

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
AD-A232 532			estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.	
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE 1987	3. REPORT TYPE AND DATES COVERED FINAL 1980-84		
4. TITLE AND SUBTITLE Underwater Helmholtz Resonator Transducers for Low-Frequency, High-Power Applications		5. FUNDING NUMBERS Work Units# 59-2014-0-5/6 59-0584-0-5/6/7 Assn Nos: DN380-557 DN780-137 respectively		
6. AUTHOR(S) A. M. Young and T. A. Henriquez		8. PERFORMING ORGANIZATION REPORT NUMBER		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Transducer Branch Underwater Sound Reference Detachment Naval Research Laboratory PO Box 568337 Orlando, FL 32856-8337		10. SPONSORING / MONITORING AGENCY REPORT NUMBER		
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Naval Ocean Research & Development Activity (Code 1228) NSTL Station, MS 39529 & Naval Ocean Systems Center (Code 641) San Diego, CA 92152-5122		11. SUPPLEMENTARY NOTES This article appeared in the Proceedings of the Institute of Acoustics Sonar Transducers Past, Present and Future an Underwater Acoustics Group Conf. held 14-15 Apr 87 in Birmingham, England. Vol. 9 Pt 2, 1987, pp 52-57		
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution unlimited		12b. DISTRIBUTION CODE		
13. ABSTRACT (Maximum 200 words) The use of Helmholtz resonator type transducers for low-frequency, high-power deep-ocean applications is discussed. The frequency range of interest is 200 Hz and above at radiated acoustic power levels up to 2 kW. Analysis and design tradeoffs are discussed.				
14. SUBJECT TERMS Helmholtz Resonators Transducers		15. NUMBER OF PAGES 8		
17. SECURITY CLASSIFICATION OF REPORT Unclassified		18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified		16. PRICE CODE
19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified		20. LIMITATION OF ABSTRACT SAR		

GENERAL INSTRUCTIONS FOR COMPLETING SF 298

The Report Documentation Page (RDP) is used in announcing and cataloging reports. It is important that this information be consistent with the rest of the report, particularly the cover and title page. Instructions for filling in each block of the form follow. It is important to *stay within the lines* to meet *optical scanning requirements*.

Block 1. Agency Use Only (Leave blank).

Block 2. Report Date. Full publication date including day, month, and year, if available (e.g. 1 Jan 88). Must cite at least the year.

Block 3. Type of Report and Dates Covered. State whether report is interim, final, etc. If applicable, enter inclusive report dates (e.g. 10 Jun 87 - 30 Jun 88).

Block 4. Title and Subtitle. A title is taken from the part of the report that provides the most meaningful and complete information. When a report is prepared in more than one volume, repeat the primary title, add volume number, and include subtitle for the specific volume. On classified documents enter the title classification in parentheses.

Block 5. Funding Numbers. To include contract and grant numbers; may include program element number(s), project number(s), task number(s), and work unit number(s). Use the following labels:

C - Contract	PR - Project
G - Grant	TA - Task
PE - Program Element	WU - Work Unit Accession No.

Block 6. Author(s). Name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. If editor or compiler, this should follow the name(s).

Block 7. Performing Organization Name(s) and Address(es). Self-explanatory.

Block 8. Performing Organization Report Number. Enter the unique alphanumeric report number(s) assigned by the organization performing the report.

Block 9. Sponsoring/Monitoring Agency Name(s) and Address(es). Self-explanatory.

Block 10. Sponsoring/Monitoring Agency Report Number. (If known)

Block 11. Supplementary Notes. Enter information not included elsewhere such as: Prepared in cooperation with...; Trans. of...; To be published in.... When a report is revised, include a statement whether the new report supersedes or supplements the older report.

Block 12a. Distribution/Availability Statement. Denotes public availability or limitations. Cite any availability to the public. Enter additional limitations or special markings in all capitals (e.g. NOFORN, REL, ITAR).

DOD - See DoDD 5230.24, "Distribution Statements on Technical Documents."

DOE - See authorities.

NASA - See Handbook NHB 2200.2.

NTIS - Leave blank.

Block 12b. Distribution Code.

DOD - Leave blank.

DOE - Enter DOE distribution categories from the Standard Distribution for Unclassified Scientific and Technical Reports.

