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Projectors and Hydrophones For An Acoustic Waveguide

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
Three projector and three hydrophone configurations have been developed to instrument three acoustic waveguides at the David W. Taylor Naval Ship Research & Development Center, Annapolis Laboratory. These transducers were required to provide sufficient signal-to-noise ratio to make measurements of acoustic reflection, absorption, and transmission coefficients at pressures up to 14 MPa, temperatures of 1 to 20°C, and over three frequency ranges spanning the limits of 1 to 100 kHz. The construction of the transducers is described, typical free-field calibration plots are shown, and the approximate (continued)

CONTENTS

PROJECTORS AND HYDROPHONES FOR AN ACOUSTIC WAVEGUIDE

INTRODUCTION

The Annapolis Laboratory of the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) is responsible for development and evaluation of acoustic anechoic coatings and echo-reduction materials employed on undersea vehicles and weapons. Three different acoustic waveguides in the form of thick-walled metal tubes are used to evaluate these materials over the frequency range 1 to 100 kHz, at pressure extremes to 14 MPa, and at temperatures from 1 to 20°C.[1,2] These tubes have been designated ALPHA, BRAVO, and CHARLIE. Commercially available transducers used as projectors and hydrophones in these tubes have proven inadequate to give the desired signal-to-noise ratio required for precise measurement of coefficients of acoustic absorption, reflection, and transmission over the stated frequency and pressure ranges. The Underwater Sound Reference Detachment of the Naval Research Laboratory (NRL-USRD) was funded to develop and test improved projectors and hydrophones for each of the waveguide tubes. Thus, six new transducers were designed, constructed, tested, and delivered in sufficient quantities to fully instrument each tube.

DESIGN CONSIDERATIONS

One continuous length of mild steel was used to fabricate each of the waveguide tubes. The ALPHA tube has a length of 12.8 m, with an inside diameter (id) of 14.13 cm, and a wall thickness of 5.64 cm. The acoustic requirements for the projector and hydrophone for this tube were established so acoustic measurements could be made over a usable frequency range of 1 to 20 kHz.

The BRAVO waveguide tube has a length of 6.4 m, with an i.d. of 6.35 cm, and a wall thickness of 6.99 cm. The transducers to be used in this tube had to effectively cover the frequency range from 4 to 50 kHz.

The CHARLIE waveguide tube is 12.8-m long, with an i.d. of 8.64 cm, and a wall thickness of 5.84 cm. Initial acoustic requirements for the projector and hydrophone to be used in this tube were established to effectively cover the frequency range 1 to 100 kHz. Due to this extremely wide bandwidth requirement, a design compromise later resulted in lowering the maximum frequency to 80 kHz for the hydrophone.

Existing provisions for mounting the projectors to the end closures of the tubes were to be used to avoid additional fabrication and installation costs. For the same reasons, the existing ports through the tube walls were to be used to insert the hydrophones. The commercial hydrophones being used were "probe types", extending into the tube cavity.

The NRL-USRD hydrophones were to be mounted flush with the tube's inside surface in the position formerly occupied by the commercial hydrophone's pressure-tight packing gland. This flush mounting was designed to eliminate acoustic interference with the traveling wave in the water.

All three of the waveguide tubes are encased in individual, full-length water jackets for temperature control. These jackets have removable access panels at each hydrophone position. Due to the close proximity of the hydrophone cable glands to these panels, the cable gland must be kept short and still be watertight. The hydrophone's cable must also be flexible enough to take a short radius of curvature.

Accurate measurements made in the acoustic waveguides require the generation of an acoustic pulse by the projector of sufficient amplitude to produce a measurable incident, reflected, and transmitted pulse sensed by the hydrophones. Therefore, the transducers need only to be stable with time and do not have to have constant response or sensitivity as a function of frequency, pressure, or temperature such as is required for a measurement standard.

The accoustic element configuration chosen for the projectors was the radially poled, piezoelectric, hemispherical shell. This configuration was chosen because of its acoustic efficiency, ability to withstand the required hydrostatic pressure, ease of construction, and reduced excitation at mechanical resonances in the waveguide tube walls. This was based on experience through use of this configuration in the NRL-USRD type G45 projector in a high-pressure calibration facility. Effective operation of this element configuration depends on decoupling it from the mounting plate or back mass. The diameter of the element required is inversely proportional to the required electroacoustic resonance which should occur at the upper end of the operating frequency range. The operating frequency range of waveguides ALPHA and BRAVO are low enough to use a single acoustic element. Waveguide CHARLIE requirements dictate an array of hemispherical elements.

Several sensor element configurations were evaluated for the waveguide hydrophones. The configurations employed were chosen because of the required operating frequency range, acoustic sensitivity, hydrostatic pressure, and flush mounting with the tube's inside diameter.

PROJECTOR CONSTRUCTION

The three new projectors developed by NRL-USRD to fulfill these requirements contain several features that are typical to the construction of each type, as shown in Figs. 1, 2, and 3. Each type projector has a back mass machined from a solid piece of Type 304 stainless steel (Item 3 of Figs. 1, 2, and 3). The machining includes oil-fill passages (not shown in the figures) through to the cavity between the butyl rubber window (Item 4 of Figs. 1, 2, and 3) and the acoustic element (Item 1 of Figs. 1, 2, and 3). Tapped holes pass through the back mass for the glass-to-metal hermetic seals used to carry power to the acoustic elements. All parts of the projector are attached to the back mass.

