**Naval Submarine Medical Research Laboratory**

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# Sonar Headphone Selection for Optimum Performance
# An Overview

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## Summary Page

### The Problem

To improve the real-time auditory detection and aural analysis capability of passive broadband sonar systems.

### The Findings

The most blatant source of acoustic signal degradation on auditory sonar systems is in the acoustic performance of headsets. Recent detection performance data have shown the need for upgrading sonar headsets to reproduce electrical energy accurately over a wider bandwidth. Headphone measurement data on commercially available headphones have shown that headphones of more appropriate bandwidth and frequency-response accuracy have not been of sealed-circumaural design. Headphones designed to completely seal around the listener's ear exhibit low-frequency variations with placement on the head and with deterioration of ear-cushion as a result of a less than perfect seal. Unfortunately, current noise levels preclude use of the more accurate, less variable, open-air types. Reduction of noise levels in sonar spaces to permit use of better headphone designs is a highly desirable solution. Recent developments in active noise canceling headsets show promise as an interim solution. A commercial model having adequately flat frequency response has been found and improved through active equalization. A prototype version of this improved headset has been evaluated.

### Application

Advanced auditory sonar system design. Aural analysis and tactical sonar headphone requirements.



## Administrative Information

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Abstract

Real-time auditory detection and aural analysis capability of passive broadband sonar systems needs improvement. A weak link in these systems is the use of communications-bandwidth low-fidelity headsets. Unfortunately, no procedure for headphone (earphone element inside headshell) frequency response measurement exists in military headset specifications. An accurate technique for headphone calibration was devised which provides the earphone element with an acoustic load similar to the one provided by a human wearer. Using this technique, headphone measurement data on commercially available headphones was collected and compared to the current sonar headsets. The advantages and disadvantages of open and sealed circumaural headsets and recent developments in noise canceling headsets are discussed, along with the possibility of reducing noise levels in sonar spaces to permit use of higher fidelity headphone designs.

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Sonar Headphone Selection for Optimum Performance
An Overview

This research on headset measurement came about as a result of our interest in making full use of auditory perceptual abilities in passive sonar applications including the use of interaural cues for detecting and discriminating acoustic target information. For optimum aural signal presentation, all perceptually useful acoustic information present in the ocean should be delivered to the ear. This broadband transfer of energy is essential since it is the combination of many frequencies (not necessarily harmonically related) all time varying in amplitude, which provide auditory cues to the listener about the presence and character of non-random energy in the listening channel.

Harris et. al. (1979) demonstrated that low-pass filtering that removes frequencies above 3 kHz, 4 kHz, or 6 kHz leads to significant reduction in sonar target **discrimination** in sea-state-noise.

Research also has shown that extending the low-frequency cutoff downward an additional 400 Hz significantly improved auditory **detection** performance (Russotti, 1987). More recent research on digital sample rate reinforces the critical need for an adequate reproduction of upper frequencies. Both detection (Russotti, et al., 1993) and discrimination (Russotti, et al. in press) were significantly degraded when sample rates used in digitizing the signal were reduced from 12.5 kHz to 6.25 kHz.

As a first step to optimizing the energy transfer, the frequency response accuracy of the operator's headset needs major improvement. As an example, the ANWIC H157-158 sonar headset used for BQQ-5 sonar systems is an aircraft pilot's voice communications headset, intentionally band-limited for that purpose and designed within the constraints of 1957 technology under specifications set forth in the original MIL E-25670 specification (U. S. Air Force, 1957). Headset technology is far improved nearly 40 years later, but appropriate techniques for measurement of such headsets are not specified.

Unfortunately, the current (1986) American National Standards Institute (ANSI) method for coupler calibration of earphones is not intended for such circumaural (around the ear) phones. It is intended only for supra-aural (on the ear) or insert earphones. Work by Shaw and others (Shaw & Thiessen, 1962; Shaw, 1966) showed that probe-tube microphone sound pressures measured under circumaural earphones on real ears were not in agreement with similar measurements made on such earphones using simple couplers. Until such discrepancies could be resolved, a standard for circumaural headphone measurement could not be written.

Research on the acoustic impedance of the human ear by Zwislocki (1957), Ithell (1963), and Delaney (1964) led to the development of several ear simulators. In these simulators, accurate impedance loading of the earphone was attempted using multiple resonant cavities (Zwislocki, 1970, 1971; Record & Hixson, 1972).

The measurement technique we devised in 1985 and proposed for use in earphone calibration in 1986 uses a laboratory type Zwislocki ear **simulator** which includes multiple cavities to model the acoustic load that an average human wearer would place on the earphone element. In standard form, this coupler uses a machined surface and fifth resonant cavity to simulate the external ear (or pinna). In developing a test and evaluation tool for hearing aid performance, Burkhard and Sacks (1975) incorporated the eardrum simulator portion of

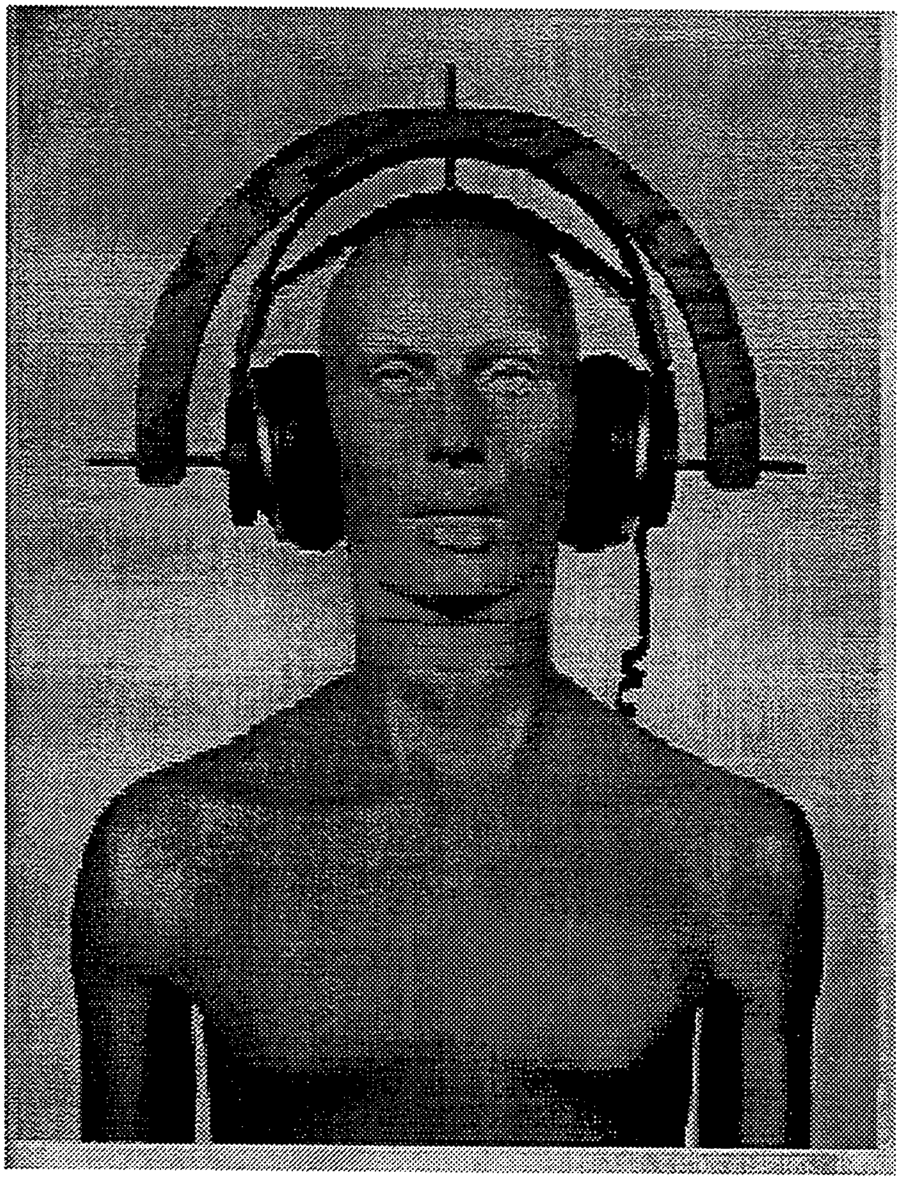

*Figure 1.* Headphone under test on KEMAR manikin.

the Zwislocki coupler into the anthropometrically average manikin KEMAR. They accurately substituted flexible pinnae and metal ear canals for the corresponding portions of the Zwislocki coupler. Acoustic measurements on this version of the KEMAR manikin are in close agreement with similar measurements on human subjects (Burkhard, 1975), and the KEMAR manikin now conforms to ANSI (1985) standards intended for airborne sound measurement.

Figure 1 shows the KEMAR manikin as used in our application. The measurement procedure is outlined in detail in Russotti, et al., 1988. The Zwislocki coupler, modified in the KEMAR manikin, has decided advantages for headset evaluation over a hard surfaced machined plate, in that any wearable headset can be tested. For a real ear, and also for the simulator, the acoustic signal that arrives at the eardrum has had its frequency response modified by the external ear structure, by resonances created by the pinna, and by the complex loading of the ear canal and eardrum with its ossicular chain. A conversion function is necessary. This converted response should correctly reference the signal measured in the coupler back to the external sound field.

The required conversion function shown in Figure 2 references the earphone element response back to the diffuse field. This transformation is the response of the human ear, or in this case the manikin-mounted ear simulator, without regard to any one direction.

Earmuff shape, size, seal, headband effectiveness and placement of headset on the head and against the ear are all major contributors to the variability one finds in earphone response measurements. Our technique samples these variables taking 5 measurements each, of 4 earphone elements. All of the xy plots of sound pressure as a function of frequency are stored using an A/D converter. They are averaged and the diffuse-field conversion function applied.

As a comparison, the upper left curve in Figure 3 shows a prototype supra-aural (on the ear) earphone tailored to have flat response on a standard 6 cc ANSI volummetric coupler. Below it is the averaged response of the same earphone element measured on the ear simulator. This is the diffuse-field corrected response of the earphone. Figure 4 shows an averaged response for one of our 24 tested models from a 1985 paper (Russotti, et al.) This Sennheiser 430 shows a total variation of 11 dB from 40 Hz to 10 kHz. We previously recommended these headsets for SSEP Code 60 Subschool New London, our land based aural target analysis facility, where they have been in use since 1985. Unfortunately, they are open air headphones.