NASA - Leave blank.

NTIS - Leave blank.

Block 13. Abstract. Include a brief (*Maximum 200 words*) factual summary of the most significant information contained in the report.

Block 14. Subject Terms. Keywords or phrases identifying major subjects in the report.

Block 15. Number of Pages. Enter the total number of pages.

Block 16. Price Code. Enter appropriate price code (*NTIS only*).

Blocks 17. - 19. Security Classifications. Self-explanatory. Enter U.S. Security Classification in accordance with U.S. Security Regulations (i.e., UNCLASSIFIED). If form contains classified information, stamp classification on the top and bottom of the page.

Block 20. Limitation of Abstract. This block must be completed to assign a limitation to the abstract. Enter either UL (unlimited) or SAR (same as report). An entry in this block is necessary if the abstract is to be limited. If blank, the abstract is assumed to be unlimited.



Proceedings of the Institute of Acoustics

Volume 9 Pt 2 1987

Sonar Transducers Past, Present and Future

an Underwater Acoustics
Group Conference held at the
University of Birmingham, England
14th/15th April 1987

Accession For	
NTIS CRA&I	☒
DTIC TAB	☐
Unannounced	☐
Justification	☐
By	
Distribution /	
Availability Codes	
Dist	Avail and/or Special
A1	20



Institute of Acoustics
25 Chambers Street
Edinburgh

ISBN 0 946731-52-7

Printed in the UK at the
University of Bath
1987

Contents

Invited Paper:

Sonar transducer developments during the period of world war II and beyond F. Massa (USA)	1
Magnetostriction in flextensional transducers J. R. Oswin, A. Maskery (UK)	23 ✓
A desktop computer program for a flextensional transducer J. L. Butler, T. J. Peirce, J. Lindberg (USA)	31 ✓
Finite element analysis of low frequency sonar transducers J. N. Decarpigny, J. C. Debus, B. Hamonic, R. Bossut, P. Tierce, D. Morel, D. Boucher, B. Tocquet (France)	42 ✓
Underwater Helmholtz resonator transducers for low-frequency high power applications A. M. Young, T. A. Henriquez (USA)	52
Problems in the realization of transducers with octave bandwidths J. R. Dunn, B. V. Smith (UK)	58
Some British sonar transducers of the 1950's R. J. Gale (UK)	70
Active electronic control of the response of a sonar transducer G. A. Steel, B. K. Gazey, B. V. Smith (UK)	79 ✓
A high power transducer array W. J. Wood, F. Wood, A. D. Goodson, J. W. R. Griffiths (UK)	88
Invited Paper:	
A discrete-time, linear systems approach to the modelling and simulation of piezoelectric transducer structures G. Hayward (UK)	101 ✓
Prediction of time and frequency domain performance of piezoelectric polymer transducers Q. X. Chen, P. A. Payne (UK)	115
A design programme to optimise high reliability wideband hydrophones L. W. Lipscombe (UK)	126 ✓
Modelling of a pressure gradient cardioid hydrophone B. Stupfel, C. Granger, J. N. Decarpigny (France)	134
Development of a laboratory prototype velocity hydrophone utilising optical measurement techniques V. J. Hughes, J. G. Boulton, J. M. Coles, T. R. Empson, N. J. Kerry (UK)	144
Inter-element coupling in arrays of large-area hydrophones R. Y. Ting, F. G. Geil (USA)	153
The development of piezoelectric ceramics for transducers D. S. Cannell (UK)	159 ✓
The receiving action of hydro acoustic transducers Z. Jagodzinski (Poland)	171
Author index	179

Proceedings of The Institute of Acoustics

UNDERWATER HELMHOLTZ RESONATOR TRANSDUCERS FOR LOW-FREQUENCY, HIGH POWER APPLICATIONS

A.M. Young and T.A. Henriquez

Naval Research Laboratory, Underwater Sound Reference Detachment,
P.O. Box 8337, Orlando, Florida, USA 32856