The butyl rubber window used on each type projector is molded to a Type 304 stainless steel ring which fits over the back mass. The butyl rubber formulation is Type B-252, chosen because of its good acoustic properties and low water permeability.

The acoustic element of each type projector is mounted to the back mass in a 0.5-mm deep slot filled with B.F. Goodrich #35075 castable RHO-C compound (Item 2 of Figs. 1, 2, and 3). A thin film remains between the acoustic element and the back mass to decouple them mechanically and electrically. When oven-cured, the B.F. Goodrich #35075 compound forms a flexible air- and oil-tight seal.

Degassed DB grade castor oil (Item 6 of Figs. 1 and 2; Item 5 of Fig. 3) is used to fill the cavity formed when the butyl rubber window is installed. It is also used to fill the cavity in the rear of the back mass after the cable gland is installed. O-ring seals are used to seal the oil-filled cavities. All the oil filling operations are done under vacuum to insure that air is not trapped in the transducer.

The cable gland (Item 7 of Figs. 1 and 2; Item 6 of Fig. 3) on each type of projector is used to mount it to the end closure of the waveguide tube. The end of the cable inside the gland is blocked with Emerson and Cumming, Inc. ECCO-Bond 51 epoxy to prevent oil migration up the cable. The cable selected to meet electrical and mechanical needs for all the projectors and hydrophones is Belden Corp. No. 8428; this is a flexible, two-conductor, shielded cable with a thick neoprene jacket. This jacket is good for use with the mechanically swaged connection at the cable gland. Each projector and hydrophone is supplied with 13 m of cable.

The projectors shown in Fig. 1 (USRD type G56) and Fig. 2 (USRD type G49) have guard frames (Item 5 of Figs. 1 and 2) designed to protect the acoustic element from mechanical impact. The guard frames are constructed of two Type 304 stainless steel rods crossing over the acoustic element inside the cavity formed by the butyl rubber window.

The three projectors described have difference acoustic elements, each with features based on the performance requirements of the waveguide tube in which they are used.

The acoustic element of the ALPHA tube projector (USRD type G56), shown as Item 1 of Fig. 1, is a 7.62-cm diameter hemisphere made with MIL-STD-1376(SHIPS), TYPE I, piezoelectric ceramic. It has a 3.2-mm thick wall and fully silvered electrode surfaces. The silvered electrode surface is stripped back approximately 0.8 mm from the edge on both the inside and outside to avoid shorting to the back mass. The nominal capacitance of the element is 29.3 nF before assembly. The electrical lead for the outer surface is fed through a slot cut in the edge of the hemisphere and bonded in place with high strength epoxy. All soldering to the silvered electrodes on any piezoelectric ceramic is done with a 2% silver bearing solder to avoid separating the silver from the ceramic.

The acoustic element of the BRAVO tube projector (USRD type G49), shown as Item 1 of Fig. 2, is a 3.81-cm diameter hemisphere, made with

MIL-STD-1376(SHIPS), TYPE III, piezoelectric ceramic. It has a 3.2-mm thick wall and fully silvered electrode surfaces. This silvered electrode surface is also stripped back approximately 0.8 mm from the edge on both the inside and outside to avoid shorting to the back mass. The nominal capacitance of the element is 5.7 nF before assembly. The electrical lead for the outer surface is fed through a slot cut in the edge of the hemisphere and bonded in place with high strength epoxy.

The acoustic element of the CHARLIE tube projector (USRD type G57), shown as Item 1 of Fig. 3, is a planar array of seven 19.0-mm diameter hemispheres; again, made with MIL-STD-1376(SHIPS), TYPE I, piezoelectric ceramic. The hemispheres have a 1.6-mm thick walls and fully silvered electrode surfaces. The silvered electrode is again stripped back approximately 0.8 mm from the edge on both the inside and outside to avoid shorting the back mass. The nominal capacitance of this parallel wired array is 23.5 nF.

HYDROPHONE CONSTRUCTION

The three new hydrophones developed by NRL-USRD to fulfill the design requirements contain several features that are typical in the construction of each type, as shown in Figs. 4, 5, and 6. Each hydrophone has a housing (Item 2 of Figs. 4, 5, and 6) machined from a solid piece of Type 304 stainless steel. Each housing is used as the assembly fixture for aligning critical parts during construction of the final sensitive element for that hydrophone.

The cable gland (Item 3 of Figs. 4, 5, and 6) for each hydrophone is fabricated by silver soldering a piece of soft copper tube into a Type 304 stainless steel disk. The soft copper is mechanically swaged on and into the outer jacket material of the cable (Item 5 of Figs. 4, 5, and 6), providing a solid, watertight, pull-resistant connection.

The preamplifier board (Item 4 of Figs. 4, 5, and 6) in each hydrophone is of standard fiberglass and copper construction. The electronic circuit (Fig. 7) is designed to provide an additional 20 dB of signal voltage gain over the sensitive element's normal output.

The sensor element assemblies of the hydrophones described are of two basic configurations.