For purposes of comparison, we have included some current headsets used in sonar

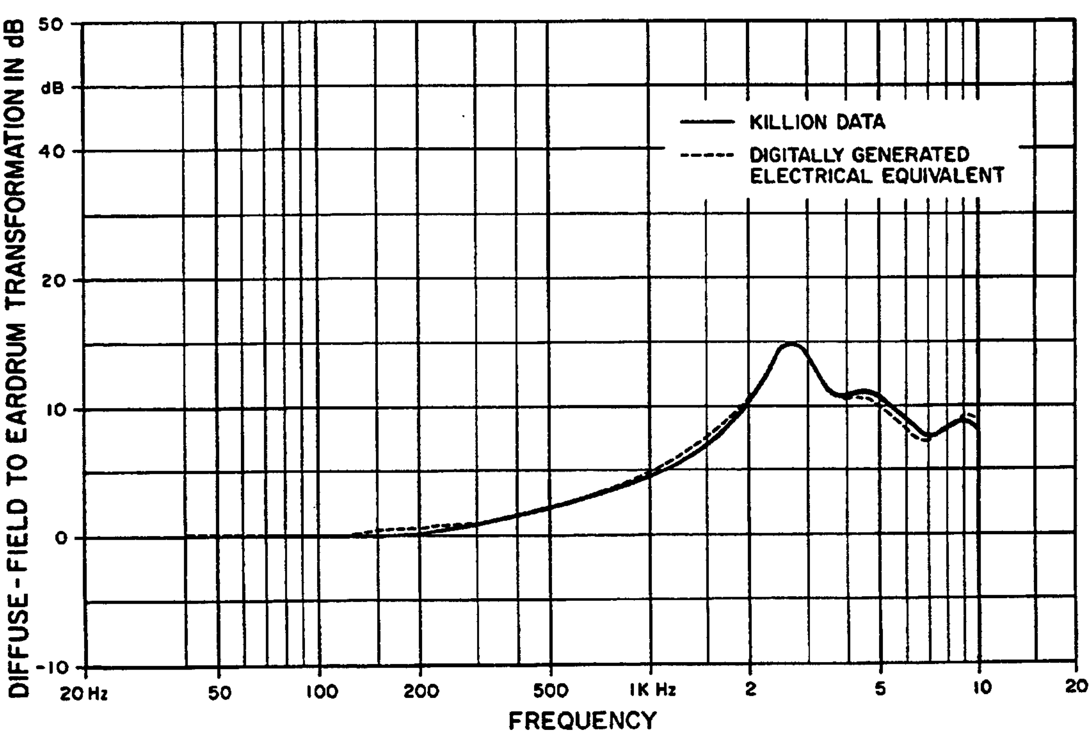


*Figure 2.* Conversion function used for diffuse-field transformation.

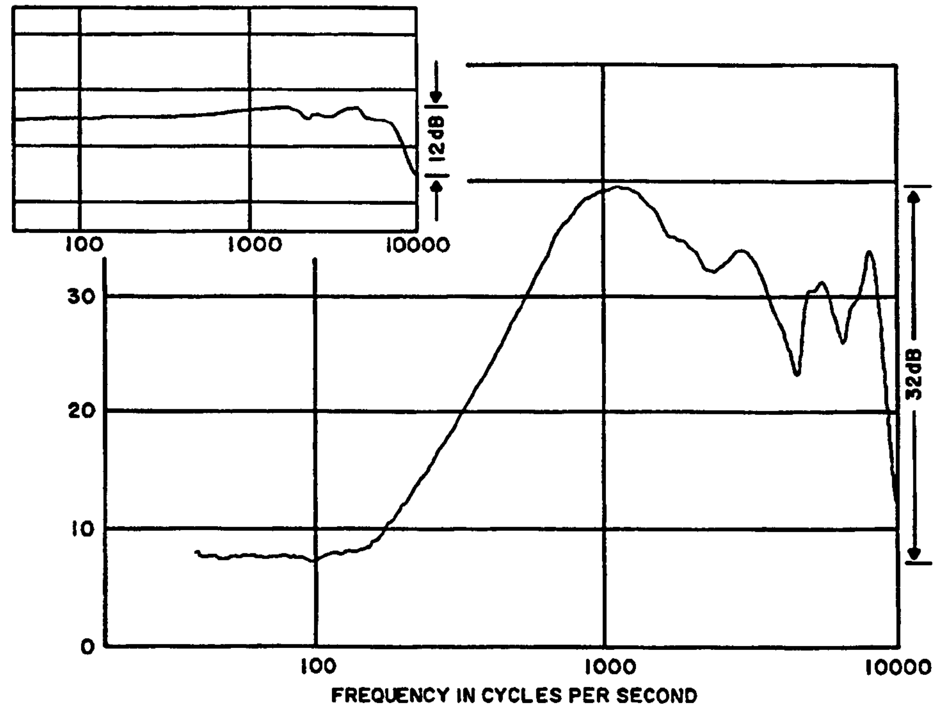


*Figure 3.* Prototype audiometric headphone designed to produce a flat frequency response on an ANSI 6cc coupler and as measured in our procedure.

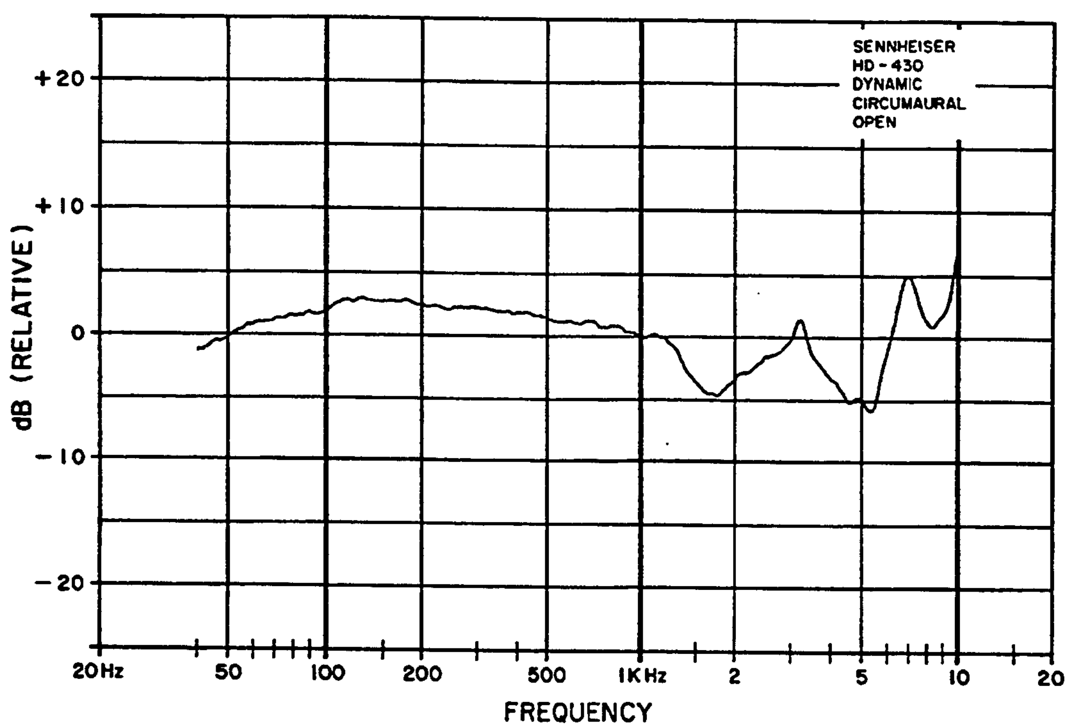


*Figure 4.* Averaged diffuse-field frequency response for the SENNHEISER HD 430 Headphone.

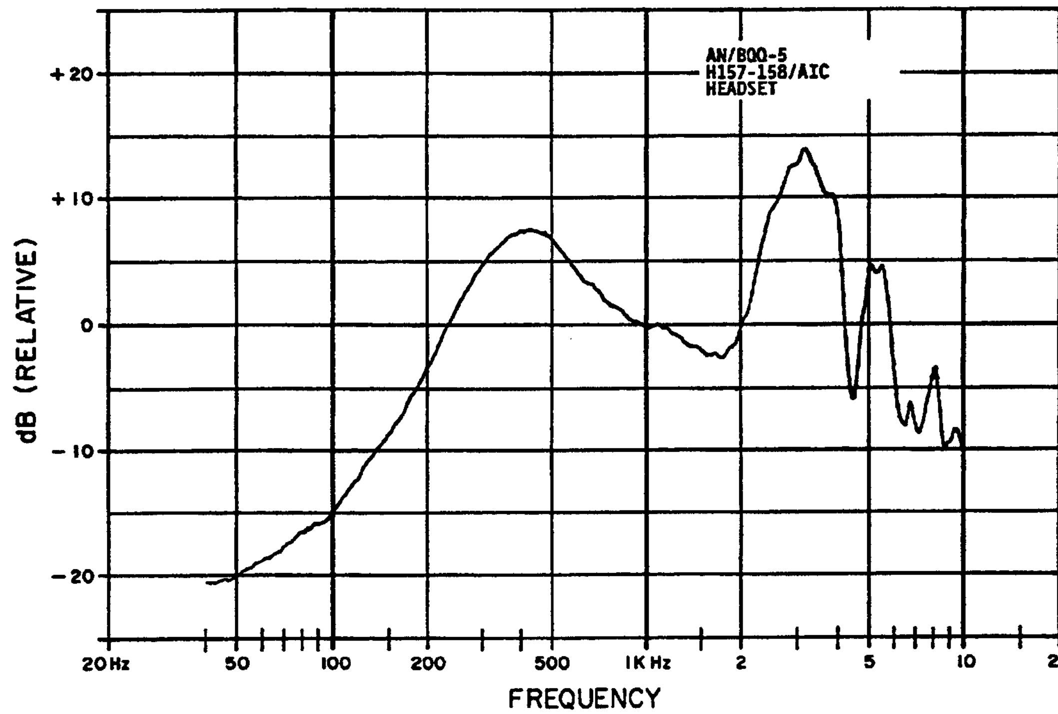


*Figure 5.* Averaged diffuse-field frequency response for the Grey H157-158/AIC Federal Stock Headset.