I. UNDERWATER HELMHOLTZ RESONATORS

When considering low-frequency underwater acoustic sources, it is recognized that, in general, the radiating device will be small when compared to the acoustic wavelength in the medium. It is this condition, not poor design practices, which precipitates the large size and weight, low efficiency, and relatively poor reliability from which high power, low-frequency sources suffer. The diminishing real part of the radiation impedance dictates low efficiency and large required volume velocities; large volume velocities, in turn, infer large force, and therefore, heavy and robust devices. When these inherent difficulties are coupled with the requirement of operation at deep ocean depths, the problems facing the transducer designer become greatly magnified. Several transduction mechanisms, in different design configurations, are capable of producing high source levels over low-frequency bandwidths of an octave or more. Most of these designs, however, require some form of depth compensation and/or pressure release for the interior of the radiator which either limits the operational depth capability of the device or greatly increases its complexity. Aside from the obvious constraints of output power and bandwidth, the design of low-frequency transducers is determined by the trade-off between achieving the operational depth capability and the restraints on size and weight. The ideal device is one which meets all of the electro-acoustic requirements while operating independently of water depth. The search for the ideal solution naturally leads to the consideration of design configurations which can be "free-flooded"; that is, configurations where no pressure differential exists across any portion of the transducer due to the surrounding hydrostatic pressure.

The Helmholtz resonator basically consists of a closed rigid cavity coupled to the external medium through an opening or orifice, as depicted in Figure 1, and as such is a "free-flooded" device. Helmholtz resonators have been used as filter elements in air acoustics and as narrow bandwidth sources in underwater acoustics. The application under consideration here, however, is the use of a Helmholtz resonator to increase the low-frequency output of a piezoelectric ceramic radiator as shown in Fig. 2. As shown in the figure, well below the frequency of its first resonance, a piezoelectric radiator normally has a positive 12-dB-per-octave slope in the output sound pressure level per volt as a function of increasing frequency. If, however, the ceramic element is used in a configuration where one of its surfaces radiates directly into the unbounded medium and the other surface radiates into the fluid-filled cavity of a Helmholtz resonator, there will be a resultant increase in the output sound pressure level at the Helmholtz resonance frequency. In this type of transducer, the ceramic radiator could generally be in the form of one of three basic configurations in which all or part of the Helmholtz cavity is formed by the ceramic. These three configurations are shown in Fig. 3. The most simple configuration is that of a piezoelectric ceramic sphere where the interior volume of the sphere forms the Helmholtz cavity.¹ This design, however, would

Proceedings of The Institute of Acoustics

HELMHOLTZ RESONATOR TRANSDUCERS

not generally be considered feasible for the frequencies desired because the mosaic construction required for large sizes makes the sphere relatively fragile and expensive. In the second configuration, a piezoelectric ceramic tube forms all but the ends of a cylindrical cavity.² The large sizes required by low-frequency applications dictate that the ceramic tube be fabricated from a stack of segmented ceramic rings as shown in the figure. In this configuration, to assure that the ceramic remains in compression, the rings must be radially prestressed by wrapping them with a glass-fiber/epoxy composite. The ring segments may be either radially or circumferentially poled although poling thickness limitations generally make circumferential poling preferable. The third configuration consists of a cylindrical metal housing with a ceramic flexural disc at one end. The flexural disc may be either bilaminar or trilaminar in construction; that is, with a mosaic of piezoelectric ceramic laminated to either one or both sides of a metal disc. Of the two configurations considered feasible for low-frequency applications, each has advantages over the other dependent primarily upon geometry constraints. When the requirements do not constrain the diameter, the flexural disc would be the most efficient radiator; if the diameter is constrained, however, the segmented ceramic rings would become the preferred radiator.

II. DESIGN CRITERIA

From the simple equation for the resonance frequency of a Helmholtz resonator

$$f_r = \frac{1}{2\pi} \sqrt{\frac{1}{C_c M_A}}, \quad (1)$$

where C_c is the compliance of the cavity and M_A is the inertance of the orifice; it would appear to be possible to design a device for operation at low frequencies with a small orifice radius and small cavity volume. However, internal losses increase with decreasing orifice size and cavity volume. Decreasing the cavity volume also decreases the volume of ceramic in the transducer and, therefore, the maximum available volume velocity. In other words, the orifice size and cavity volume may be decreased only at the expense of a lower acoustic output power capability. Obviously then, for high-power applications, it is desirable to maximize the orifice size and cavity volume within the size and weight restraints of the requirements.