• The sensor element of the ALPHA tube hydrophone (USRD type H82M), shown as Item 1 of Fig. 4, and the BRAVO tube hydrophone (USRD type H82), shown as Item 1 of Fig. 5, is the same moving piston type assembly. The MIL-STD-1376(SHIPS), TYPE I, piezoelectric ceramic is in the form of two 12.7-mm dia by 3.2-mm thick disks, electrically connected in parallel. The element has a nominal capacitance of 800 pF and is contained in an eighteen-layer stacked assembly. Other respective layers in this stack are: expanded nickel foil electrodes, conductive silver epoxy, fiberglass cloth, high strength epoxy, a Type 304 stainless steel front piston, a tungsten back mass, and the aluminum rear alignment piston. This assembly is aligned in the cavity at the front of the housing by two 70 durometer O-rings, one in the back piston, the other in the front piston. The front O-ring also serves as a high pressure seal.

• The sensor element of the CHARLIE tube hydrophone (USRD type H89), shown as Item 1 of Fig. 6, is also a moving p.. ·on type. The MIL-STD-1376(SHIPS), TYPE I, piezoelectric ceramic is in the form of a radially poled tube 9.5-mm od by 9.5-mm long, with a 1.6 mm wall thickness. The nominal capacitance of this tube is 1.6 nF. The piezoelectric ceramic tube is contained in a nine-layer assembly. Other respective layers are: a Type 304 stainless steel front piston, fiberglass cloth, high strength epoxy, and a Mallory Type 1000 tungsten alloy back mass/alignment piston combination. This assembly is aligned in the cavity at the front of the housing by two 70 durometer O-rings, one in the back mass/alignment piston and the other in the front piston. The front O-ring also serves as a high-pressure seal. The sensitive element is further decoupled from the housing by a stack of 0.063-mm thick onionskin paper washers (Item 6 of Fig. 6), approximately 3.2-mm high, under the back mass/alignment piston.

TEST RESULTS AND DISCUSSION

The transmitting voltage response (TVR) of the ALPHA waveguide tube projector is shown in Fig. 8. It can be seen from the plot that the type G56 projector effectively covers the required 1 to 20 kHz frequency range. The maximum safe continuous wave (cw) driving voltage is 600 V rms. The type H82M hydrophone developed for this tube has a free-field voltage sensitivity (FFVS), as shown in Fig. 9, which effectively covers the required frequency range.

The TVR of the type G49 projector to be used in the BRAVO waveguide tube is shown in Fig. 10. This projector can be driven with 400 V rms for maximum cw acoustic output. The FFVS of the type H82 hydrophone is shown in Fig. 11. Both of these transducers can be effectively used over the required 4 to 50 kHz frequency range of the BRAVO waveguide.

The TVR of the type G57 projector used in the CHARLIE waveguide tube is shown in Fig. 12. This projector can be effectively used up to the required 100 kHz frequency. The maximum cw driving voltage is 300 V rms. The type H89 hydrophone developed for this waveguide tube has an FFVS as shown in Fig. 13. This hydrophone has decreasing sensitivity over the frequency range above the electroacoustic resonance. Inspection of Fig. 12 shows that the projector voltage response is increasing in this frequency range, which will somewhat offset the reduced hydrophone sensitivity.

All of these calibrations were made in the NRL-USRD Lake Facility and do not show performance of the transducers in the waveguide tubes. They did indicate sufficient response and sensitivity in the required frequency ranges to be installed in the waveguides for further evaluation. The transducers developed for waveguides ALPHA and CHARLIE have been installed and evaluated for acoustic measurements; initial data have shown a significant increase in signal-to-noise ratio. Initial measurements in waveguide ALPHA (G56 and H82M) show an approximate increase in signal-to-noise ratio of 20 dB in the frequency range 1 to 20 kHz. The waveguide CHARLIE transducers (G57 and H89) have shown an increase in signal-to-noise ratio of from 5 to 23 dB in the frequency range 7 to 50 kHz; no increase was measured in the 50 to 80 kHz range.

The acoustic performance of the waveguide BRAVO (USRD type G49 and H82) had not been measured at the time of this report.

CONCLUSIONS

The projectors provided by the NRL-USRD have improved DTNSRDC's waveguide performance because of their broader operating frequency range and increased acoustic output. The projectors have also lowered acoustic noise in the waveguide tubes because of reduced excitation of mechanical resonances in the tubes. The hydrophones provided by the NRL-USRD have improved performance because of their broader operating frequency range, increased acoustic sensitivity, and less interference with the acoustic wave in the water.

The NRL-USRD has developed improved acoustic transducers for three DTNSRDC waveguide tubes. The new transducers increase the measurement capabilities of DTNSRDC due to increased acoustic signal-to-noise ratio.