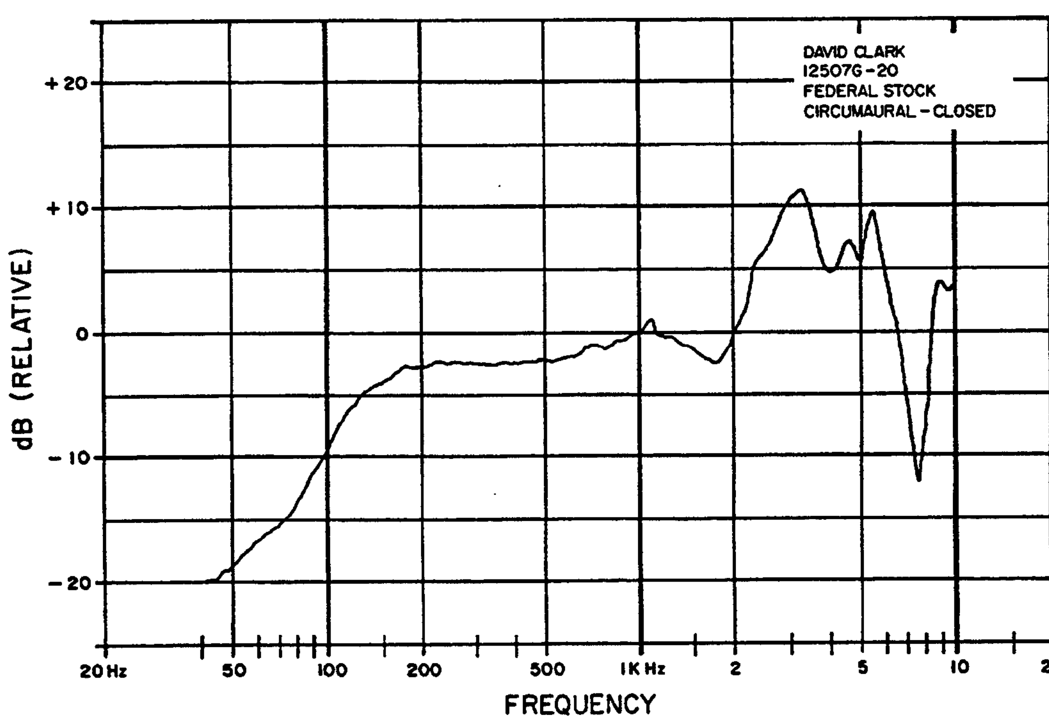


*Figure 6.* Averaged diffuse-field frequency response for the DAVID CLARK 12507G-20 Federal Stock Headset.

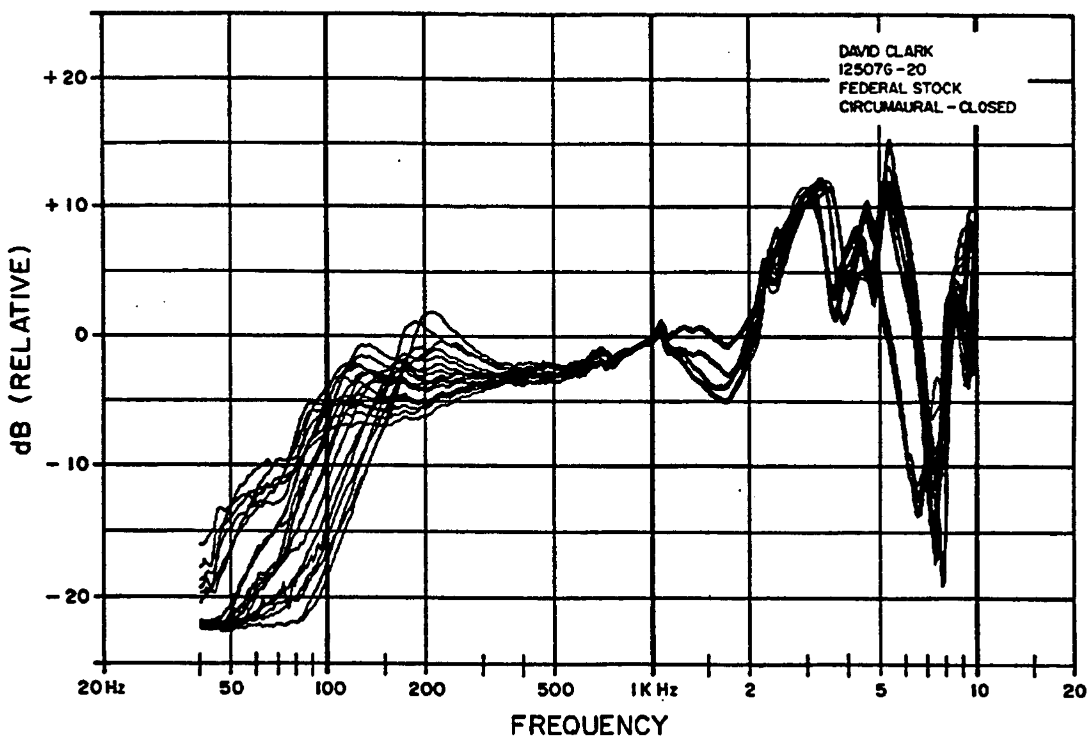


*Figure 7.* Twenty converted earphone responses for the DAVID CLARK 12507G-20 headset (4 elements, 5 measurements each).

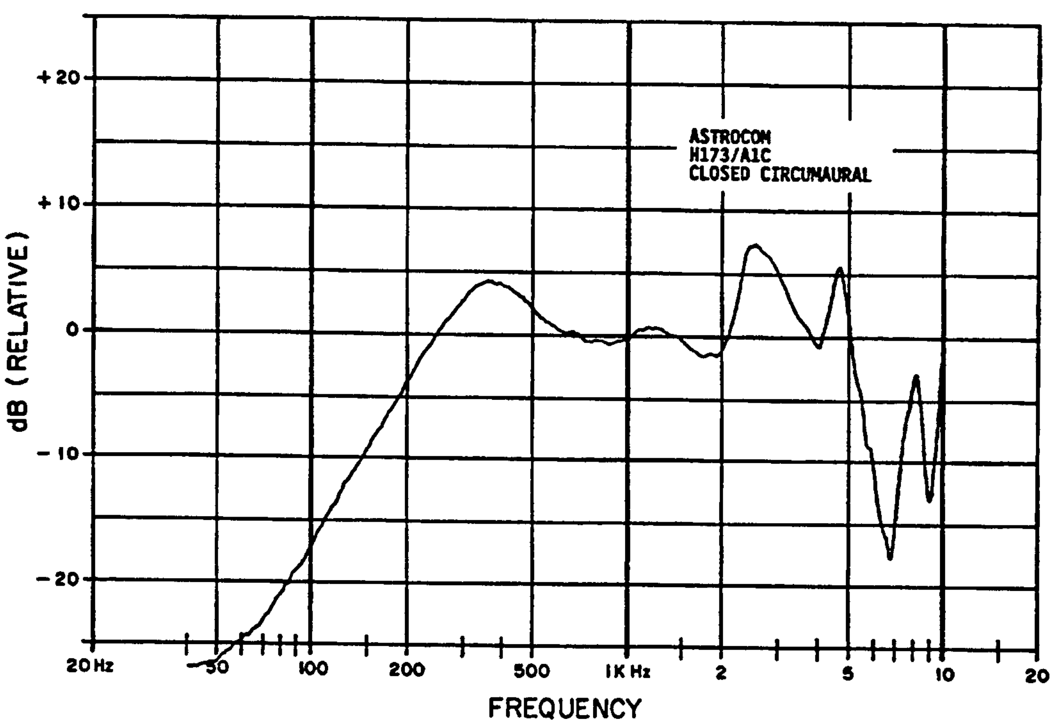


*Figure 8.* Averaged diffuse-field frequency response for the ASTROCOM H173/AIC Federal Stock Headset.

systems along with some proposed headsets. Figure 5 is the averaged and corrected response of the previously mentioned H157-158 AIC headset which shows a 35 dB total variation in response over the 40 Hz to 10 kHz measurement range and a 29 dB variation over the narrower 100 Hz to 10 kHz range. Figure 6 shows the David Clark federal-stock sonar headset currently used, with a 31 dB response variation in the 40 Hz to 10 kHz range and a 23 dB variation from 100 Hz to 10 kHz.

Figure 7, which plots the individual 20 corrected response curves for the David Clark, shows clearly why we sample the responses of 4 earphone elements over 5 placements of that element on the ear. The 4 distinct groupings in the 1 to 2 kHz region and the single element's unique response in the 4 to 8 kHz region are representative of many manufacturers' quality control. Headset specifications can reduce this variability by defining tolerances required from sample to sample over a specified frequency range. In addition these individual curves reveal the major problem with most sealed circumaural phones. There is an inconsistent low-frequency response found in sealed circumaural phones as a result of their inherent need for a proper pressure seal against the head. By its' very design, the earphone element in a sealed circumaural headphone must operate as a pressure transducer. Acoustic leaks will change its sound pressure output - in this case exhibiting a measurement variation of 15 dB at 100 Hz. Of course, such variations increase with deterioration or hardening of the vinyl ear cushions. A more logical solution to the problem would be the overall reduction of airborne noise in sonar workspaces. Such a solution would be in line with a general need to reduce radiated energy and would allow use of more accurate, far more comfortable headphones. In our testing since 1985, we have yet to find a sealed circumaural passive noise-occluding headset that was not of limited bandwidth.

Figure 8 shows the airborne sonar operator's headset, the Astrocom H173/AIC, a closed circumaural headset which shows a 34 dB response variation from 40 Hz to 10 kHz and a 25 dB variation from 100 Hz to 10 kHz. Figure 9 shows the diffuse-field response of the Joyce Telectronics Corporation JTC57-275 headset available through federal stock. This is a communication headset having a response variation of 36 dB from 40 Hz to 10 kHz and 28.5 dB variation from 100 Hz to 10 kHz. It has been included for reference purposes since many sonar personnel have requested information regarding its suitability for sonar operator use.

For the same reasons we are including the response characteristics of the Hughes Aircraft model 4506408 military headset as Figure 10. This federal stock headset produces a diffuse-field response variation of 26.5 dB from 40 Hz to 10 kHz, with a 21.5 dB variation from 100 Hz to 10 kHz and is not appropriate as a wideband sensor operator headset.

Figure 11 depicts the diffuse-field frequency response of the headset originally specified for BSY-1, the Sennheiser HMD 414. Since it is a supra-aural headset, it provides minimal attenuation of airborne noise and is far less comfortable in extended use than circumaural designs. As seen in the figure, there is a response variation of 22 dB from 40 Hz to 10 kHz. It has a 10 dB per octave slope just under 200 Hz and, although not shown here (the measurement device serves as an earphone coupler not an ear simulator above 10 kHz), appears to drop off rapidly by 20 dB from 10 to 14 kHz.