In reality, the Helmholtz resonance frequency for a given orifice inertance is determined not only the compliance of the cavity, but by the compliance of the total system. That is, the resonance frequency is influenced by other mechanical compliances in the system such as the compliance of the piezoelectric ceramic driver, C_d . Woollett³ identified the relationship between the cavity compliance, C_c , and the driver compliance, C_d , as an important design parameter and defined it as

$$\alpha = \frac{C_d}{C_d + C_c}. \quad (2)$$

It can be shown that for a given design, the output power is proportional to the factor $(1 - \alpha)^2$ while the viscous loss in the cavity is inversely proportional to $(1 - \alpha)$. Therefore, if the compliance of the driver becomes large

Proceedings of The Institute of Acoustics

HELMHOLTZ RESONATOR TRANSDUCERS

in relation to the compliance of the cavity, the output power will decrease and the viscous loss in the cavity will increase.

The radiated power at the Helmholtz resonance frequency is, of course, determined in large part by the Q of the device. There is maximum, or lossless, Q associated with any Helmholtz resonator and it is primarily dependent upon the size of the transducer. That is, in general, for a given frequency, the larger the transducer becomes, the higher will be its Q, or sharpness of resonance. The Q actually obtained in practice, however, is strongly dependent upon internal losses in the system, primarily viscous losses in the cavity and orifice.

A second parameter which affects the maximum radiated power at the Helmholtz resonance frequency is the fracture stress of the piezoelectric ceramic. If the Q of the system is high, the pressure inside the cavity can cause the fracture stress of the ceramic to be exceeded at high drive levels. The result would be a catastrophic failure of the material. The maximum allowable sound pressure level that can be obtained near the resonance frequency may be determined from the geometry of, and the material used to construct, the ceramic driver.

III. ANALYSIS, MODELING, AND EXPERIMENTAL RESULTS

The most simple model used to describe underwater Helmholtz resonator transducers is a lumped element equivalent circuit. The values for the elements are determined from the geometry of the device and the parameters of the materials used. With all of the mechanical and acoustical elements converted to their electrical equivalents, the model is analyzed through the use of electronic circuit analysis techniques. This traditional modeling approach works quite well as long as the initial assumption of representing the device as a combination of lumped masses, compliances and resistances holds true. For most transducers, this is usually the case when the largest dimension of the radiator is small when compared to the acoustic wavelength in water. When using this technique for Helmholtz resonator transducers, however, additional care must be taken because of the nonlinear losses associated with viscous flow in the cavity and orifice and because, in order to obtain lumped representations of the cavity compliance and orifice inertance, the boundary between the two must be clearly definable. That is, the "aspect ratio", or the ratio of the ORIFICE diameter to THE LENGTH CAVITY, becomes an important consideration. As the diameter of the orifice approaches that of the cavity (aspect ratio $\rightarrow 1$), the effective inertance and compliance are much more difficult to define and not properly represented as lumped elements; the other extreme, aspect ratio $\rightarrow \infty$, is of no interest as a high power radiator. In any case, the electro-mechano-acoustical circuit is a good diagrammatic representation in that it clearly shows the two radiators in the system coupled by the compliance of the cavity.

A further complication in the design of underwater Helmholtz resonators is the structure required to support the active element(s) and to form the cavity closures. Not only must resonances in these structures be avoided for the frequency band of interest, but they must also maintain the stiffness of the cavity. That is, if these structural elements are not stiff enough, they will add to the compliance of the cavity, and therefore, cause a shift in the Helmholtz resonance frequency. A second effect caused by these elements not being "stiff enough" is acoustic radiation from their surfaces exposed to the

Proceedings of The Institute of Acoustics

HELMHOLTZ RESONATOR TRANSDUCERS

unbounded medium; that is, one surface of these structures is often exposed to the high pressure in the cavity and the resulting vibration makes them potential radiators. The significance of these structures as radiators is obviously dependent upon their relative amplitudes and phases.

Although this type of structural vibration problem does not lend itself to solution via equivalent circuit analysis, it is ideally suited to the methods of finite element analysis. A relatively new modeling technique we are applying to transducer analysis is: a surface velocity distribution for a transducer structure is generated by a finite element model which is in turn, used as the input to a generalized acoustic radiation impedance model⁴. Experimental feedback is provided via the techniques of modal analysis and, of course, by the measured electroacoustic parameters. Initial results look quite promising.