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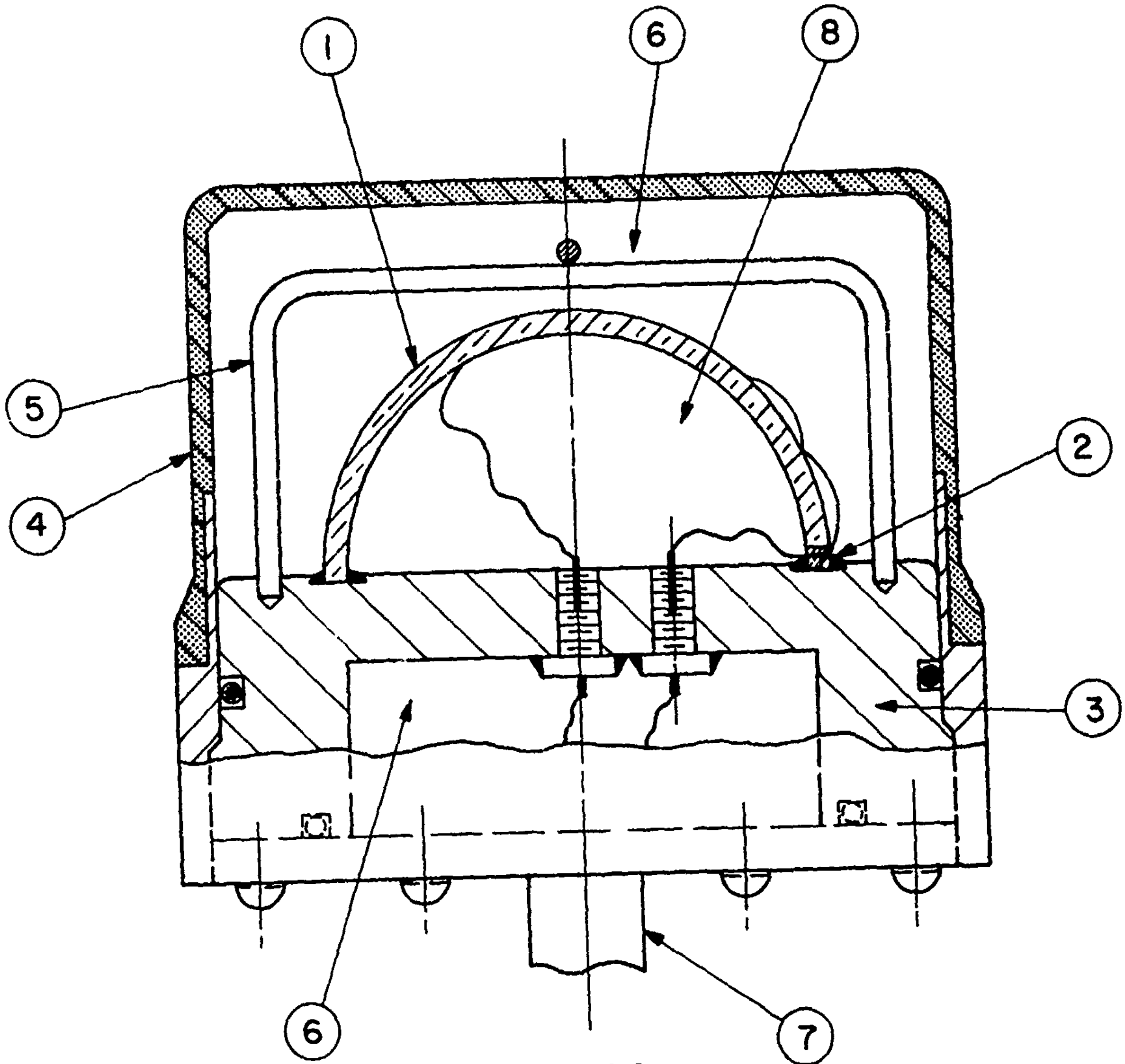
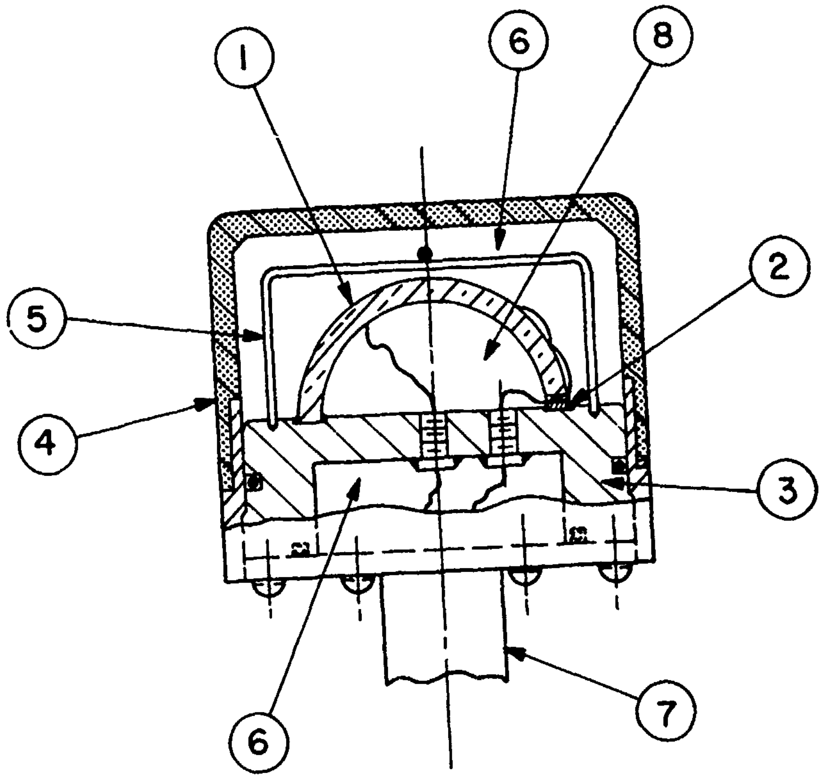
2. John J. Eynck, "Evaluation of Techniques for Testing Underwater Acoustic Absorbers and Reflectors in Wave Guides," Rubber Laboratory, SFRANBAY NAVSHIPYD, Report No. 165-59, 14 Mar 1969.