We have also tested nine new conventional broadband (high fidelity) headsets. The best model tested to date is the Sennheiser model HD250 shown in Figure 12. A closed circumaural model, though with minimal noise reduction, it has a total variation of 11 dB over the

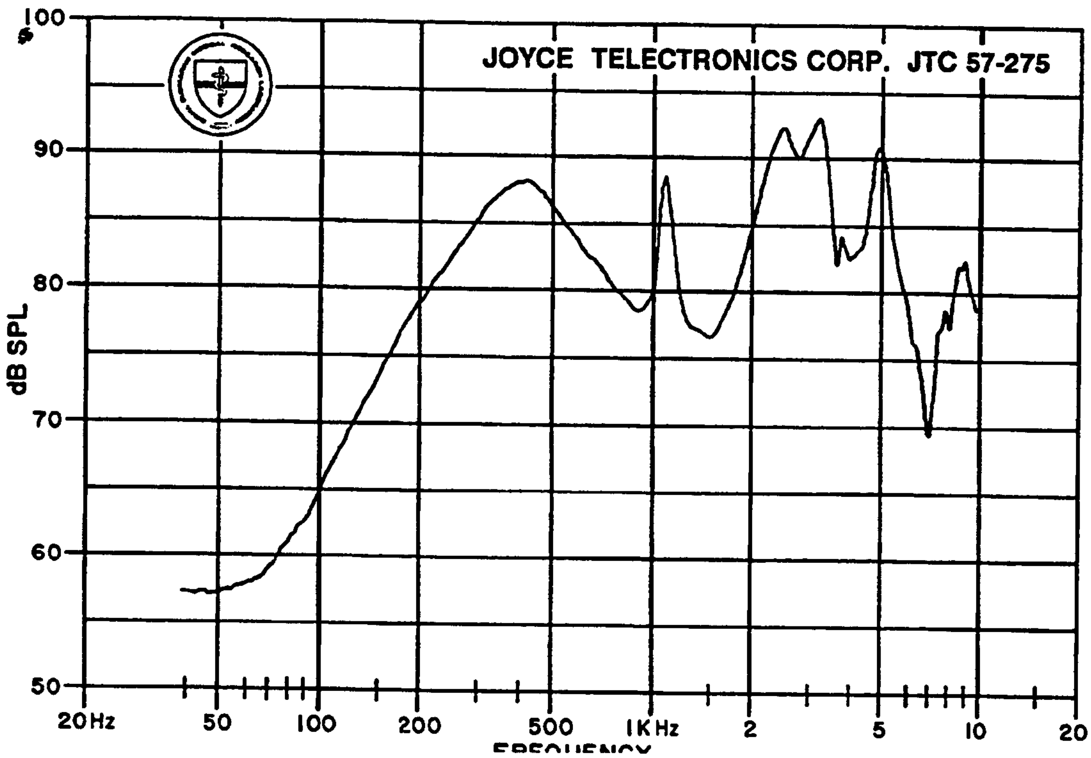


*Figure 9.* Averaged diffuse-field frequency response for the JOYCE TELECTRONICS CORP. JTC 57-275 Federal Stock Headset.

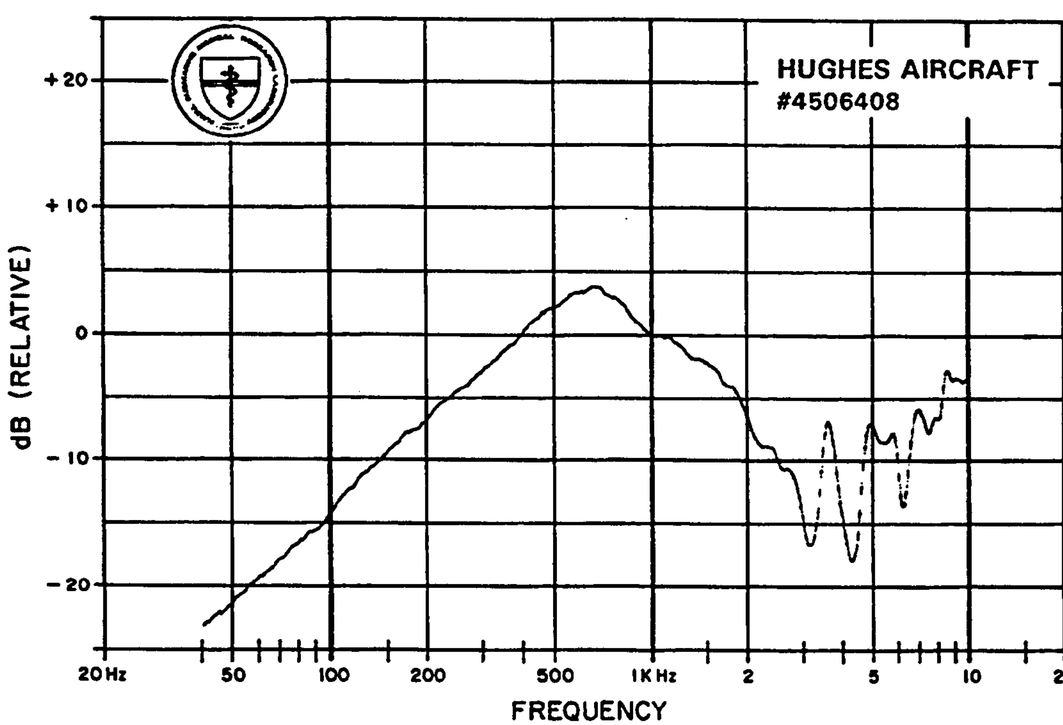


*Figure 10.* Averaged diffuse-field frequency response for the HUGHES AIRCRAFT #4506408 Headset.

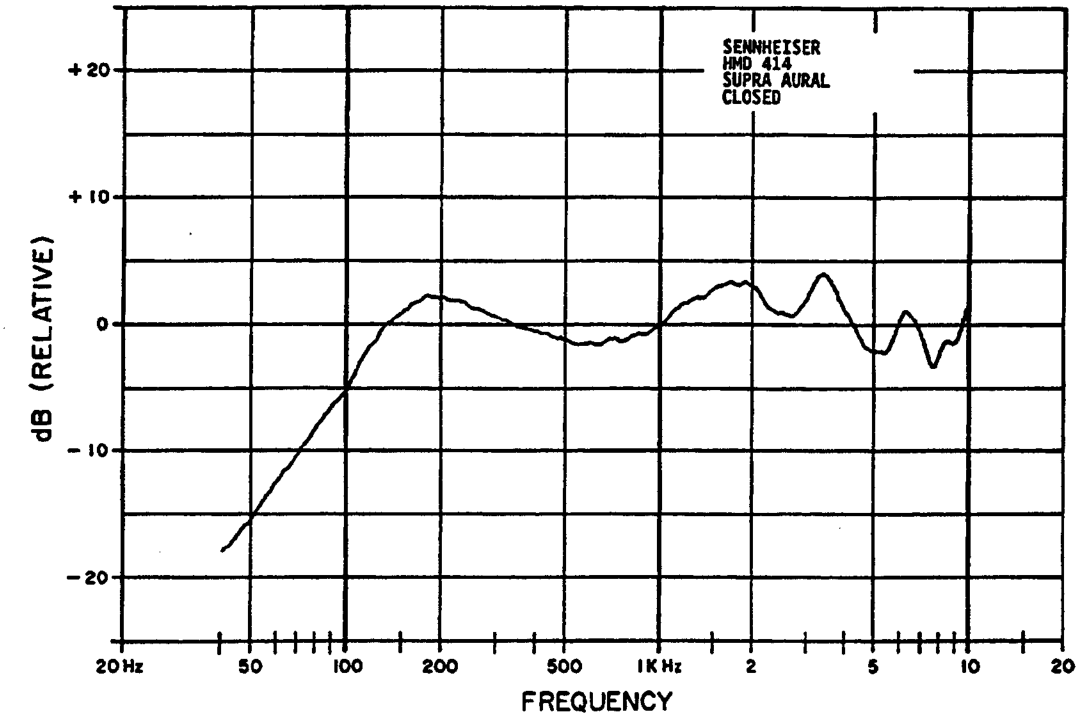


*Figure 11.* Averaged diffuse-f9eld frequency response for the SENNHEISER HMD 414 Headset.

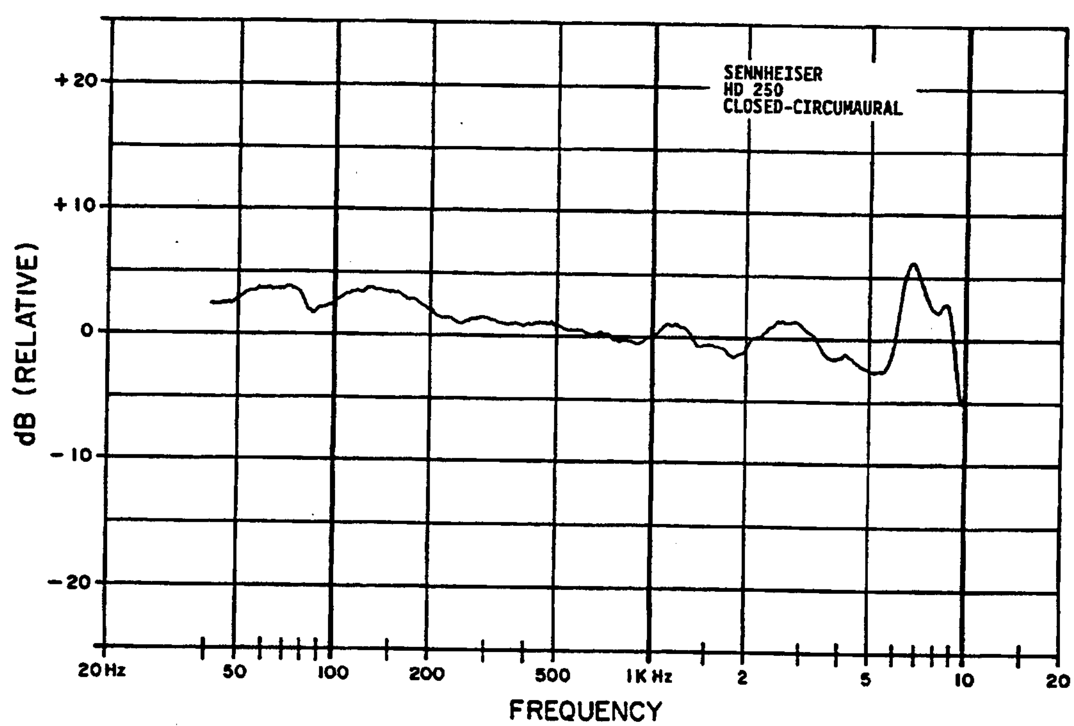


*Figure 12.* Averaged diffuse-field frequuency response for the SENNHEISER HD 250 Headphone.

*Figure 13.* SENNHEISER HMD 250.MIL Headset prototyped with NSMRL.

40 Hz to 10 kHz range. BSY 2 sonar system design calls for reduced noise in sonar spaces. This Sennheiser headset is the model we recommend for the BSY-2 system given the reduced noise levels in BSY-2 sonar spaces (Commanding Officer NSMRL, 1990). At our suggestion, a boom microphone was added to the headband to isolate it from the earcup shell and to allow boom placement on either side of the head with simple rotation of the boom on its mount. The new model has been designated the HMD250.MIL. This microphone equipped headset is shown in Figure 13. It is extremely lightweight yet rugged, with high tensile-strength stainless steel signal cables dressed down vertically from the boom side of the headband. The small diameter smooth cabling is exceptionally well implemented and unobtrusive to the user, especially when terminated in a Nexus U-384/U five conductor phone-style plug. Diffuse-field frequency response curves for the eight remaining high fidelity models tested, are presented in an appendix for reference purposes.

