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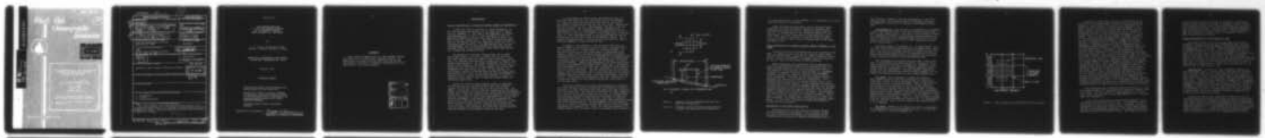

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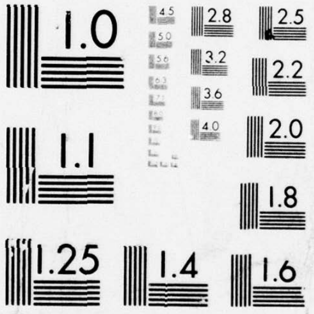
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Woods Hole Oceanographic Institution

PING-THROUGH-THE-HULL 3.5 kHz ECHO-SOUNDING SYSTEMS ON THE RESEARCH VESSELS CHAIN, ATLANTIS II, AND KNORR

by

S. T. Knott, Frederick R. Hess,
Warren E. Witzell and Earl M. Young

February 1978

TECHNICAL REPORT

Prepared for the Office of Naval Research under Contract N00014-74-C-0262; NR 083-004.

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Approved for Distribution Elizabeth T. Bunce

Elizabeth T. Bunce, Acting Chairman
Department of Geology & Geophysics

ABSTRACT

This report documents the 3.5. kHz sounding systems currently in use on Woods Hole research vessels. To help others to install similar facilities, we discuss the history, installation technique, performance and calibrations of our various systems.

INTRODUCTION

Initial Installations on Research Vessels CHAIN and ATLANTIS II

In 1967 and 1968 we procured, as loaned equipment, 3.5 kHz echo-sounding transducers for our ships the R.V. CHAIN and R.V. ATLANTIS II. The hope of the Department of Geology and Geophysics was to have 3.5 kHz available for both the CHAIN and ATLANTIS II during their 1969 autumn cruises (numbers 96 and 54, respectively). The Office of Naval Research and U.S. Geological Survey each supplied a towed fish with the transducer array installed. The ONR-supplied fish (on loan from NAVOCEANO) was an Alpine Geophysics Associates design; the USGS system, an EDO Corporation Model 330A towed vehicle with a Model 240 transducer array.

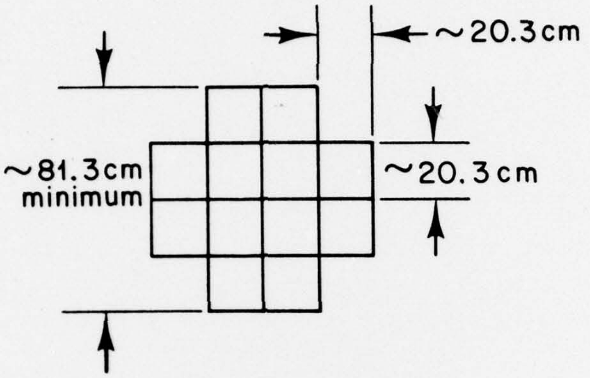
The prospect of routinely towing either one of these large items, about a ton each in weight, was not enticing. Work went ahead through the summer of 1969, however, to modify or to consider modifications of these fish to improve their towing characteristics. The Alpine Geophysics unit had a tow point so far forward of the center of gravity in water that it would only tow horizontally at high speeds, and its tail was inadequate for good control of yaw. It was, however, far more compact and easily handled than the EDO unit which, when received and first tried in the Black Sea from the ATLANTIS II (cruise 49) by K. Prada, had positive buoyancy, a result of modifications by USGS so that it might be surface-towed from relatively small ships.

