# NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

## SUBMARINE BASE, GROTON, CONN.


REPORT NUMBER 1052

# PROPOSED TRANSFER-FUNCTION TECHNIQUE FOR EARPHONE ANALYSIS


by

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and
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Naval Medical Research and Development Command
Research Work Unit M0933.004-0006


Released by:
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Commanding Officer
Naval Submarine Medical Research Laboratory

20 June 1985

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NAVAL MEDICAL RESEARCH AND DEVELOPMENT COMMAND
Research Project 64117N MØ933 MØ933 ØØ4 ØØØ6

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## SUMMARY PAGE


### PROBLEM

This research was prompted by the need to select a suitable headset for auditory processing of passive-sonar information. Accurate measurement of earphone frequency response is essential to making such selection. No standard for frequency response of an earphone on an average listener exists.

### FINDINGS

This report proposes an earphone-measurement method that uses an ear-simulating coupler mounted in an anthropometrically average acoustic-test mannikin, KEMAR. Our method uses a digital transfer-function technique to correct digitally stored earphone frequency-response data. The transfer function is based on available data on the random-incidence sound-pressure response of the mannikin ear at eardrum position.

### APPLICATION

The reported technique applies directly to testing and evaluating headsets for use in passive auditory-sonar-system design. The technique is suitable for circumaural and supraaural earphone designs and is adaptable to insert earphones.



## ADMINISTRATIVE INFORMATION

This research was carried out under Naval Medical Research and Development Command Work Unit 64117N M0933 M0933 004 0006, "Development of engineering specifications for optimum auditory classification/detection through headphones." It was submitted for review on 30 April 1985, approved for release on 20 June 1985, and designated as NSMRL Report Number 1052.

PUBLISHED BY NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

## ABSTRACT

The selection of an accurate transducer for auditory processing of passive sonar signals requires accurate measurement of frequency response. No standard for such measurement exists. The method proposed here uses a modified Zwislocki acoustic coupler mounted in an anthropometrically and acoustically average mannikin, KEMAR, in order to simulate the acoustic load that an average human ear would place on the earphone element. A transfer function was generated from published data on the random-incidence sound-pressure response of the mannikin ear at "eardrum" position. A computerized signal-collection and -analysis system subtracted this transfer function from stored earphone-response data. Responses were averaged across samples of left and right earphone elements and across repeated measurements that sampled variability due to headset placement, seal around the ear, and headband tension. Analog plots of earphone frequency response were indistinguishable from computer regenerated plots of that same frequency response. Comparison of raw data and corrected data show the correction procedure to be within .2 dB of perfect accuracy.

## INTRODUCTION

The Navy needs to select headsets that are suitable for auditory processing of passive sonar information. Accurate frequency-response measurement is essential, but the current American National Standard method for coupler calibration of earphones (American National Standards Institute [ANSI], 1973) is intended only for traditional supraaural earphones or insert earphones. As the standard says, "An adequate basis for the coupler calibration of circumaural earphones does not yet exist." Charan, Cox, and Niemoeller (1965) reviewed three nonstandard couplers that, despite frequency limitations, might be used for testing circumaural earphones; Shaw and Thiessen (1962) and Shaw (1966) compared real-ear probe-tube sound pressures in circumaural earphones with those measured in couplers. As traditionally used, couplers give inaccurate representations of the frequency response of earphones on a human wearer.

In 1967, the American Standards Institute writing group on coupler calibration of earphones (Benson, et al., 1967) concluded that a standard for coupler calibration of circumaural earphones could not yet be written. They based their conclusions on the Charan et al. (1965) and Shaw (1966) work as well as on their recognition that they had insufficient knowledge of factors that affect coupling between earphone and ear. Work on the acoustical impedance of the human ear by Zwislocki (1957), Ithell (1963), and Delaney (1964) led to the development and testing of several ear simulators (Delaney, Whittle, Cook, & Scott, 1967). Accurate impedance loading of the earphone was attempted by using multiple resonant cavities connected acoustically between microphone and earphone.