We have tested several active noise canceling (ANC) headset prototypes. One of these, the Sennheiser HMEC 45 (an HME 1410 Series headset), looks somewhat like the supra-aural BSY 1 headset (HMD 414) externally but employs electret microphones mounted outward on each earpiece which pick up airborne noise and then generate an inverse of the noise using an external processor. Figure 14 shows the averaged diffuse referenced response of the prototype which produced a 21 dB variation from 40 Hz to 10 kHz with ANC "off."

Figure 15 shows the interactive effects of active noise cancellation on the frequency response of the headset. The notch at 450 Hz would render this headset less than ideal for passive sonar purposes. A second prototype

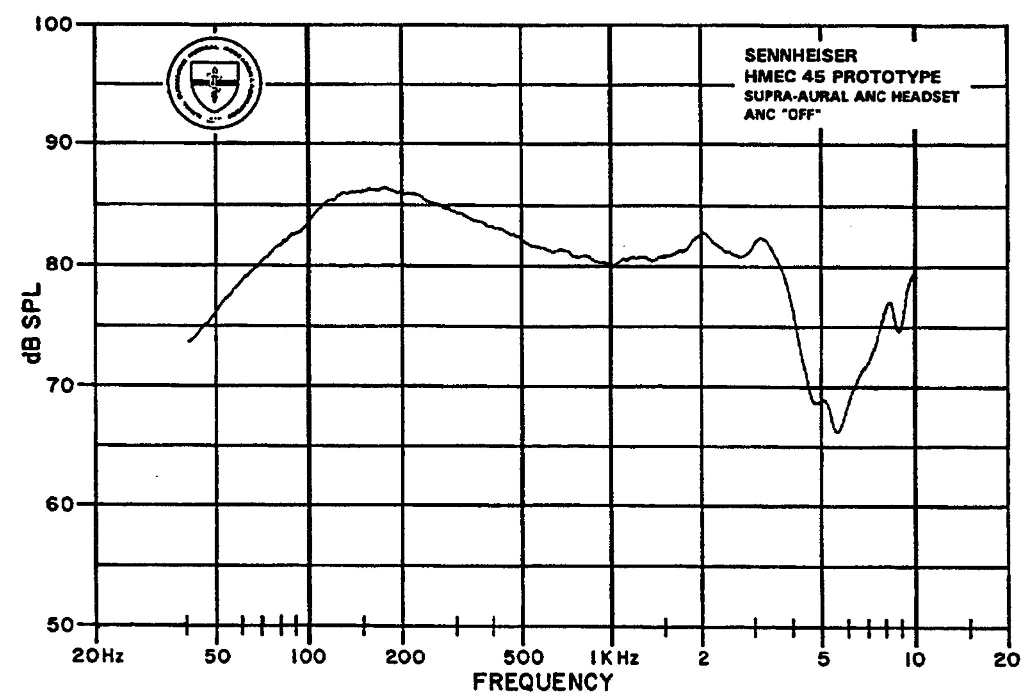


*Figure 14.* Averaged diffuse-field frequency response for the SENNHEISER HMEC 45 prototypt supra-aural ANC Headset.

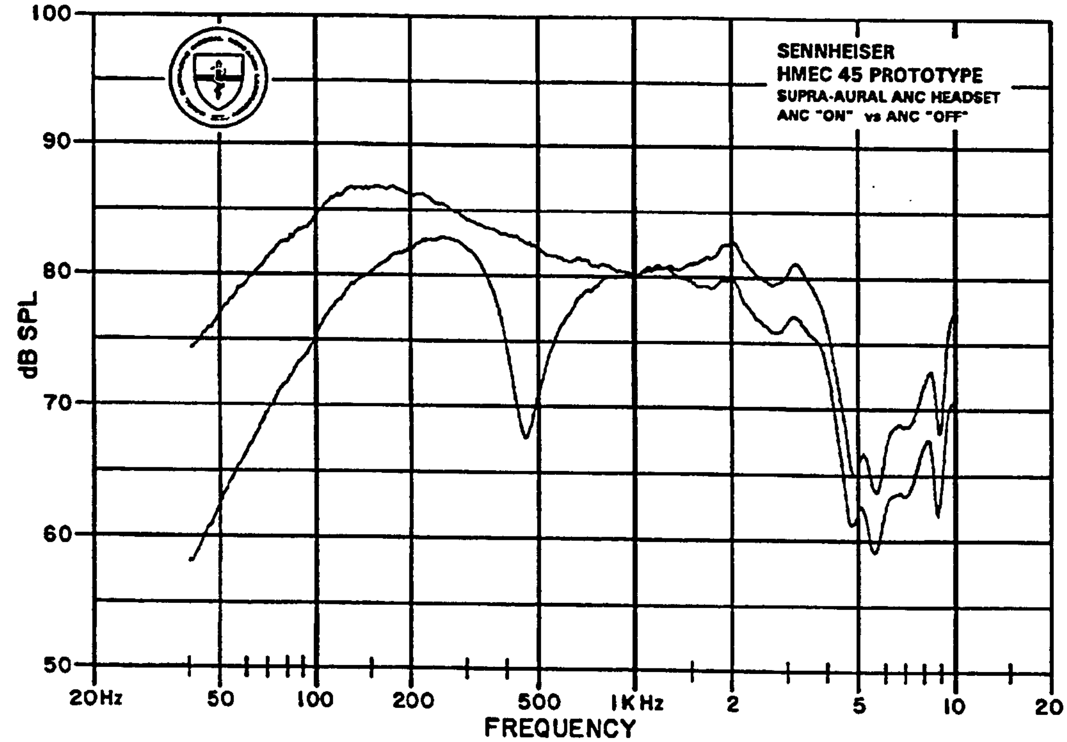


*Figure 15.* Averaged diffuse-field frequency response for the SENNHEISER HM#C 45 prototype headset "ANC on" vs "ANC off".

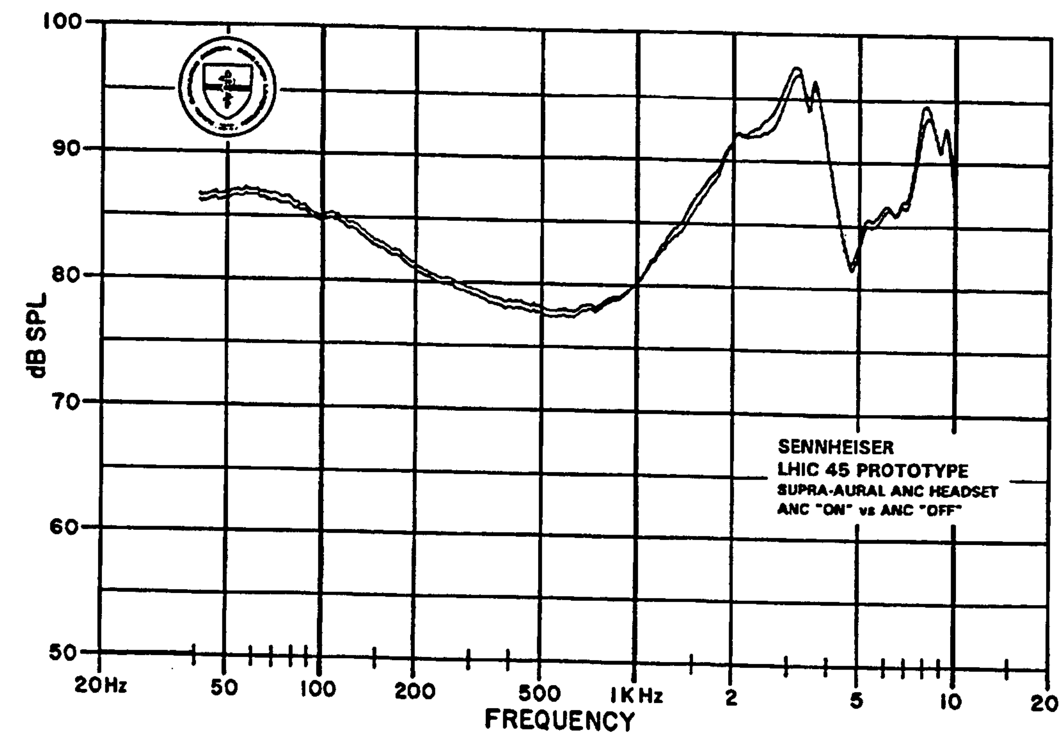


*Figure 16.* Averaged diffuse-field frequency response for the SENNHEISER LHIC prototype supra-aural ANC Headset, "ANC on" vs "ANC off{.

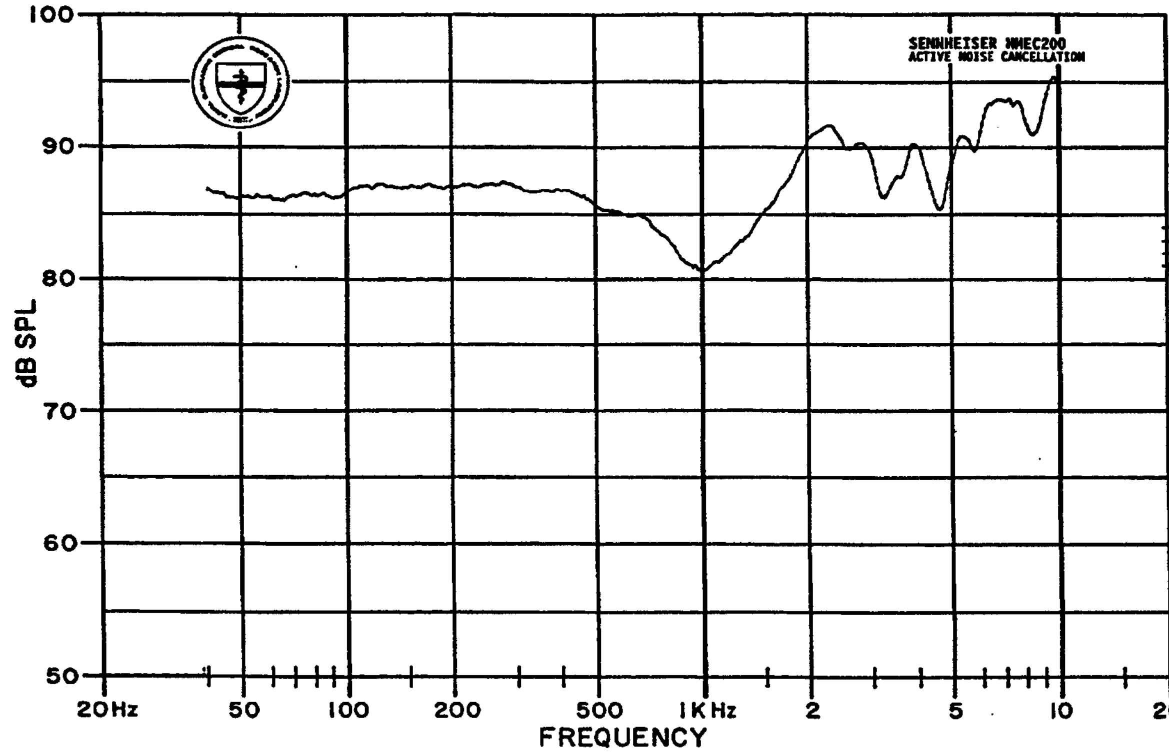


*Figure 17.* Averaged diffuse-field frequency response for the SENNHEISER HMEC 200 sealed circumaural ANC Headset.