Plans for coring on each proposed cruise, an operation carried out from the starboard side of the ship, mandated rigging the fish for towing from the stern of each ship. For CHAIN, a rudimentary towing scheme was rigged to tow the smaller Alpine fish through the stern A-frame using Commercial Engineering faired chain. This was considered to be primarily a fair weather rig, but sufficient to obtain some experience with the new gear. Outfitting ATLANTIS II presented a more sticky problem because at that time she had neither a stern A-frame nor a crane that could handle heavy dynamic loads beyond the after rail of the fantail. Some ideas for modifying and rigging the EDO fish for towing were developed, but these were not particularly inviting because its performance under tow was poor.

It struck Hess and Knott rather simultaneously that the whole EDO fish might fit into the center well of the ATLANTIS II. Then we could simply flood the well leaving its bottom cover plate in position and use the fish as a "hull" installation. But the fish would not fit. Nevertheless, the plan to use the well was pursued. The transducer assembly, EDO Model 240, a double-cross array of 12 transducers, was removed from the fish and fitted to a 48-inch tub welded to the bottom plate of the well (Fig. 1). The transducers hang in the water-filled tub and the bottom plate of the well serves as the acoustic window. This proved a successful plan as shown by dock-side tests and reports from the ATLANTIS II after she was at sea.

On CHAIN, it was awkward to tow the Alpine fish from the after A-frame of the ship but it was at least a workable option for our group when it joined CHAIN in the Canary Islands. At the start of our leg of the cruise when we investigated other options, Captain Davis and Chief Engineer McLaughlin helpfully suggested that we could use the #3 cofferdam for a transducer location within the ship, and flood the compartment with enough water to provide acoustic coupling between the transducers, the ship's hull and seawater. Because the cofferdam is not wide enough fore-and-aft to accommodate the double-cross array, the 12 transducers were reassembled in an array that was 2 transducers wide fore-and-aft and 6 wide athwartship. This was installed on the starboard side of the keel structure. This is obviously not the most advantageous array configuration for a rolling ship because it produces greater directivity athwartship (a narrower beam-width) than fore and aft. Furthermore, the cofferdam's location, separated as it is from the ship's four main diesel engines by a fuel tank, is not the most quiet.

With this installation we again demonstrated the feasibility of a ping-through-the-hull installation, and managed to collect far more, at times excellent, data than might have been collected with the towed fish. Most data were collected at ship's speeds up to 10 knots with two main engines on the line. At higher speeds with 4-engine operation,hull-carried noise became too great for receiving weak echoes in rough terrain. Even then in moderate sea states,echoes from the flat-lying seafloor were generally recordable with good penetration. On the ATLANTIS II noise reception was not so much of a problem because the transducer tub is almost completely surrounded by air. Thus, the array is decoupled to a greater extent from hull-borne noise; but probably more important,



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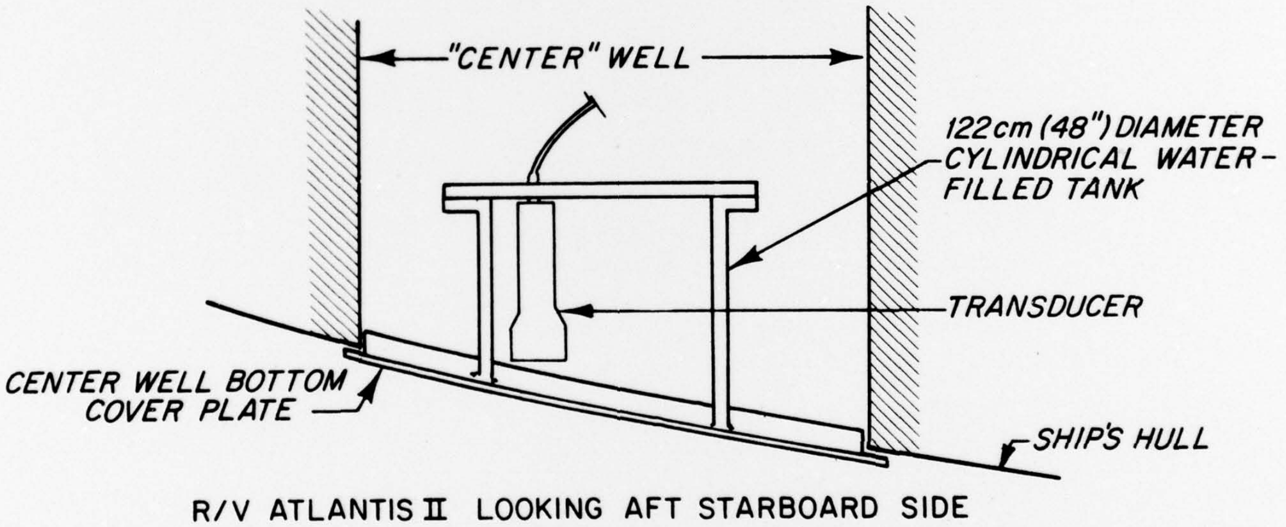

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Figure 1a Transducer faces are arranged so that they form a double-cross configuration.