SCALE 1:1

1. Acoustic Element
2. RHO-C Decoupling Material
3. Back Mass
4. Butyl Rubber Window
5. Guard Frame
6. DB Grade Castor Oil
7. Cable Gland
8. Air

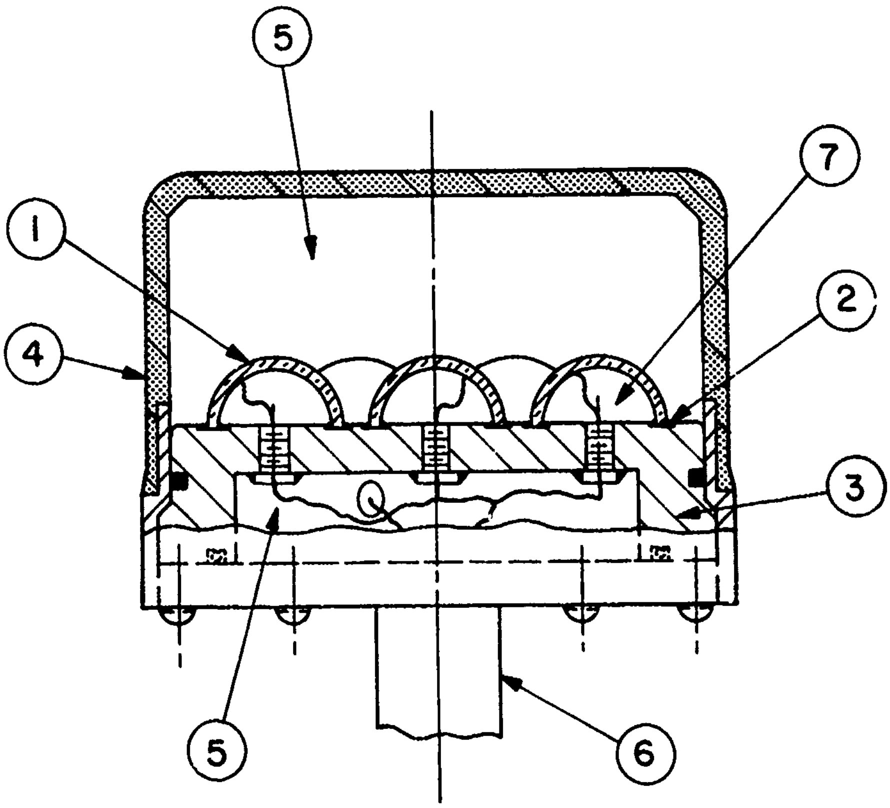
Fig. 1 - USRD Type G56 Transducer



SCALE 1:1

1. Acoustic Element
2. RHO-C Decoupling Material
3. Back Mass
4. Butyl Rubber Window
5. Guard Frame
6. DB Grade Castor Oil
7. Cable Gland
8. Air

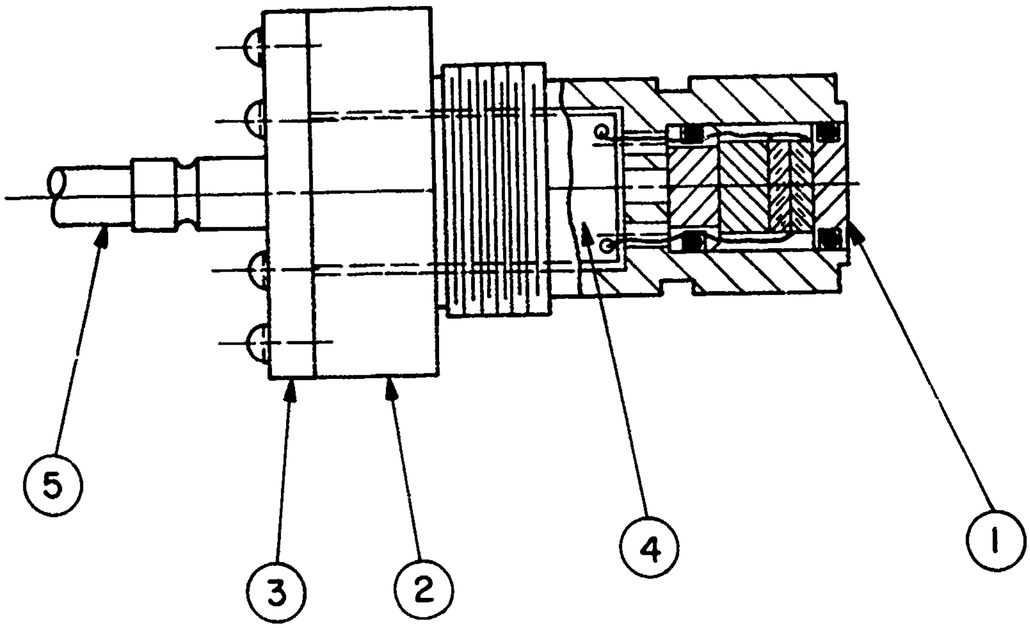
Fig. 2 - USRD Type G49 Transducer



SCALE 1:1

1. Acoustic Element
2. RHO-C Decoupling Material
3. Back Mass
4. Butyl Rubber Window
5. DB Grade Castor Oil
6. Cable Gland
7. Air