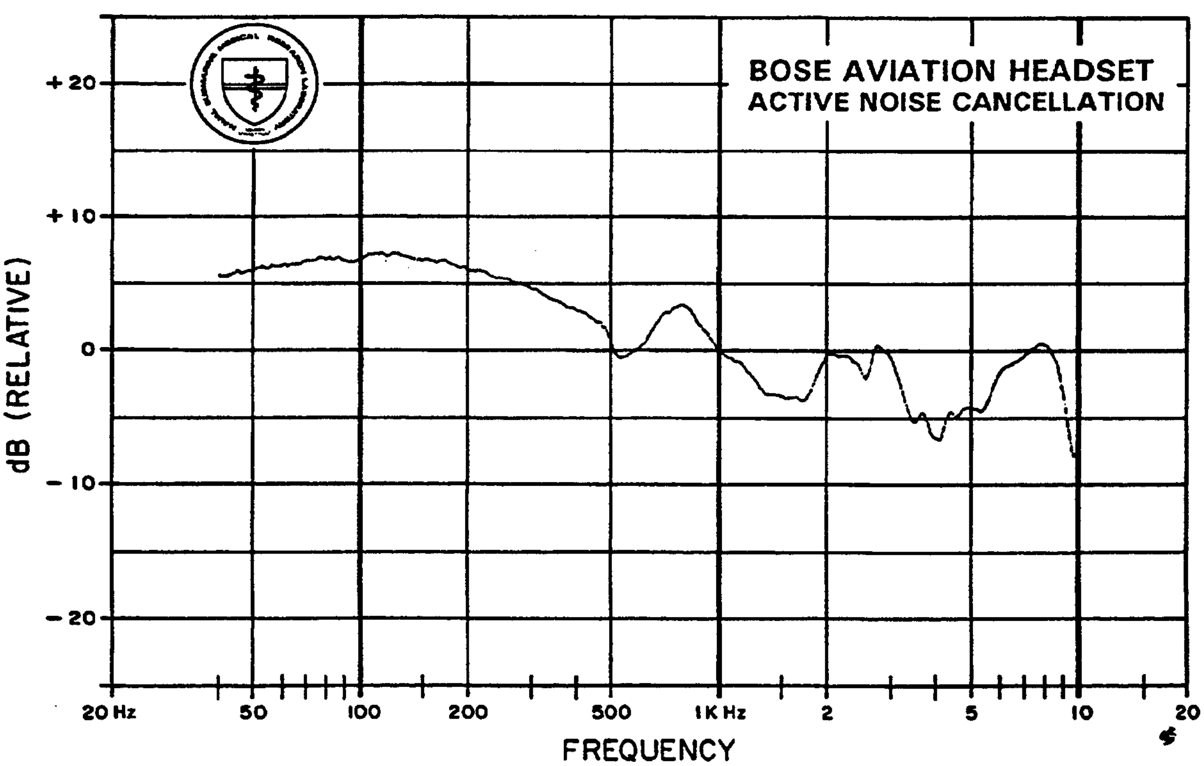


*Figure 18.* Averaged diffuse-field frequency response for the BOSE AVIATION HEADSET sealed circumaural ANC Headset.

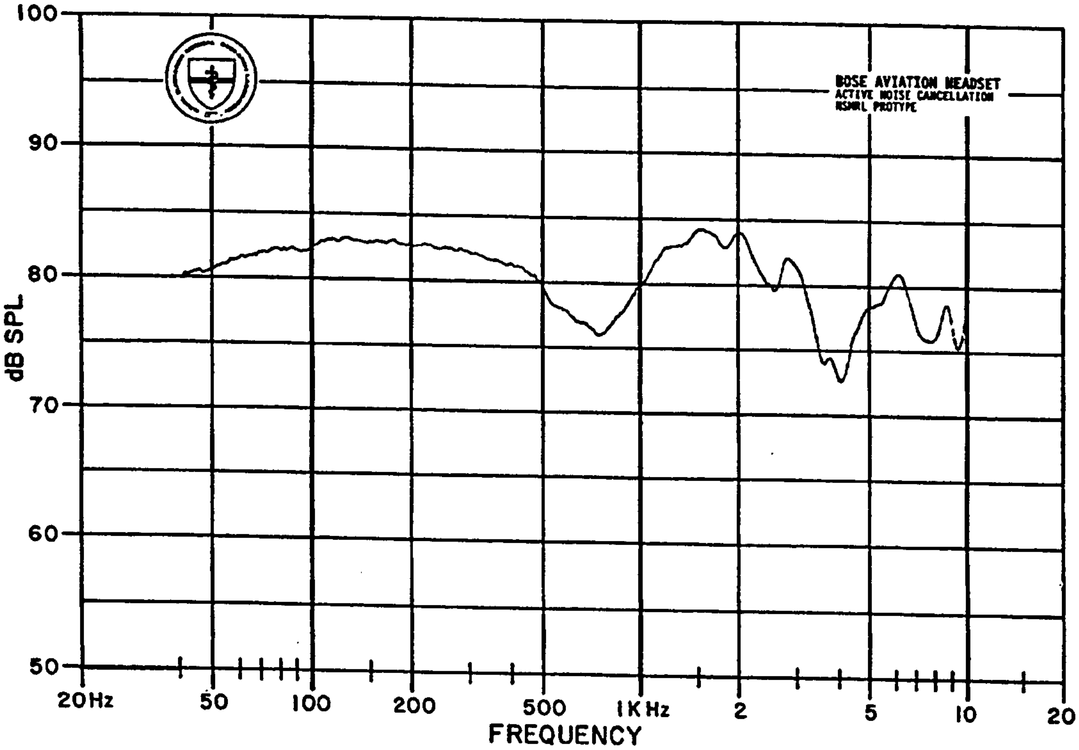


*Figure 19.* Averaged diffuse-field frequency response for the BOSE AVIATION/NSMRL prototype sealed circumaural ANC Headset.


*Figure 20.* BOSE AVIATION HEADSET.

active noise cancellation model was made available for testing. This model, designated the LHIC 45, used substantially smaller supra-aural earphone elements with self-contained electret microphones and noise cancellation circuitry. The two curves shown in Figure 16 represent the averaged diffuse-field frequency response to a swept tone set to produce 80 dB SPL at the headphone at 1 kHz. The upper curve is the measured response with no cancellation, and the lower is with cancellation on. Unlike the previously mentioned HMEC-45, no artifacts were introduced into the frequency response by the operation of the ANC circuitry. While the real time noise cancellation was extremely effective, the earphone element was of a communication bandwidth and, therefore, not currently useful for passive sonar application.

Figure 17 presents the diffuse-field-referenced frequency response data (ANC "on") of a Sennheiser HMEC 200 ANC headset which uses a Peltor passive noise occluding headshell for additional noise attenuation. This headset produces an averaged diffuse-field-referenced frequency response variation of 14.5 dB from 40 Hz to 10 kHz.

Figure 18 depicts the Bose Aviation ANC headset in a non standard configuration (a low frequency filter has been removed). Total frequency response variation from 40 Hz to 10 kHz is 15 dB. This sealed circumaural headset and the Sennheiser/Peltor mentioned above use an **internal** microphone in each earcup whose signal is compared against the instantaneous electrical signal. The difference signal is inverted and added to the electrical signal sent to the earphone element to actively null any unintended acoustic energy found in the earcup. Subsequent to our frequency response measurements on the Aviation headset, we conferred with the manufacturer and suggested that active equalization might be added to further enhance the measured diffuse-field response. The result of their efforts is shown in Figure 19. This alteration known as the Dan Gager/NSMRL prototype exhibits an improved frequency response (11.5 dB total variation 40 to 10k Hz) that competes favorably with high fidelity headsets, with the added benefit of superior noise attenuation. Most importantly, the fact that its' ANC circuitry compares the acoustic signal in the headshell to the intended electrical signal automatically corrects for diminished sound-pressure output related to a less than perfect seal. The Bose Aviation Headset is shown in Figure 20. No external changes to the headshell of this commercial model are caused by the modifications for our prototype.

Concurrent with our headset research, a military aviation ANC headset was developed for the Air Force with newly designed earcups of smaller size for use inside flight helmets. The headset also meets TEMPEST requirements for radiated energy. Figure 21 depicts the diffuse-field response of this communications headset. Total frequency response variation was measured at 23.5 and 24 dB for right and left earphone assemblies in the 40 to 10k Hz range. Subsequent to a Naval Air Warfare Center Aircraft Division request for added active equalization as implemented in our collaboration, Bose has prototyped an improved *sensor operator* version of that military headset as shown in Figure 22. Total frequency response variation averaged across earphone elements is 18.5 dB over the 40 to 10k Hz range, with a 12 dB variation within the narrower 40 to 8.5k Hz range.

For our submarine sonar requirements the higher fidelity commercial aviation headset modified as the Dan Gager/NSMRL prototype shown in Figure 19 is the better and far less expensive choice. This headset has been taken out-to-sea by Acoustic Intelligence (ACINT) specialists and was given a very positive evaluation (Russotti, 1993). Following that evaluation these prototype headsets were

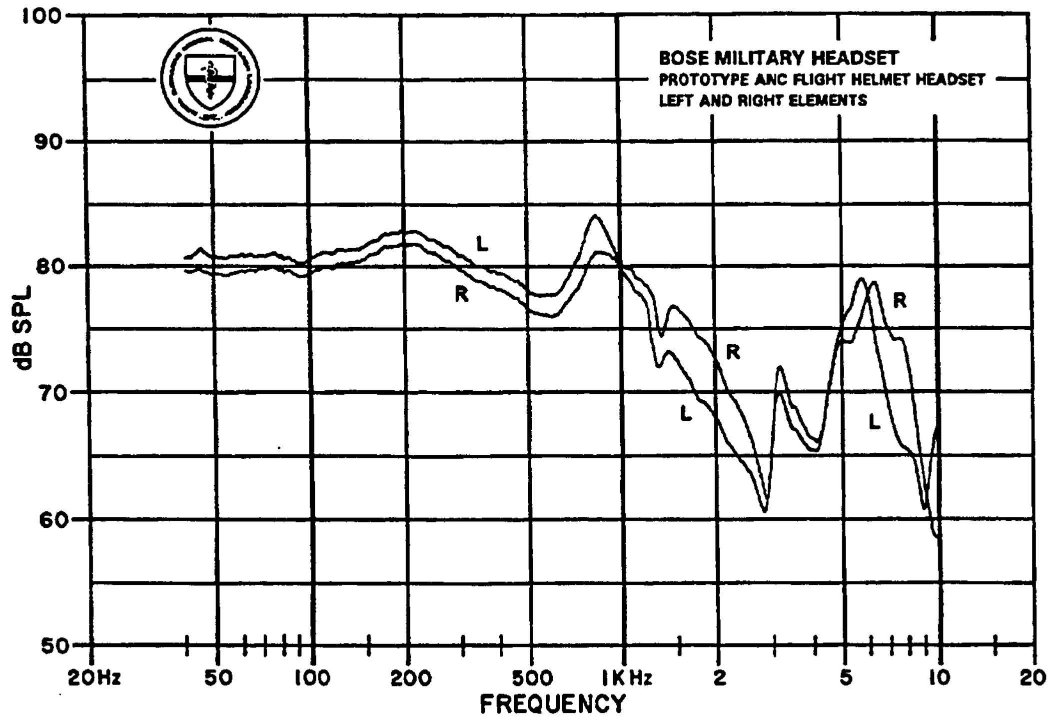


*Figure 21.* Averaged diffuse-field frequency response for the BOSE AVIATION MILITARY HEADSET prototype ANC Flight Helmet Communications Headset for USAF.