Figure 1b Transducers are hung from the top of the tank that is welded to the cover plate of the center well.

the steam power plant of the ATLANTIS II is generally less noisy than the diesels of the CHAIN.

These installations show merit, but it should be emplasized that the usual problems of quenching associated with hull-mounted transducers remain. These are really improvisations. If budgets permit, they should be modified to provide a dome, to offset the acoustic window below the ship's hull, or at least a fair-water so that the acoustic window is kept more nearly free of the air bubbles that stream along the ship's hull.

Final Installations on Research Vessels CHAIN, ATLANTIS II, and KNORR

The EDO fish and its transducers had to be returned to the USGS. At about the same time the new research vessel KNORR arrived at Woods Hole. Twenty-four 3.5 kHz transducers, twelve each to outfit the ATLANTIS II and KNORR, were then loaned us by the U.S. Navy via the Office of Naval Research.

These transducers were apparently made as experimental units using polyurethane rubber for the transducer face, and there was some question as to the long-term resistance of this material to the passage of water through it. Poly<u>ether</u> urethane is supposed to be more resistant than poly<u>ester</u> urethane, but we were unable to find out which was used in these transducers. The term used by the urethane industry to describe this osmosis-like effect is "hydrolysis". In a somewhat similar situation, our seismic arrays (Knott, 1973) use polyether urethane tubing. We have detected no migration of water into the oil-filled hydrophone sections, but the water and ethylene-glycol-filled tail section does lose its internal hydraulic pressure and the specific gravity of the remaining liquid increases over a period of a few weeks. This suggests that water migrates from the tail section to seawater. Therefore, to reduce the possibility of "hydrolysis" in these 3.5 kHz transducers, we coated their faces with polysulfide rubber paint. In 1977 these transducers on KNORR and ATLANTIS II continue to be serviceable.

Description of the Three Installations

The installations on each ship are different because of the variations in hull design. This has shown in general that significant differences in installation can be tolerated, but the effects of specific differences have not been measured. Common to all the installations is the tank structure which can be pressurized to relatively low pressures (maximum of 10-15 psi) to simulate a keel-depth environment.

The ATLANTIS II: The new array of transducers for ATLANTIS II was installed as before in the tub attached to the bottom plate of the "center" well. This well is not actually on center. It is immediately forward of the engine room and starboard of the keel where there is a moderate slope of about 10 to 15 degrees to the bilge, and it is aft of the longitudinal center of the ship (Figure 1).

The bottom plate (17.8 lbs/sq. ft., or approximately 1.11 cm (7/16 inch) plate) is reinforced with ell-shaped ribs. Where the tub or tank is installed, the flats of these ribs are cut away. The transmission path from the transducers is then primarily through the bottom plate, the remaining vertical parts of the ribs being parallel to the transmission path.

The transducers are attached and hang from a cover plate that is constructed to be near-horizontal. Therefore, as in these cases where the bilge is sloping, the "acoustic" window slopes relative to the plane of a coherent wavefront transmitted from the transducers. This and internal reflections within the tank enclosure alter pulse shapes somewhat, but the effects are generally minimal for most sounding operations.

The CHAIN: The transducers on CHAIN were moved by Hess, after cruise 96, from the cofferdam to a location at frame #40, forward of the longitudinal center of the ship and on the port side of the keel structure. This is about six feet forward of the locations of the two 12 kHz hull-mounted transducers on either side of the internal keel structure. Here an internal tank was constructed between the longitudinal and traverse strength members of the hull. The spacing of these members permits the twelve transducers to be arranged in a symmetrical array between them (Fig. 2). The hull plates through which we transceive on CHAIN are 16lbs/sq. ft., or approximately 0.99 cm (3/8inch) thick, and the slope of the bilge is about 5 to 10 degrees.

