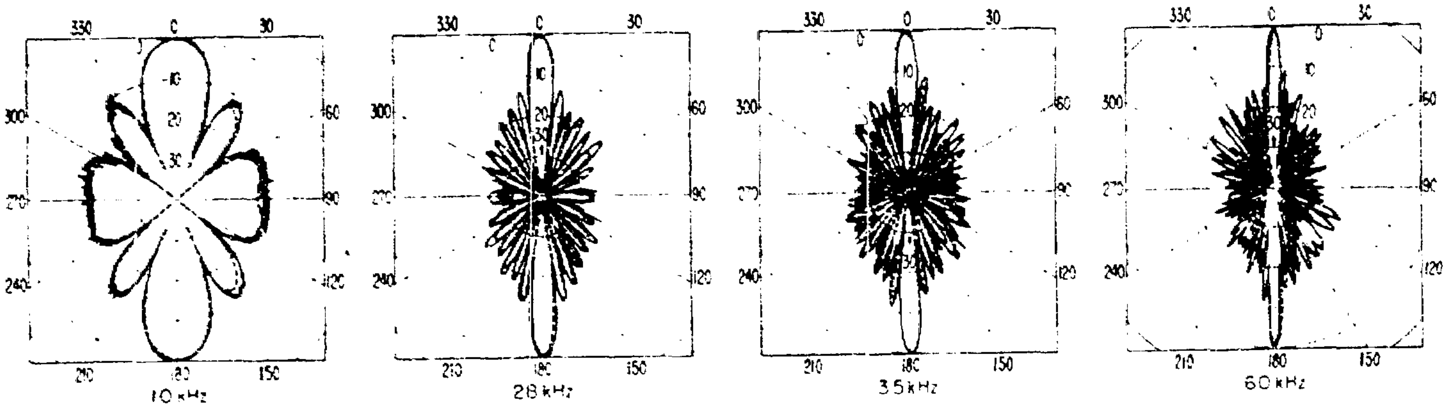
B1. G. Pida, D.J.G. Gregan, "Comparison of Far Field and Near Field Calibration Using the NRL Near Field Calibration Array", USL Symposium Report No. 995 Vol. I, pp. 234-257, Proceedings on 26th Navy Symposium on Underwater Acoustics, 12-14 Nov. 1968.(CONFIDENTIAL)



(U) Fig. B1 — 18-ft line array directivity pattern at 2 kHz by nearfield technique and computed farfield