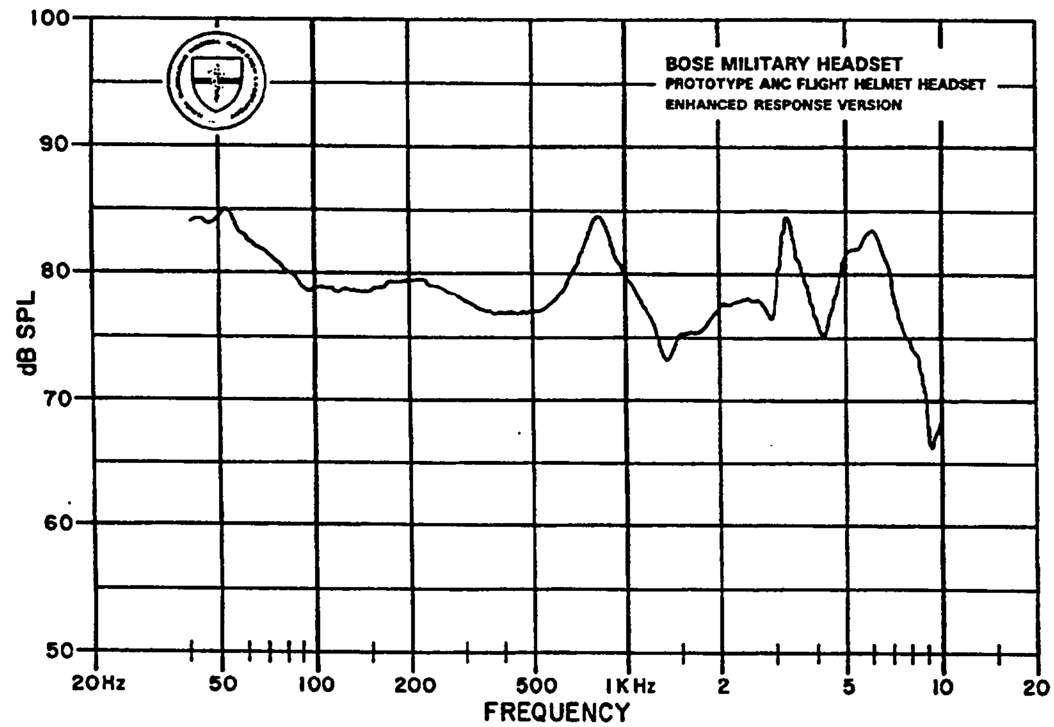


*Figure 22.* Averaged diffuse-field frequency response for the BOSE AVIATION MILITARY HEADSET rototype ANC Flight Helmet Headset with enhanced response.

recommended to Office of Naval Intelligence, Code 25, for ACINT use (Commanding Officer NSMRL, 1993). They were given an extended at-sea evaluation by two BSY-1 equipped submarines (Commanding Officer USS San Juan, 1993), and were also used in shorter deployment aboard two BQQ-5 equipped submarines (Benedetto et al, 1995). Comments by the crews of these boats were highly favorable in terms of the added information provided and positive in their acceptability and comfort, but expressed a desire for more durable earcushions and a lighter overall weight. The easily replaceable earcushions are soft silicone gel-filled pads formed as two concentric rings and covered by a thin urethane membrane skin. Initially designed for a life cycle of 1000 hours of intermittent use in aircraft, the cushions managed to survive under continuous use and longer duration, but at-sea 1000 hours translates to 41.6 days. Their condition following an extended deployment far in excess of 1000 hours indicated that earcushion replacement was necessary. Although the urethane membrane skin remained intact, silicone gel had migrated under and around a foam substrate and the concentric ring appearance had been obliterated. Once new cushions were snapped into place all headsets were in excellent operation. No component failures occurred. Work is underway to produce a more durable earcushion with the same excellent comfort and noise reduction characteristics. Given its aural capabilities, we strongly recommend this headset prototype be required for the broadband search operator and sonar supervisor. Our second choice for all other operators is the Sennheiser HD 250 (ruggedized) or the microphone equipped HMD 250-MIL. This headset also was given highly favorable evaluations by the same four sonar crews that evaluated the ANC headsets, and all HD 250 and HMD 250-MIL headsets survived their extended at-sea deployment without any earphone element failure. While the microphone equipped HMD 250-MIL version has a single-sheathed shielded cord of high tensile-strength stainless steel with strain-relieved connection to the headshell at the microphone boom, the commercial version HD 250 has not been equally ruggedized. As a consequence the less durable copper conductor "Y" cords failed on 2 headsets. Earlier version HD 250 headsets used by ACINT specialists had a stainless steel conductor "Y" cord and no failures were encountered. The solution was to modify the copper conductor "Y" cord as was done on the 250-MIL version so that the cord is not being pulled at its connection to the headshell. No further cord failure problems were encountered. However, we would strongly recommend that the stainless steel cords be specified and that they be installed configured as in the HMD 250-MIL version. These headsets are the most accurate headsets we have tested to date and are lightweight and extremely comfortable. Though nominally of "closed" circumaural design they incorporate tiny capillary tube vents which limit the pressure seal and appear to reduce the low frequency variability normally encountered with closed headsets. Although these circumaural headsets provide some noise attenuation (Williams, 1992), we cannot recommend them for critical use such as passive broadband (PBB) and sonar supervisor in current sonar spaces on BQQ5 and BSY1 due to ambient noise levels. They are the headsets we have specified for the quieter environment designed for BSY2 (Commanding Officer NSMRL, 1990).

Future iterations of submarine command control centers may require concentrations of operators in close proximity. To eliminate the inevitable problems of battle station operating conditions interfering with critical listening, ANC headsets may be essential to specific sensor operators in such environments.

As general purpose operator headsets both are ideal in that the sound pressure output across frequency is predictable and flat. This is of particular importance in the implementation of narrow bandwidth or single frequency auditory alarms which would vary in amplitude at different selected frequencies on headsets of poorer fidelity. Both headsets exhibit a sufficiently flat diffuse-field response which make them suitable for virtual reality three-dimensional auditory presentations, since the necessary head-related transfer functions required for different source locations can be imposed on their known non-directional response.

In summary, we have found, and have overseen modifications on, two highly useful wide-band sensor operator headsets which can be selected according to noise environment. There will always be some degree of discomfort associated with closed-shell noise-reducing headsets. Temperatures at the eardrum are at body core-temperature. Even the lightest, best fitting, noise barriers cannot overcome the heat and moisture buildup they create by virtue of their seal around the external ear. Unfortunately, open-air ANC headsets do not attenuate enough across the necessary spectrum. By far, the best solution to noise reduction is to eliminate its source. For the present however, the most cost-effective solution is through use of appropriate noise attenuating headsets.

## References


American National Standard Method for Coupler Calibration of Earphones." ANSI S3.7-1973 (R1986), American National Standards Institute, New York, 1973.

American National Standards Institute. (1985). *Specification for a Manikin for Simulated In-Situ Airborne Acoustic Measurements* (ANSI S3.36-1985). New York: American National Standards Institute,

Benedetto, J. L., Russotti, J. S., Harvey, J. T., and Hanna, T. E. (1995). *At-sea tests of headphones and active filters* (NSMRL Report 1195). Groton, CT: Naval Submarine Medical Research Laboratory.

Benson, R. W., Charan, K. K., Day, J. W., Harris, J. D., Niemoeller, A. F., Rudmose, W., Shaw, E. A., and Weissler, P. G. (1967). Limitations on the Use of Circumaural Earphones. *Journal of the Acoustical Society of America, 41*, 713-714.

Burkhard, M. D., and Sachs, R. M. (1975). Anthropometric Manikin for Acoustic Research. *Journal of the Acoustical Society of America, 58*, 214-222.

Burkhard, M. D. (Ed) (1978). *Manikin Measurements*. Elk Grove Village, IL: Industrial Research Products.

Commanding Officer, NSMRL. (1990). Sonar Headset Evaluation and Recommendation. Naval Submarine Medical Research Laboratory ltr, 3960, Ser 50/459 dtd 13 April 1990.

Commanding Officer, NSMRL. (1993). Sonar Headset Evaluation and Recommendation for ACINT use. Naval Submarine Medical Research Laboratory ltr, 3960, Ser 40/418 dtd 12 October 1993.

Commanding Officer, USS SAN JUAN, SSN 751. (1993). Evaluation of Noise Canceling Headset for AN/BSY-1 Sonar Suite. 3900, Ser 622 dtd 14 December 1993.

Delaney, M. E. (1964). The Acoustical Impedance of Human Ears. *Journal of Sound Vibration, 1*, 455-467.

Delaney, M. E., Whittle, L. S., Cook, J. P., and Scott, V. (1967). Performance

Studies on a New Artificial Ear. *Acustica, 18*, 231-237.

Harris, J. D., Kerivan, J. E., and Russotti, J. S. (1979). The necessity for high frequency hearing in passive sonar listening (NSMRL Report 862). Groton, CT: Naval Submarine Medical Research Laboratory and *Military Medicine, 144*, 3 33-336.

Ithell, A. H. (1963). The Measurement of the Acoustical Input Impedance of Human Ears. *Acustica, 13*, 140-145.

Ithell, A. H. (1963). A Determination of the Acoustical Input Impedance Characteristics of Human Ears. *Acustica, 13*, 311-314.

Killion, M. C. (1979). Equalization Filter for Eardrum-Pressure Recording Using a KEMAR Manikin. *Journal of the Audio Engineering Society, 27*, 13-16.

Record, H. L., and Hixson, E. L. (1972). *The Design and Evaluation of an Artificial Ear* (Tech. Memo 32). Austin, TX: Acoustics Research Lab, Electronics Research Center, University of Texas.