The KNORR: KNORR has an unusual hull form to accommodate the forward and aft cycloidal propulsion units. It also has a bow chamber, as does the ATLANTIS II.

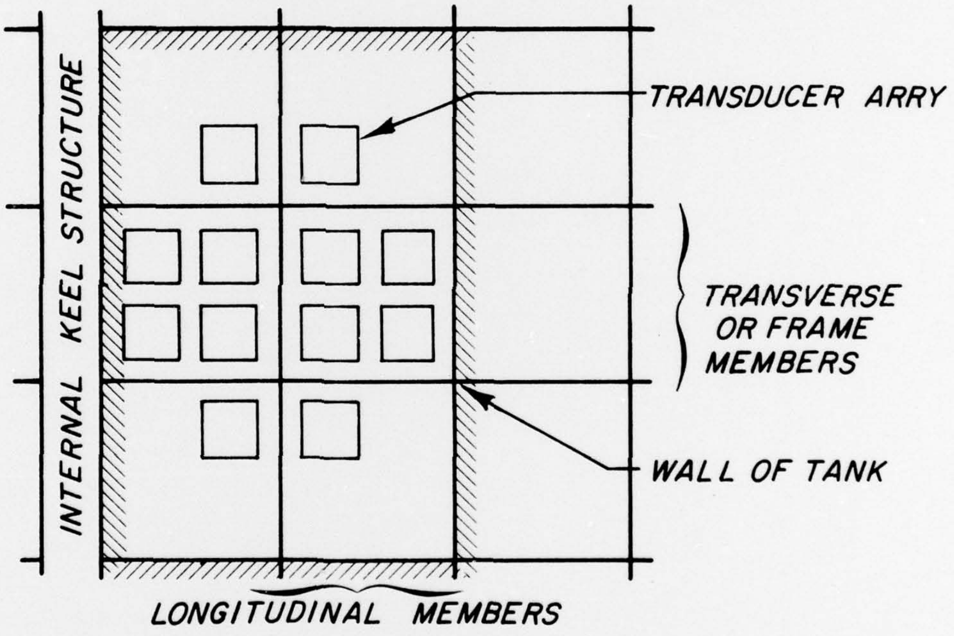


Figure 2 Array configuration on R/V CHAIN within hull structures

Transducers mounted near the bow, or at the foot of the stem, such as in a bow chamber, generally have the advantage (except in rough weather) of being in an environment that is relatively quiet, and free of entrained air bubbles in the water. Some of the best noise-free echo-soundings have been collected from such 12 kHz installations (e.g., Cousteau's RV CALYPSO and the no longer existing installation on the RV CHAIN). Plans to alter the bow chamber on KNORR to accept a 3.5 kHz array were made and approved by the Coast Guard, but we could not afford the alteration. On KNORR the forward cycloid is immediately aft of the bow chamber, so that when operating it creates sufficient noise to compromise such advantages almost completely. For these reasons we placed the 3.5 kHz transducers on this ship as far as possible from the cycloids and as near as possible to the deepest part of the hull to reduce "quenching" of transmitted signals by entrained air bubble streams. This location is directly under the control flat area in the auxilliary engine room space (frame 41 on the port side of the keel structure). Forward of this location and aft of the bow chamber, the draft decreases abruptly to accommodate the forward cycloid. Draft is maximum forward of the longitudinal center of the ship (near the transducer location), and decreases from there aft under the main engine room towards the stern, except for a skeg structure immediately forward of the aft cycloid. Other locations that might be used, such as the "center" well, which is between the engine room and aft cycloid, are less favorable because of noise created by the engines and propulsion units, and because of turbulence and entrained air from the cycloids. (It is generally agreed that any sounding installation on this ship is subjected to a higher noise environment than is expected on any ship of conventional design.)

The transducers were mounted by Knott and Witzell in a tank constructed between the longitudinal and transverse frames, much as on CHAIN. The hull plates are approximately 1.27 cm (1/2 inch) thick, and the bilge slopes approximately 15 to 20 degrees under the transducers.