—— Measured by NFCA

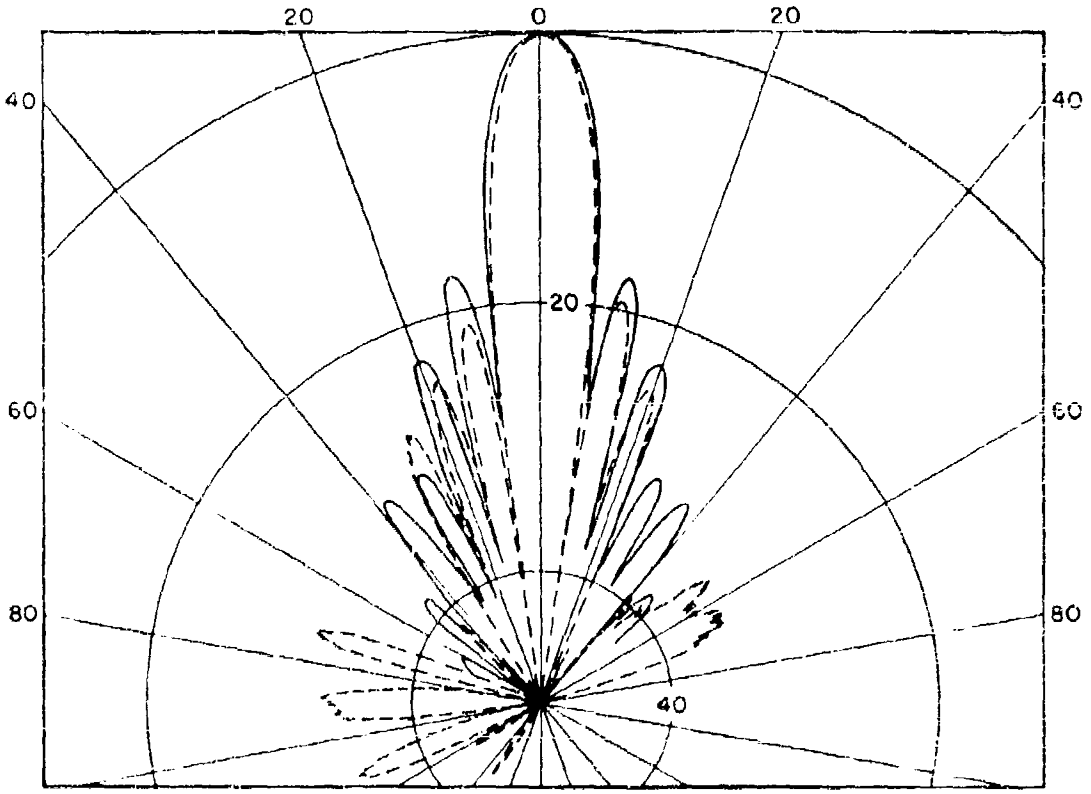
--- Computed



(U) Fig. B2 — Cruciform array directivity pattern at 1, 2.8, 3.5, and 6 kHz by nearfield technique and computed farfield