There is not sufficient space available here to show experimental results, but the oral presentation will compare predicted performance from equivalent circuit and finite element/radiation impedance analyses with measured results for at least three separate devices.

REFERENCES

- [1] T.A. Henriquez, "The USRD F39A 1-kHz Underwater Helmholtz Resonator", Naval Research Laboratory Report Number 7740 (10 April 1974).
- [2] A.M. Young, A.C. Tims, T.A. Henriquez, "The Development of a High-Power, Low-Frequency Underwater Acoustic Source for Use in a Deep-Towed Geophysical Array System", Naval Research Laboratory Report Number 8633 (15 November 1982).
- [3] R.S. Woollett, "Underwater Helmholtz Resonator Transducers: General Design Principles", Naval Underwater Systems Center Technical Report Number 5633 (6 July 1977).
- [4] R.E. Montgomery, C.M. Ruggiero, T.A. Henriquez, E.A. Jenne, "Numerical Models Used in Transducer Design", paper C.1, presented at 112th meeting of the Acoustical Society of America, Anaheim, California (9 December 1986).

Proceedings of The Institute of Acoustics

HELMHOLTZ RESONATOR TRANSDUCERS

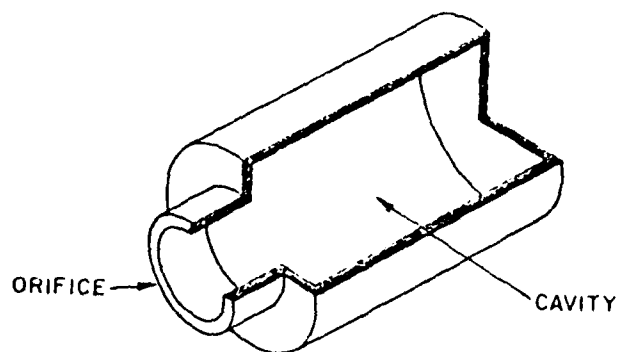


Figure 1. Basic configuration of the Helmholtz Resonator.

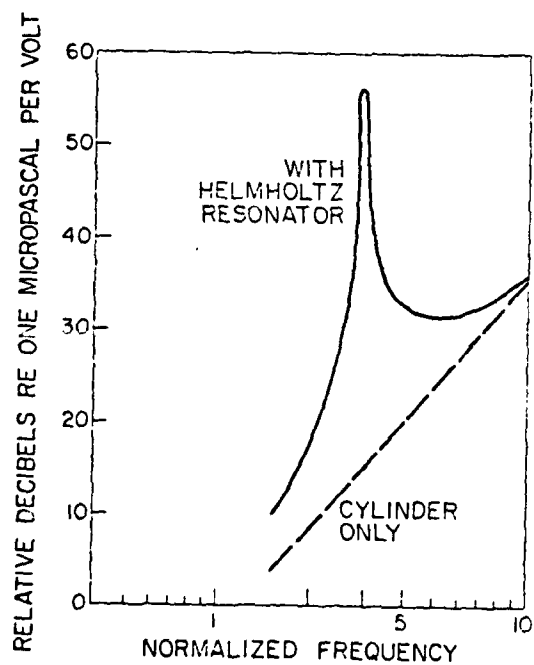
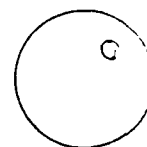


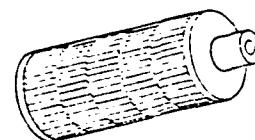
Figure 2. Transmitting voltage response of a fluid-filled piezoelectric ceramic tube with and without a Helmholtz resonator (orifice in one end).

Proceedings of The Institute of Acoustics

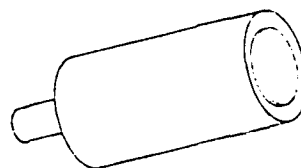
HELMHOLTZ RESONATOR TRANSDUCERS



(a) CERAMIC SPHERE



(b) CERAMIC TUBE



(c) CERAMIC FLEXURAL DISC

Figure 3. Three basic configurations of underwater piezoelectric Helmholtz resonators.