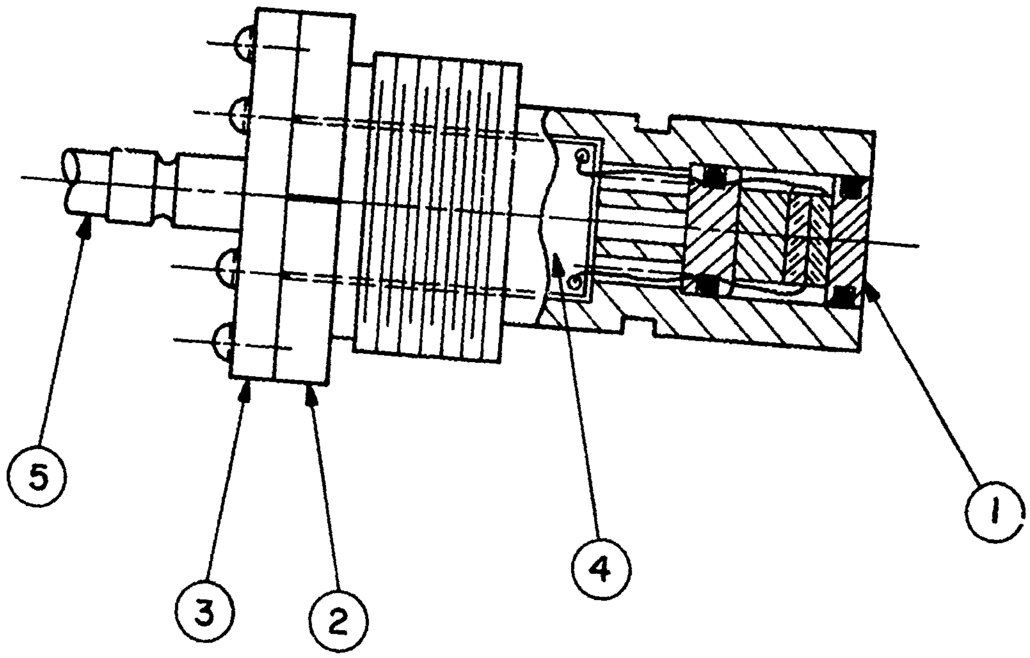
Fig. 3 - USRD Type G57 Transducer



SCALE 1:1

1. Sensor Element
2. Housing
3. Cable Gland
4. Preamplifier
5. Cable

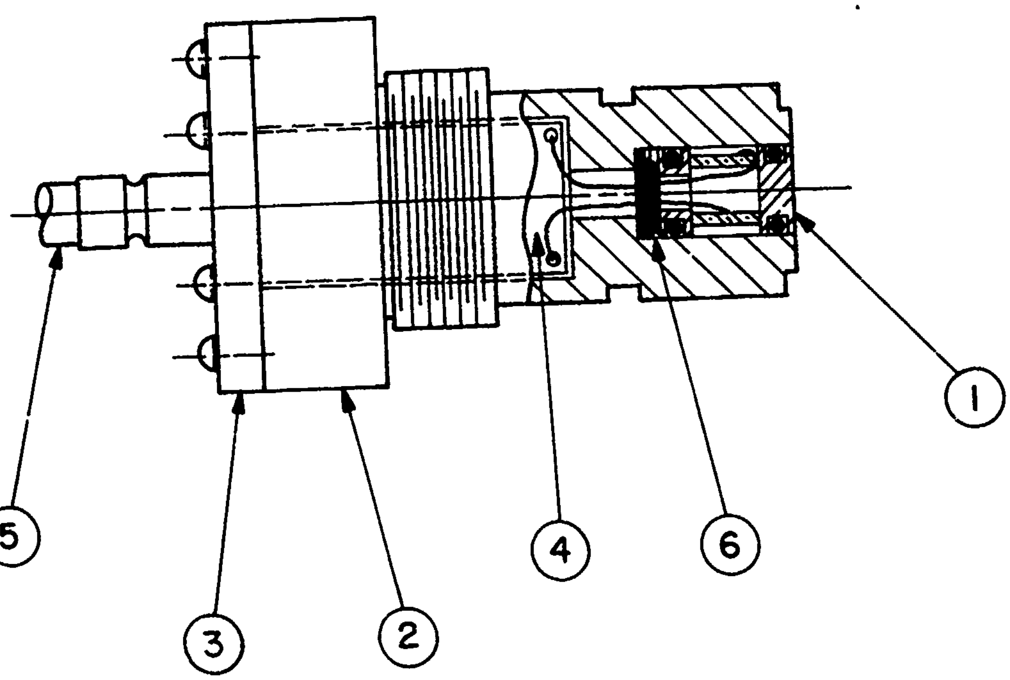
Fig. 4 - USRD Type H82M Hydrophone



SCALE 1:1

1. Sensor Element
2. Housing
3. Cable Gland
4. Preamplifier
5. Cable

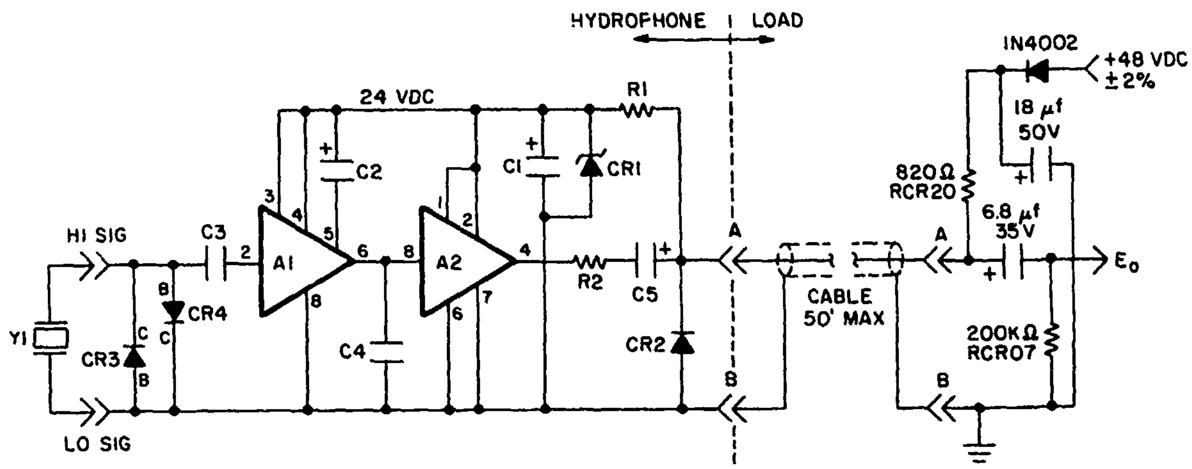
Fig. 5 - USRD Type H82 Hydrophone



SCALE 1:1

1. Sensor Element
2. Housing
3. Cable Gland
4. Preamplifier
5. Cable
6. Onionskin Paper Washers

Fig. 6 - USRD Type H89 Hydrophone



R2	51Ω OPTIONAL -SEE NOTE 3	RCR07	1
RI	820Ω	RCR20	1
C5	6.8μf, 35V	CSR13	1