In all these installations the air-borne intensity of the transmitted 3.5 kHz pulse is very high. An innovation used on this ship, but not on the others, was to "insulate" the tank acoustically to reduce the level of the 3.5 kHz signal reaching the ears of watchstanders stationed in the engine control flat immediately above the transducer array. The audible intensity of the transmitted pulse heard by the engineers is definitely reduced by the insulation as might be expected. There, however, is no significant reduction in the noise received by the array from the ship's machinery, since most noise reception appears to come via the hull structures and the water. The insulation was made up of alternate "loaded" layers of "compliant" material made of sheet-lead and plywood.

General Performance of the Transducer Arrays

The layout of each array is much the same in size and arrangement, although there are small differences from one array to another such as the spaces between the transducers necessary to accommodate hull structures. These dimensions range from 1 cm between transducers in the array in the ATLANTIS II tank to about 10 cm in the tanks of the CHAIN and KNORR. The angle of that part of the bilge or bottom plate that acts as the "acoustic window" also differs from ship to ship, and the dimensions from the faces of the individual transducers of each given array to the "window" vary. In spite of these variations, the acoustic output of these groups of transducers indicates that each performs for the most part as a simple planar array.

Transmission: Like many 3.5 kHz transducers commercially available today, such as the Massa Model TR75A and the EDO model 240, a single transducer has a small active face and is quite omnidirectional. One transducer handles only a few hundred watts input while transmitting (for the Massa, 600 watts maximum at 30% duty cycle). Using the Massa TR75A as an example with its on-axis transmitting response of about 175 dB re 1 μ Pascal at 1 meter per watt, it should deliver an output pressure of about 195 dB re 1 μ Pascal at a meter when driven at about 100 watts. An array of 12 transducers is used to increase directivity as well as output pressure levels (an on-axis pressure increase of approximately 22 dB for the 12-transducer array).

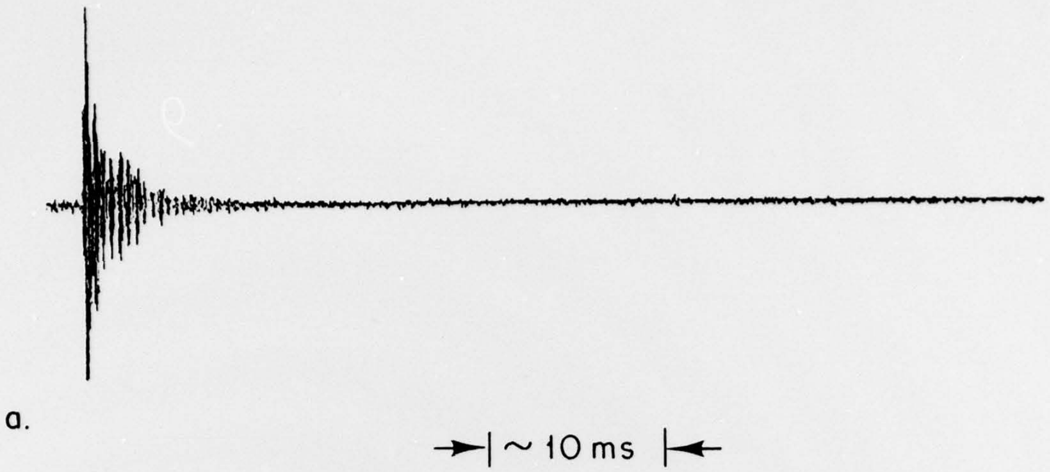
We have not specifically measured the directivity of the resulting acoustic systems on our ships, but while in the process of placing monitoring transducers to measure on-axis output pressure levels, we have determined approximately that a broad beam is developed commensurate with the dimensions of the array at 3.5 kHz (about 3dB down at 30°). Appropriately high acoustic output pressures indicate that a coherent wave front is generated on-axis from the combined output of the 12 transducers of the arrays.

Measurements were made with carefully placed monitoring hydrophones at the dock in 20 meters of water from CHAIN, and from transducers lowered 30 to 100 meters below the hull while at sea on ATLANTIS II and KNORR.