In 1970, the International Electrotechnical Commission (IEC) described 5 types of artificial ears:

| | |
|---|---|
| Type 1 | Simple, conventional type consisting of a single cavity |
| Type 2 | Simple, conventional type designed specifically for telephone measurement |
| Type 3 | Wideband, multiple-cavity type for audiometric measurements |
| Type 4 | Special type for calibration of insert earphones |
| Type 5 | Laboratory type that faithfully reproduces the characteristics of the human ear |

At that time, IEC published its recommendations for a type 3 artificial ear for supra-aural earphones. Several type-3 designs were developed, including one by Bruel and Kjaer (Artificial Ear Type 4153) and Record and Hixson's (1972). Zwislocki (1970, 1971) developed an ear-like coupler that can serve as a type 3, 4, or 5 ear simulator.

The part of Zwislocki's device that simulated the acoustic impedance of the pinna was removable for measurement of insert earphones and could be modified with a flat plate extension for circumaural earphones.

Although the Zwislocki coupler accurately represents the acoustic impedances of an average ear, its use as an earphone-measuring device imposes certain limitations. For a real ear, the acoustic signal that arrives at the eardrum has had its frequency response modified by the external-ear structures. This nonlinear transformation of the signal outside the ear into the signal at the eardrum is mimicked by the ear simulator, so a transfer-function correction is required in order to recognize the linearity of the frequency response of an earphone element mounted on a coupler.

In developing a test and evaluation tool for predicting hearing-aid performance, Burkhard and Sachs (1975) incorporated the eardrum-simulator portion of the Zwislocki coupler into an anthropometrically average mannikin, KEMAR, and substituted flexible pinnae and metal ear canals for the corresponding hard-metal upper portions of the Zwislocki Coupler. Acoustic measurements on KEMAR show close agreement with similar measurements on human subjects (Shaw, 1974; Burkhard and Sachs, 1975).

1) Measurement System - Physical Characteristics

Work at this laboratory uses a version of KEMAR that has been fitted with a modified Zwislocki coupler that includes flexible pinnae and the ear canal adaptors developed by Burkhard and Sachs. The coupler contains a cylindrical, hard-walled cavity, 7.5 mm in diameter, that is physically connected to 4 side-branch resonant chambers. Each branch serves as a series acoustic network contributing inertance, resistance, and compliance. By design, the ear canal's physical length is slightly modified from that of an average human ear in order to make the canal resonance of the simulator match that of the average ear. Acoustically and dimensionally average pinnae were selected for the ear simulator.

In reaction to an earphone diaphragm's motion, steady-state, low-frequency test tones will eventually induce accelerometer-like movement in the earphone. The artifact can be eliminated by rigidly limiting outward movement of the earphone without adding static pressure in excess of headband force. The device we fabricated to prevent the accelerometer effect is shown in Figure 1. It consists of a laminated hardwood yoke, 3/4" thick x 1-1/4" wide, bent in an arc with an inner radius of 6". One hard rubber pad, mounted on threaded rod, is located at each end and at the top of the yoke. When fully extended toward the