C4	330pf	CK05	1
C3	0.068μf	CK05	1
C2	3.3μf, 15V	CSR13	1
CI	6.8μf, 35V	CSR13	1
CR3, CR4	2N929		1
CR2	IN914B		1
CRI	IN552B		1
A2	LH0002 OR EQUIV.		1
AI	753 INTEGRATED CIRCUIT ELTEC	NRL DWG E1901	1
PART NO	DESCRIPTION	SPECIFICATION	QTY REQ'D

Fig. 7 - USRD Types H82, H82M, and H89 Preamplifier Schematic & Circuit Components

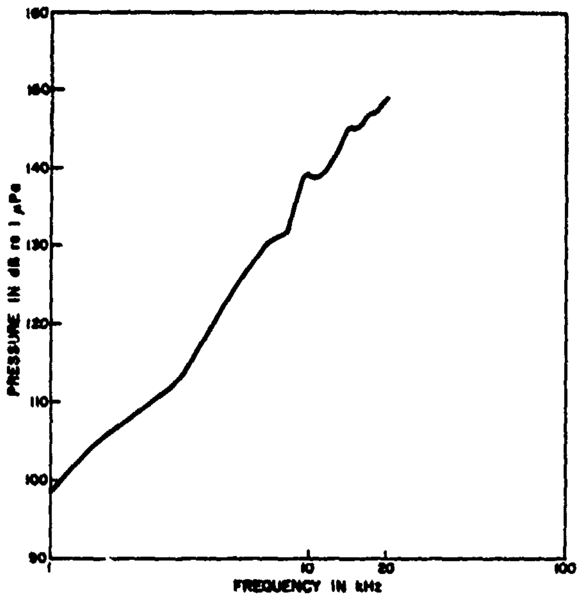


Fig. 8 - Transmitting Voltage Response - USRD
Type G56 Transducer (*Pressure at 1 m per volt*)

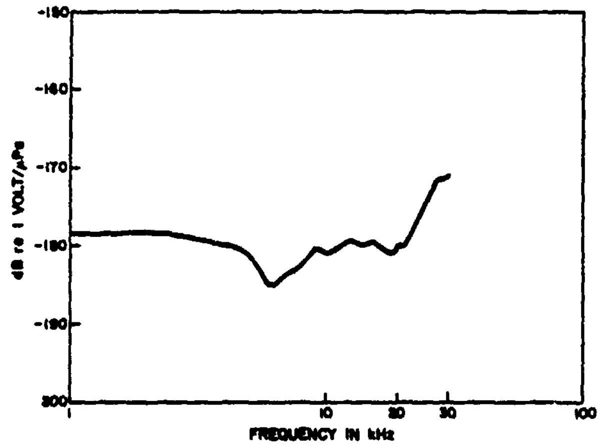


Fig. 9 - Free-Field Voltage Sensitivity - USRD
Type H82M Hydrophone (*Open-circuit voltage*)