We see two effects upon pulse shape during transmission and reception via these tank installations. First, there is a reverberant tail to the outgoing pulse, apparently due to reflections within the transducer tank, which is about an order of magnitude less in amplitude than the pulse. (No acoustic absorption materials are used inside any of the tanks.) A somewhat similar tail is associated with reception of short (0.5 ms) pulses generated by an external sound source (Fig. 3). In neither case does this low-level pulse-tail significantly effect sounding results. Second, the complex impedance characteristics of the transducer arrays show secondary resonances that are apparently caused by the tank enclosures (Fig. 4).

The nominal impedances of different types of 3.5 kHz transducers vary and there are variations between transducer in each array group. Similarly, these also involve phase angle differences. The transducers are not necessarily preselected to be within certain impedance and phase angle tolerances. Thus, for a given installation we have first measured these characteristics in a quasi-freefiel (off the dock) to determine an optimum grouping so that a reasonable balance of transmitted energy will be distributed across the arrays.

<u>Transceivers</u>: It should be noted that most relatively inexpensive and readily available transceivers such as the EDO Model 248 series, or the ORE Model 140, produce square wave drive to the transducer array rather than sine wave. In practice the typical transducer is parallel tuned by a transformer circuit. In parallel tuning, the impedance presented by the transducer is generally characterized as being at a peak at resonance and at lower values off resonance, as opposed with being minimum at resonance for series tuning. The spectrum of the square wave has, however, considerable harmonic content. Because of this, the transmitters look into a circuit presenting low impedances off-resonance which causes large transmitting current transients at frequencies outside the band of interest. This results in large transient peak currents in the power amplifier stages and consequent distortion and poor power transfer. Maximum drive levels are therefore limited by overload circuits to protect the amplifiers rather than by the capability of the transducers.



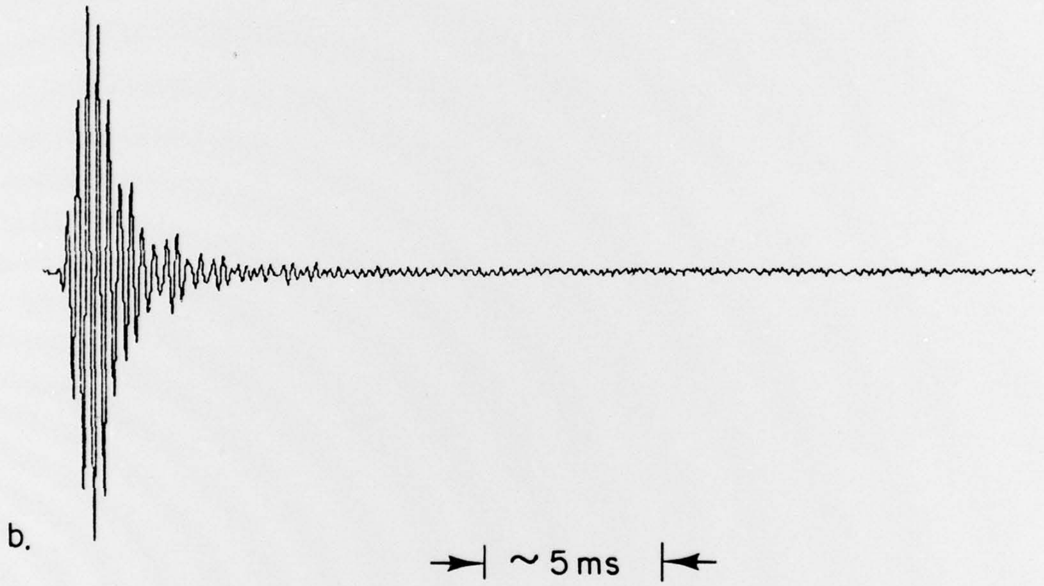


Figure 3a Pulsed response of transducer array to a 0.2 ms pulse from Edo 248 transmitter. Transmitted pulse monitored at reference hydrophone suspended about 30 meters below ship (Atlantis II).

Figure 3b Receiving response of transducer array and Edo 248 receiver to a 1.0 ms pulse transmitted from remote transducer about 30 meters below ship (Atlantis II).