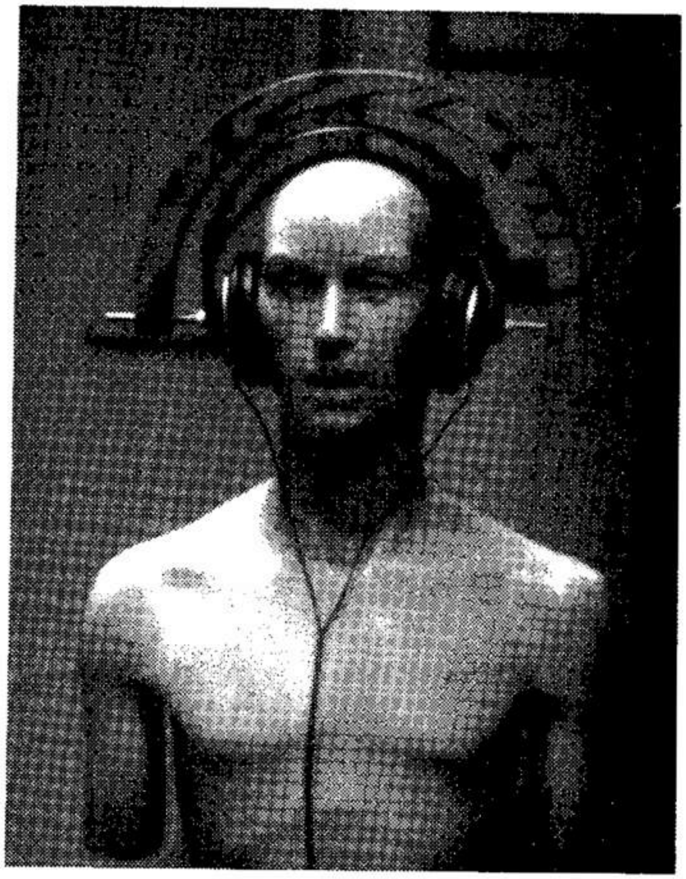

Figure 1 Headset on KEMAR mannikin with zero-static-force restraining yoke in place

center, these pads reduce the yoke's radius from 6" to 3-1/2".

2) Measurement System - Electronic Components

Figure 2 is a block diagram of the measurement system. A Bruel and Kjaer 4134 1/2" condenser microphone was mounted at eardrum position in the coupler. Microphone output was fed to a Bruel and Kjaer 2619 preamplifier and from there to a Bruel and Kjaer 2610 measuring amplifier. The y axis of a Bruel and Kjaer 2308 X-Y recorder received the amplifier's output; the x axis received a calibrated, frequency-correlated DC output ramp from a Bruel and Kjaer 1027 Sine Random Generator. A Digital LPS 11 A/D converter also received both the x and y DC voltages.

3) Measurement System - Transfer-Function Characteristics

An ideally flat earphone is one whose output level does not vary as a function of frequency. But even if such an earphone existed, ear-simulator tests of its frequency response could be confounded. For most types of earphone elements, resonances created by the pinna and by the complex loading of the ear canal would create nonlinearities.

Killion (1979) collected average random-incidence sound-pressure response data on KEMAR (Figure 3). His curve permits us to account for the resonance of the pinna and for the effects of the ear canal. The dotted line in Figure 3 shows our digitized version of Killion's data. The curve was generated by sweeping a narrow band of noise (from a Bruel and Kjaer 1027 Sine Random Generator) from 40 Hz to 10000 Hz; the band was shaped by a General Radio 1925 multifilter and fed to a Bruel and Kjaer 2610 measuring amplifier whose dc output fed the x axis of a Bruel and Kjaer 2308 X-Y Recorder. A Digital Equipment Company (DEC) PDP 11/34 computer following a DEC LPS 11 A/D converter provided a digital version of the signals. The PDP 11/34 could also subtract the stored transfer function from individual earphone response curves.

4) Test Method

Earphone sound-pressure response to a constant-amplitude, swept-sinusoidal signal was measured in the modified Zwislocki coupler mounted in KEMAR. Earmuff shape, size, and seal; headband effectiveness; and placement of the headset on the head are all major contributors to the variability one finds in earphone response measurements. We sampled this variability by taking 5 measurements on each earphone element.

Accelerometer-like movement of the earphones was prevented during pure-tone testing by loosely fitting the rigid yoke around the headset under test. One pad was