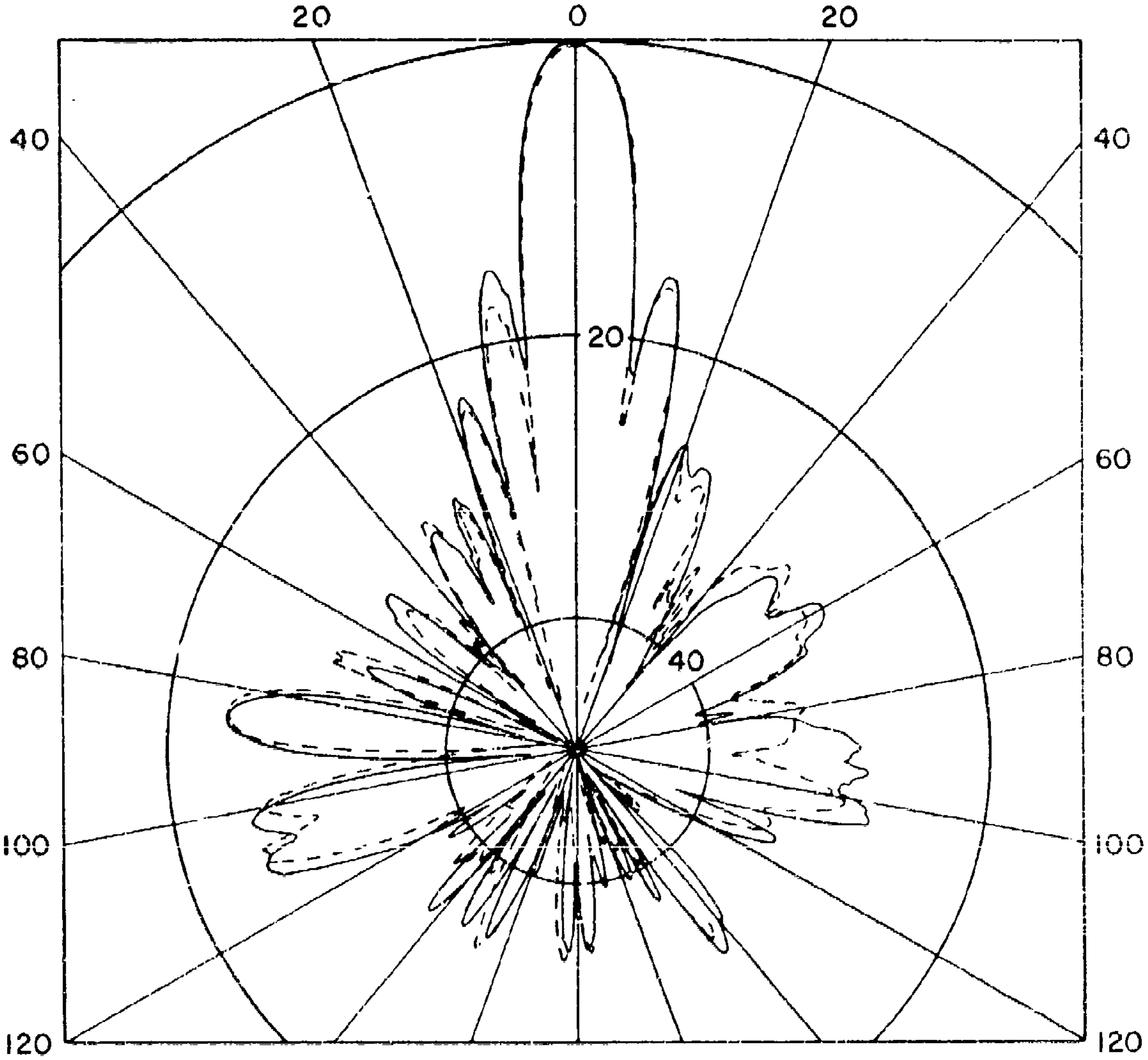
—— Measured by NFCA

--- Computed



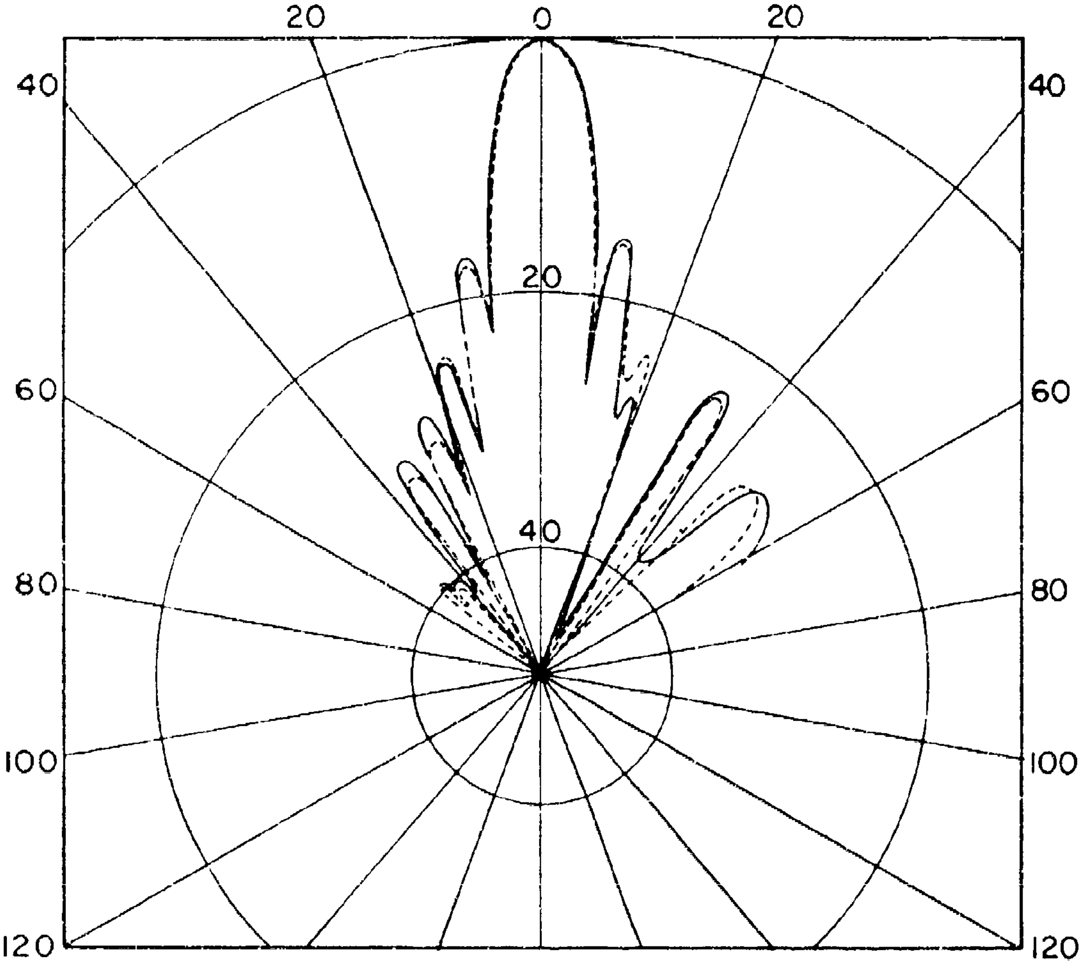
(C) Fig. B3 -- BQS-6 submarine sonar transducer (with dome) directivity pattern at 3.5 kHz by nearfield technique and computed farfield

—— Computed
--- Measured by NFCA



(C) Fig. B4 — BQS-6 submarine sonar transducer (with dome) directivity pattern at 3.5 kHz by nearfield and classical farfield techniques