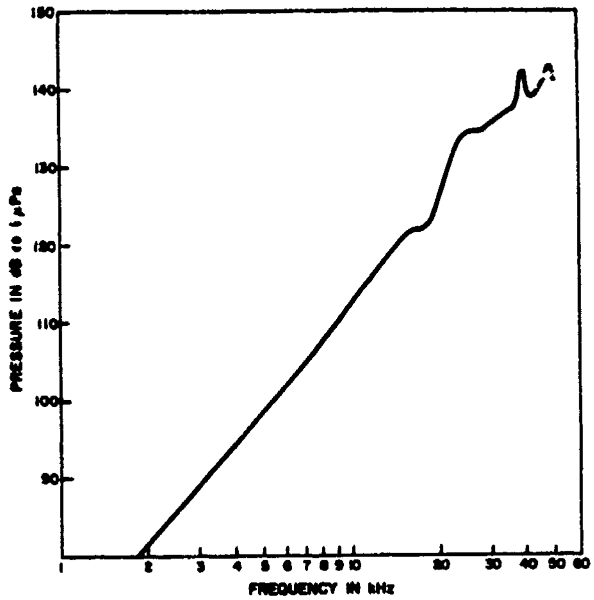


Fig. 10 - Transmitting Voltage Response - USRD Type G49 Transducer (*Pressure at 1 m per volt*)

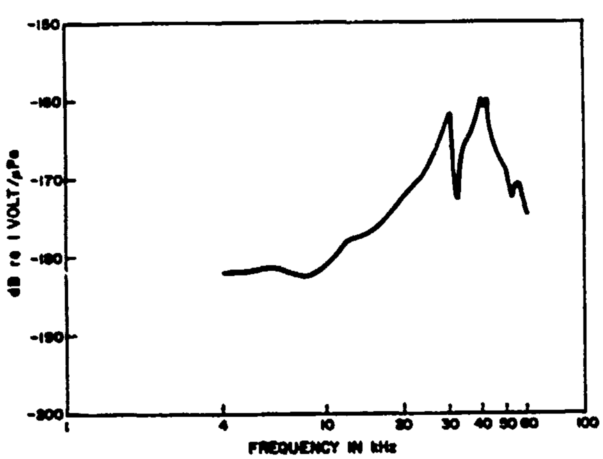


Fig. 11 - Free-Field Voltage Sensitivity - USRD Type H82 Hydrophone (*Open-circuit voltage*)

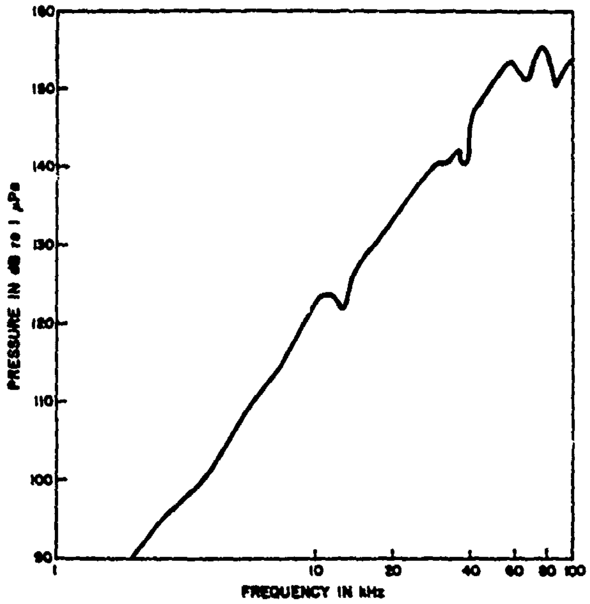


Fig. 12 - Transmitting Voltage Response - USRD
Type G57 Transducer (*Pressure at 1 m per volt*)

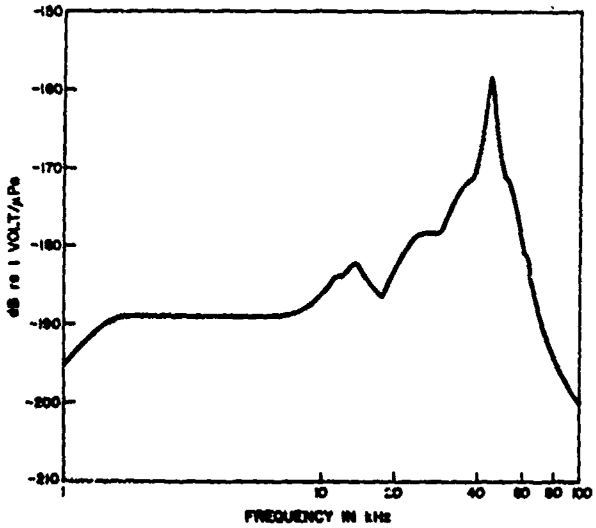


Fig. 13 - Free-Field Voltage Sensitivity - USRD
Type H89 Hydrophone (*Open-circuit voltage*)