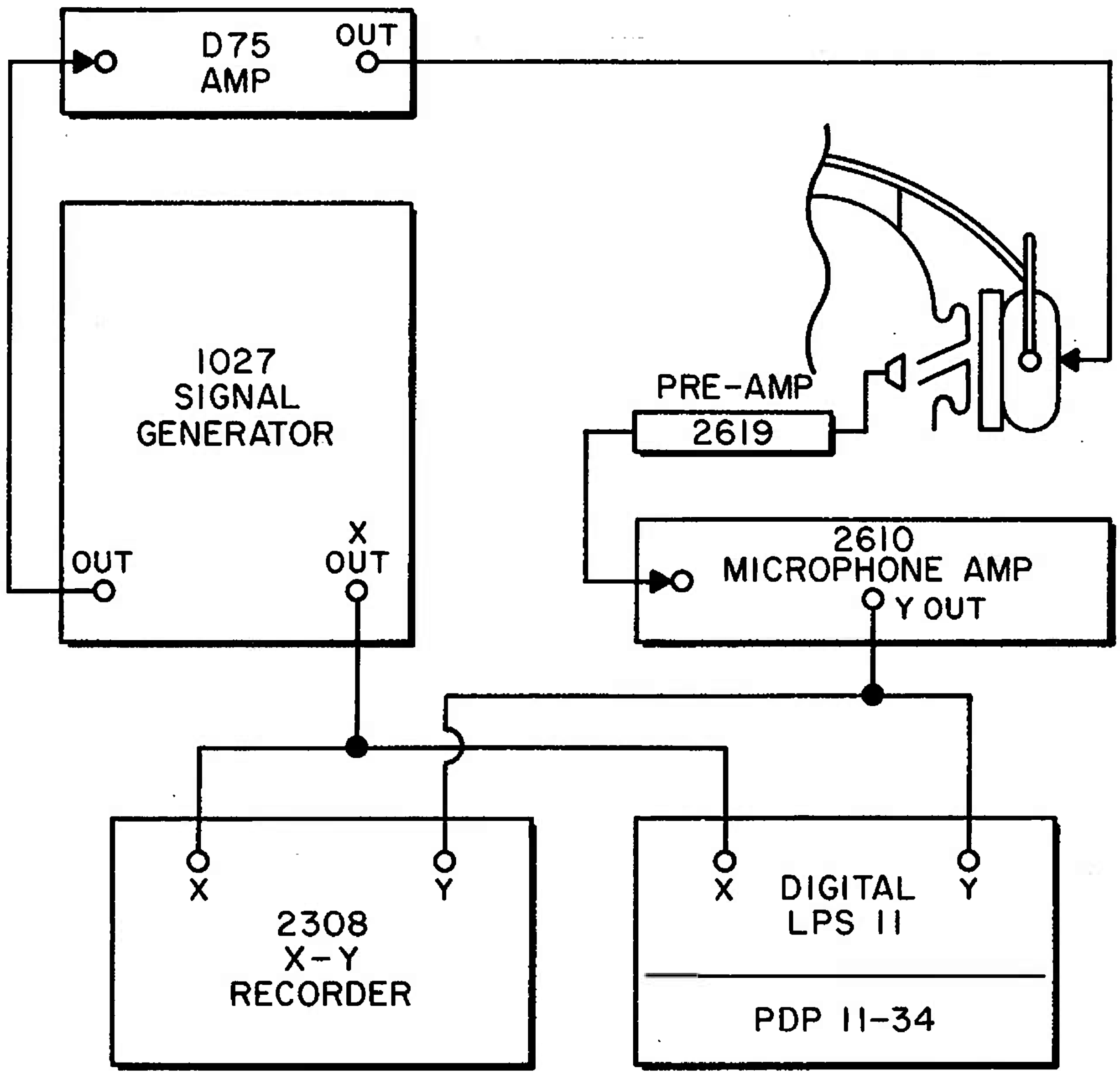


Figure 2 Diagram of earphone measurement system

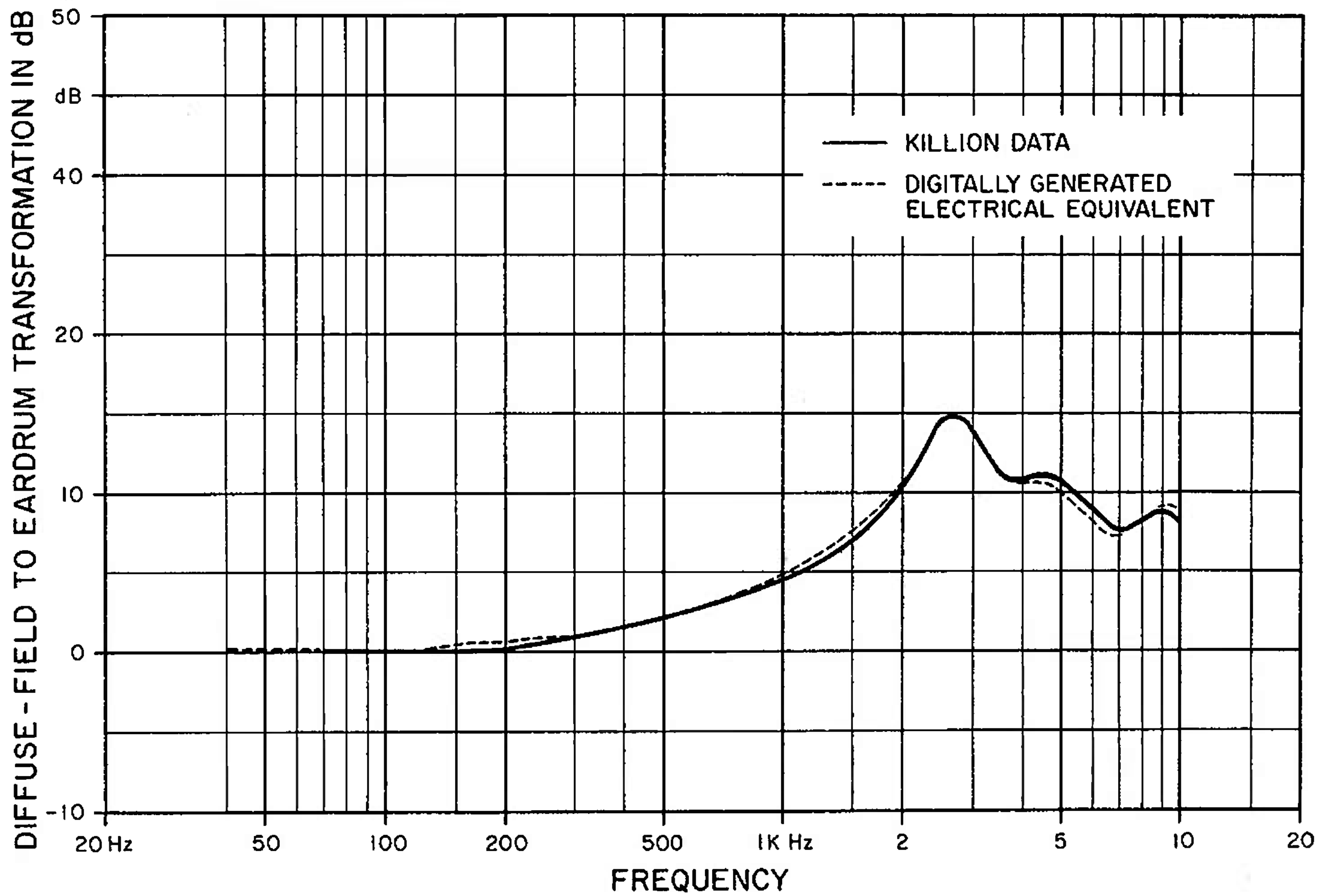


Figure 3 Transfer function for headset response measurement

centered over the back of each earphone, then adjusted close to but not touching the back surface. Finer adjustment assured that the yoke could be moved without binding against or moving the earphones. For each curve, the headset was removed and refitted over the ear. For this purpose, a series of concentric marks was made around the mannikin's ear canal at $90^{\circ}$ intervals.

Digitally-stored data curves for each tested model were averaged and corrected for the nonlinear response of the coupler. By making 5 tests on the left and right earphones on each of 2 samples of each model, averages based on 20 individual response curves could be obtained.

## RESULTS

Simultaneously generated analog and digital plots lay within a .2 dB range. Figure 4 shows an average of 5 curves for one earphone. The upper curve represents uncorrected data. The lower curve plots the same data, but corrected for the transfer function. They too show a .2 dB maximum difference. Such differences are most likely a function of the x-y plotter error rather than the transfer-function technique.