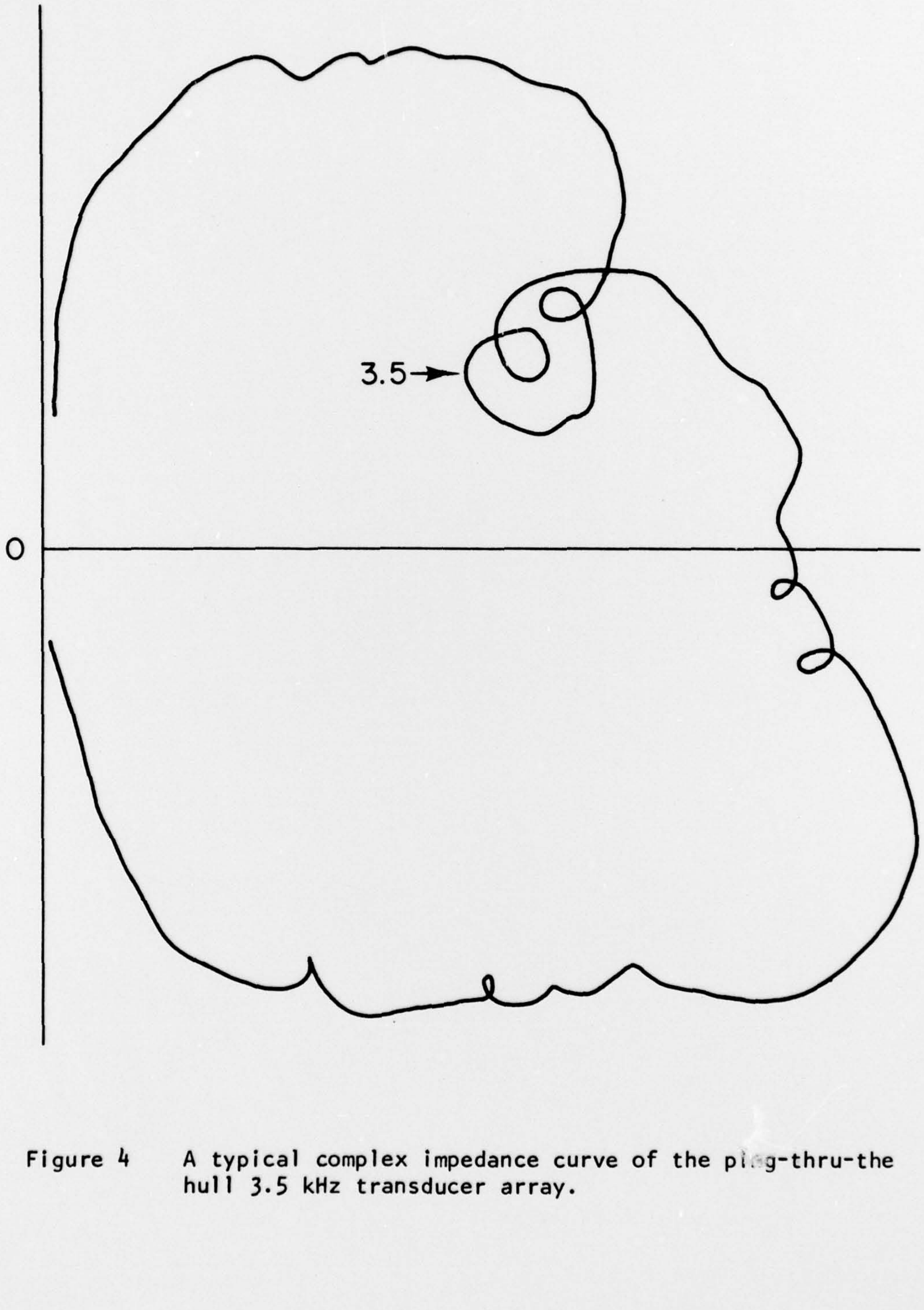


Figure 4 A typical complex impedance curve of the plug-thru-the hull 3.5 kHz transducer array.

As previously mentioned, the on-axis source level per watt characteristic of the Massa TR75A is about 175 dB re 1 μ Pascal at 1 meter. At 100 watts drive this would increase 20 dB to 195 dB, and with 12 transducers combined in a planar array we might expect an on-axis pressure about 22 dB higher or about 217 dB re 1 μ Pascal at 1 meter. If there were no coupling losses from transmitter to transducer to seawater, the transmitter would only have to deliver about 1200 watts to the array to produce the 217 dB on-axis pressure level.