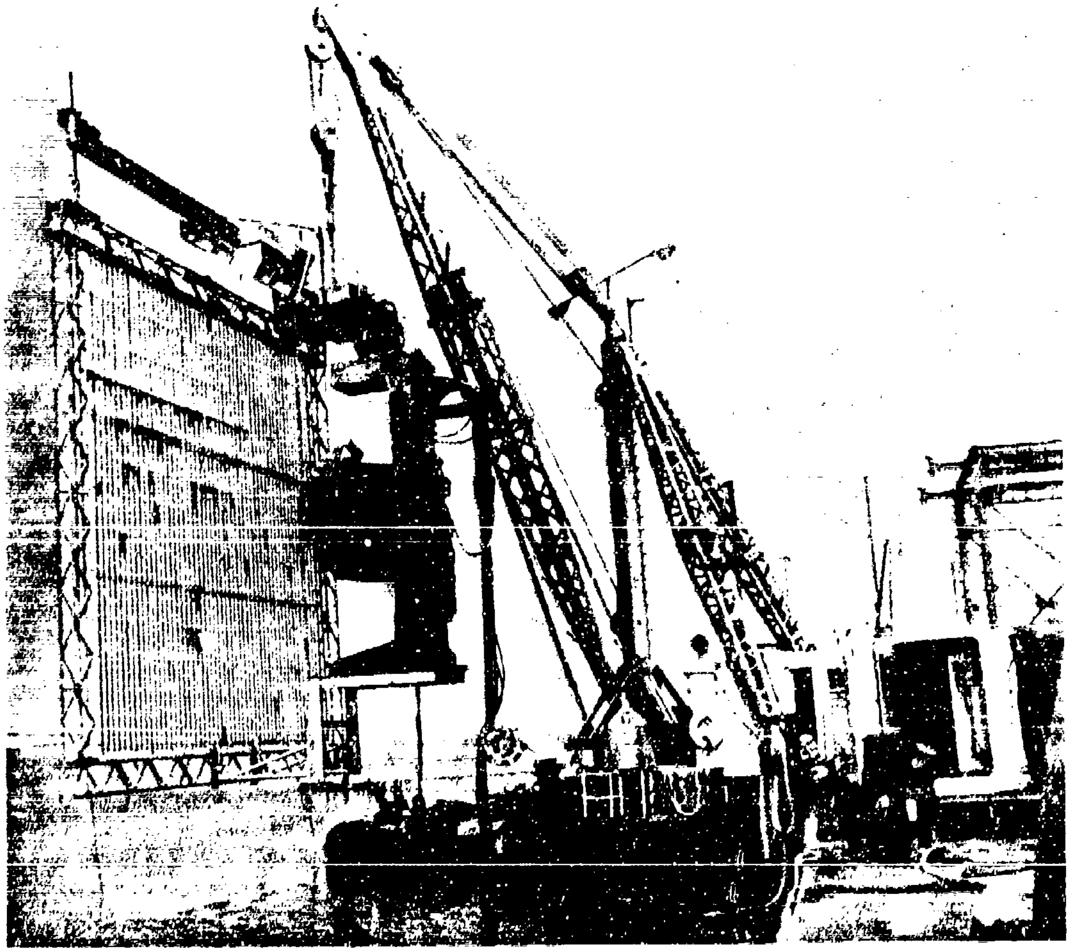
—— Measured by farfield technique
--- Measured by NFCA



(C) Fig. B5 — BQS-6 submarine sonar transducer (without dome) directivity pattern at 3.5 kHz by nearfield and classical farfield techniques

—— Measured by farfield technique

--- Measured by NFCA (BQS-6 and NFCA on common structural suspension)



(U) Fig. B6 — Photo of BQS-6 submarine sonar transducer and NFCA on common structural suspension

UNITED STATES GOVERNMENT

Memorandum

7100-029

DATE: 26 February 2004

REPLY TO ATTN OF: Burton G. Hurdle (Code 7103)

SUBJECT: REVIEW OF REF (A) FOR DECLASSIFICATION

TO: Code 1221.1

REF: (a) "Dockside In Situ Measurements on SQS-26 Sonar Transducer with NRL Large Nearfield Calibration Array" (U), George Pida and Dorsey Gregan, Acoustics Division, NRL Memo Report 3003, March 1975 (C)

1. Reference (a) describe the results of a series of calibrations of the SQS-26CX Sonar transducer with the NRL Nearfield Calibration Array. The transducers had been installed on the USS BLAKELY (1072).
2. The technology and equipment of reference (a) have long been superseded. The current value of these papers is historical
3. Based on the above, it is recommended that reference (a) be declassified and released with no restrictions

Burton G. Hurdle

BURTON G. HURDLE
NRL Code 7103

CONCUR:

Edward R. Franchi 3/1/2004
E.R. Franchi Date
Superintendent, Acoustics Division

CONCUR:

Tina Smallwood 3/3/04
Tina Smallwood Date
NRL Code 1221.1