Figure 5 presents corrected frequency response for 4 earphones, all the same model, each tested 5 times. Figure 6 presents the average of these 20 responses.

## DISCUSSION

The proposed transfer-function technique is clearly a reliable way to measure the frequency responses of headsets (including not only the earphone element, but also the circumaural muff or supraural cushion and the headband. Every aspect of the headset is sampled.

Digital storage and retrieval of x-y plots introduced less than .2 dB alteration at any frequency. These differences are tiny and can probably be attributed to plotter-calibration errors. Digital removal of the transfer function from the measured earphone response proved to be highly accurate.

Testing of insert-type earphones would necessitate the use of a different transfer function, which would not include the resonance of the pinna. Composite data on the transfer function between the entrance to the ear canal and the eardrum is available (Shaw, 1974) and could be generated and stored using identical methods to those used here.

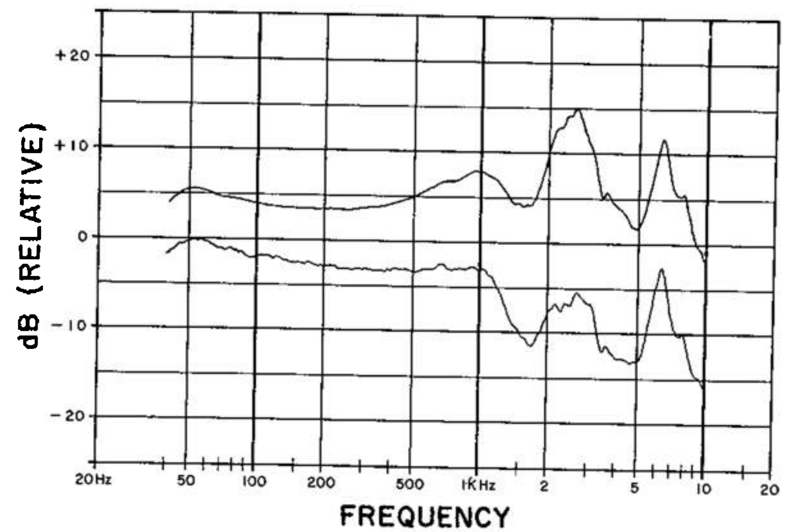


Figure 4 Average of 5 response curves for a single earphone element: upper curve, uncorrected; lower curve, transfer-corrected