In reality when we typically drive the 12-transducer array with an EDO 248, we overlook the matching problem and use a brute -force mode of transmission. The usual matching network consists merely of an appropriate winding of the transmitter output transformer going directly to the input of the transducers connected in parallelled series pairs. To get a 210 to 215 dB re 1 μ Pascal source level at 1 meter, the corresponding transmitting voltage and current levels measured respectively across a 1000 to 1 divider and a 1 Ohm series resistor in the output line, indicate a transmitter output of about 1960 watts. This power level is attained after modifying the overload circuit of the 2000 watt (transmitter), and it is not increased appreciably by simply using the EDO 10 kilowatt modification kit without better matching arrangements. The same is true for the 10 kilowatt ORE model 140 transceiver. A possible LC low pass network in the line, at each transducer, that is tuned to the fundamental frequency, could remove harmonics and make the load on the transmitters more nearly resistive. Of less value is a band pass filter placed in the line at the output of the transmitter, because this narrows the bandwidth and thus decreases time resolution which reduces the usefulness of the sounding records. The former method has not yet been put to routine, the latter was tried and discarded.

Reception: For receiving, the array is about 6 dB more sensitive than a single transducer because the 12 transducers are connected in paralleled series pairs. The sensitivity of the Massa TR75A and the EDO 240 is about-170 dBV per μ Pascal and thus the typical array is about -164 dBV per μ Pascal.

Automatic gain control circuits are introduced into many of today's transceivers. To obtain linear response for such studies as seafloor reflectivity, we connect our monitoring signal leads to the output of the receiving transformer of the EDO 248C. The received voltages here are 13.8 dB higher than at Test Point 1 of the unit, which is directly across the transmission line to the transducers. Similar arrangements can be made with other transceivers.

In addition to the 12-transducer array installation on the RV KNORR, we made a smaller receiving array of four 3.5 kHz transducers in the bow chamber to see if noise levels there would be reduced enough to improve 3.5 kHz operations on that ship. With this arrangement we then can transmit from the 12 transducer array, a location where received noise levels are high, while receiving in the bow chamber where noise levels may be low. This produces a small improvement in reception particularly when the forward cycloid is secured. A towed receiving array such as that used for seismic profiling provides best reception at present. In this broadband receiving system the signal is filtered in the 3.5 kHz band after reception and some amplification (Knott, ibid).

CONCLUSIONS

A ping-through-the-hull arrangement is a practical and inexpensive method to provide intermediate-frequency, in-hull sounding systems for research vessels that do not have sea-chests or the like designed into their hulls for the purpose. No hull penetrations are required. The transducers and connections are all installed within the ship so there is no need for dry dock services. The system can be serviced at sea or dock-side. Successful transceiving operation at 3.5 kHz can be expected through hull plates at least as thick as about 1.5 cm. Although useful installations can be made in almost any part of the ship's bilges that can be flooded enough to provide acoustic coupling from the transducer face to the hull plates to the seawater, tank installations are better because they can also be pressurized. Adequate coupling is supplied by fresh water and its use with alkaline anti-corrosion compounds reduces corrosion problems.

ACKNOWLEDGMENTS

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Reference

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PING-THROUGH-THE-HULL 3.5 kHz ECHO-SOUNDING SYSTEMS ON THE RESEARCH VESSELS CHAIN, ATLANTIS II, AND KNORR by S. T. Knott, Frederick R. Hess, Warren E. Witzell and Earl M. Young. 14 pages. February 1978. Prepared for the Office of Naval Research under Contract N00014-74-C-0262; NR 083-004.

This report documents the 3.5 kHz sounding systems currently in use on Woods Hole research vessels. To help others to install similar facilities, we discuss the history, installation technique, performance and calibrations of our various systems.

1. Echo-sounding
2. 3.5 kHz
3. Ping-through-the-hull

I. Knott, S. T.
II. Hess, Frederick R.
III. Witzell, Warren E.
IV. Young, Earl M.
V. N00014-74-C-0262; NR 083-004

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