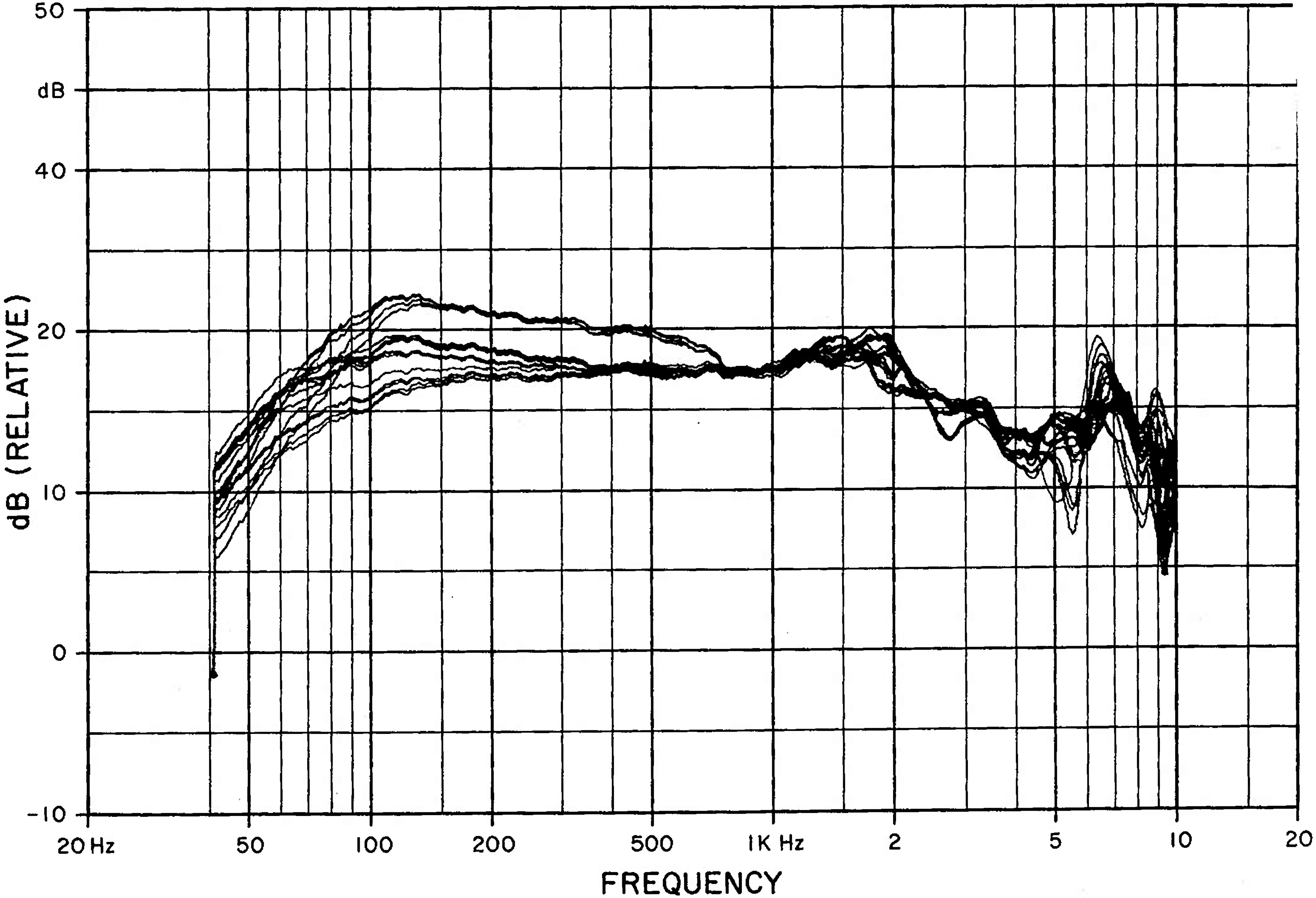


Figure 5 2Ø earphone responses for a selected headset

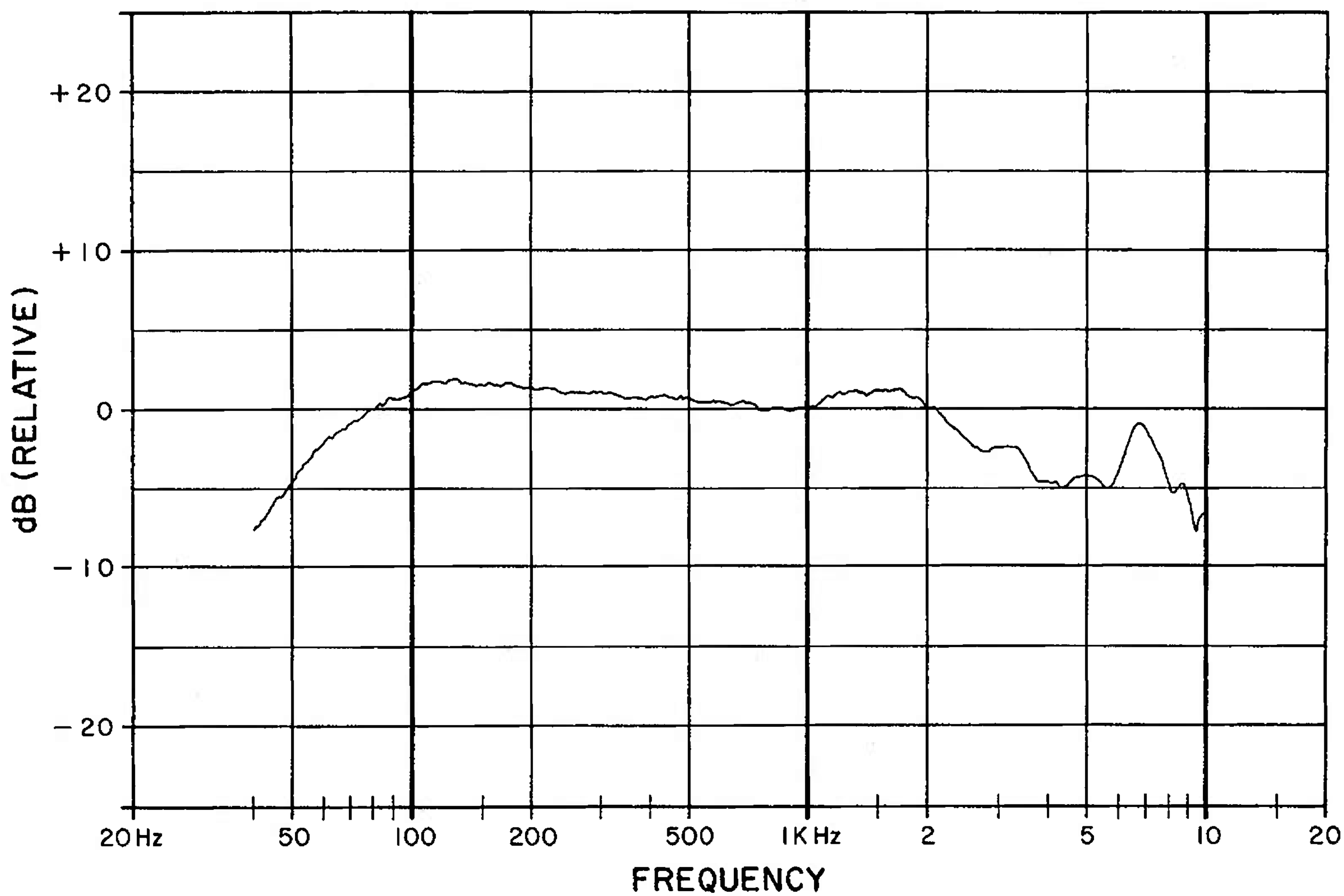


Figure 6 Averaged earphone response for same earphone shown in Figure 5

Summary

Digital transfer-function techniques have been used to measure frequency response of earphones that have been accurately loaded by an ear-simulating device. The device, a modified Zwislocki coupler, is available mounted in an anthropometrically and acoustically average mannikin, KEMAR. Headsets are measured repeatedly as worn and as subject to many of the same variabilities encountered by the average user. Digitized frequency-response data are corrected for the transfer function of the device. Several samples are tested in order to provide an averaged corrected response. The technique is adaptable to all types of headsets.

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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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|---|---|---|
| 1. REPORT NUMBER<br>NSMRL Report # 1052 | 2. GOVT ACCESSION NO. | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE (and Subtitle)<br>Proposed transfer-function technique for earphone analysis | | 5. TYPE OF REPORT & PERIOD COVERED<br>Interim Report |
| | | 6. PERFORMING ORG. REPORT NUMBER<br>NSMRL Report # 1052 |
| 7. AUTHOR(s)<br>J.S. Russotti, T. Santoro, G.B. Haskell, R. Neal | | 8. CONTRACT OR GRANT NUMBER(s) |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Naval Submarine Medical Research Laboratory<br>Box 900, Naval Submarine Base NLON<br>Groton, CT 06349 | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS<br>64117N M0933 M0933 004 0006 |
| 11. CONTROLLING OFFICE NAME AND ADDRESS | | 12. REPORT DATE<br>20 Jun 1985 |
| | | 13. NUMBER OF PAGES<br>13 |
| 14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)<br>Naval Medical Research and Development Command | | 15. SECURITY CLASS. (of this report)<br>Unclassified |
| | | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT (of this Report)

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Sonar, Passive sonar, Aural detection, Headsets, Headset measurement, Electroacoustics, Auditory processing.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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