Russotti, J. S., Haskell, G. B., Neal, R., Santoro, T. P., and Carpenter, S. M. (1985). *Frequency response and distortion measurement of headsets for use in auditory displays* (Repdort 1066). Groton, CT: Naval Submarine Medical Research Laboratory.

Russotti, J. S. (1987). (U) *Effects of system bandwidth on passive sonar target detection using normal and experimental auditory displays* (Report 1103). Groton, CT: Naval Submarine Medical Research Laboratory

Russotti, J. S., Santoro, T. P., and Haskell, G. B. (1988). Proposed technique for earphone calibration. *Audio Engineering Society Journal, 36*, 643-650.

Russotti, J.S. (1993). At-Sea Evaluation of a Prototype Active-Noise Canceling Headset (Memorandum for the Record). Groton, CT: Naval Submarine Medical Research Laboratory.

Russotti, J.S., Santoro, T.P., Hanna, T.E., Wojtowicz, J.J. (1993). *Effects of digital sampling rate and bit quantization on passive auditory sonar target detection performance* (Report 1184). Groton, CT: Naval Submarine Medical Research Laboratory.

Russotti, J.S., Santoro, T.P., Hanna, T.E., and Leo, T. (In Review). Effects of digital sampling rate and bit quantization on the auditory discrimination of passive sonar-targets. Groton, CT: Naval Submarine Medical Research Laboratory.

Shaw, E. A. G., and Thiessen, G. J. (1962). Acoustics of Circumaural Earphones. *Journal of the Acoustical Society of America, 34*, 1233-1246.

Shaw, E. A. G. (1966). Ear Canal Pressure Generated by Circumaural and Supra-Aural Earphones. *Journal of the Acoustical Society of America, 39*, 471-479.

Shaw, E. A. G. (1974). Transformation of Sound Pressure from Free Field to the Eardrum in the Horizontal Plane. *Journal of the Acoustical Society of America, 56*, 1848-1860.

Williams, C. E. (1992). Sound Attenuation Evaluation of Sennheiser Model HD250 Headset (NAMRL-26-5720 Ser 26/0457 dtd 03 June 1992). Naval Aerospace Medical Research Laboratory

Zwislocki, J. J. (1957). Some Measurements of the Impedance at the Eardrum. *Journal of the Acoustical Society of America, 29,* 349-356.

Zwislocki, J. J. (1970). *Acoustic Coupler for* Earphone Calibration (Spec. Rep. LSC-S-7). Syracuse, NY: Laboratory of Sensory Communication.

Zwislocki, J. J. (1971). *An Ear-Like Coupler for Earphone Calibration* (Spec. Rep. LSC-S-9). Syracuse, NY: Laboratory of Sensory Communication.

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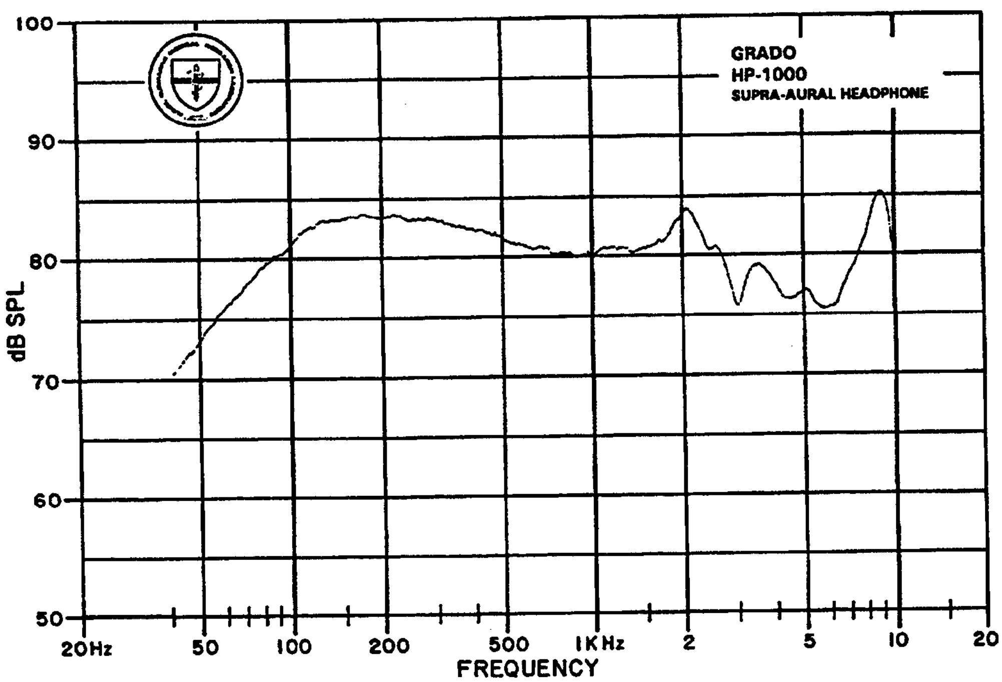
# APPENDIX



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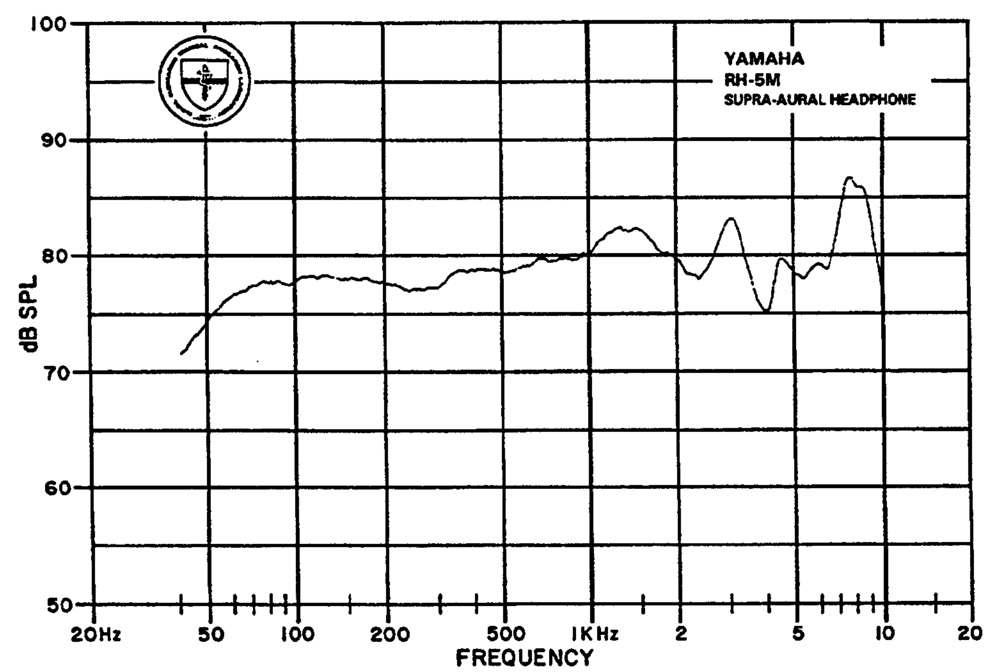

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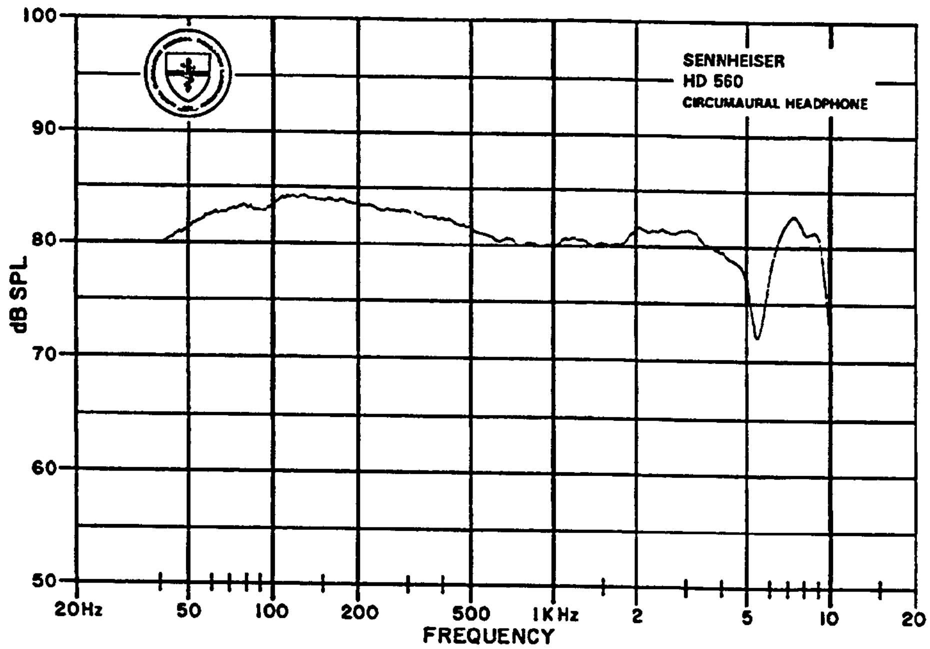
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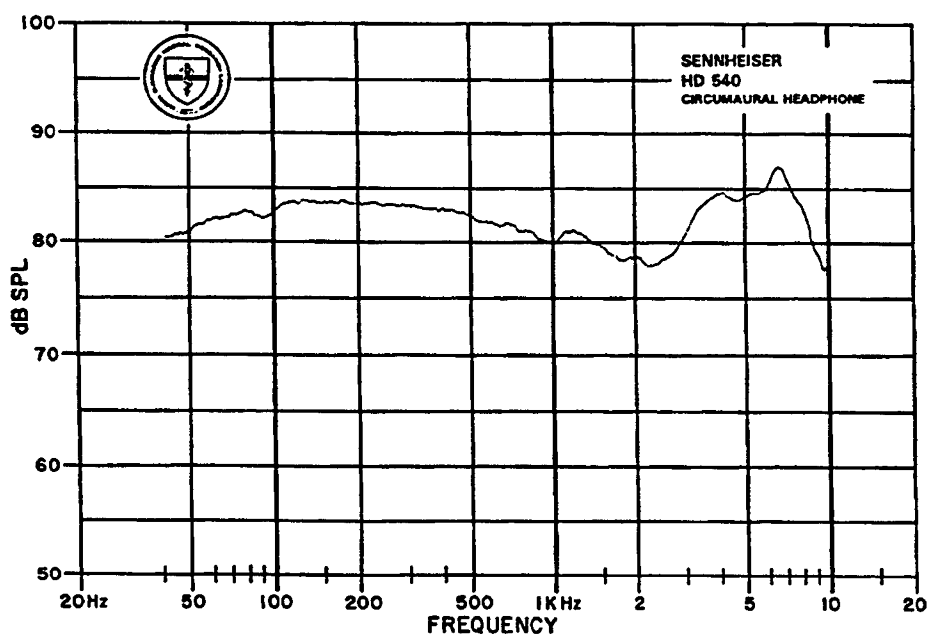
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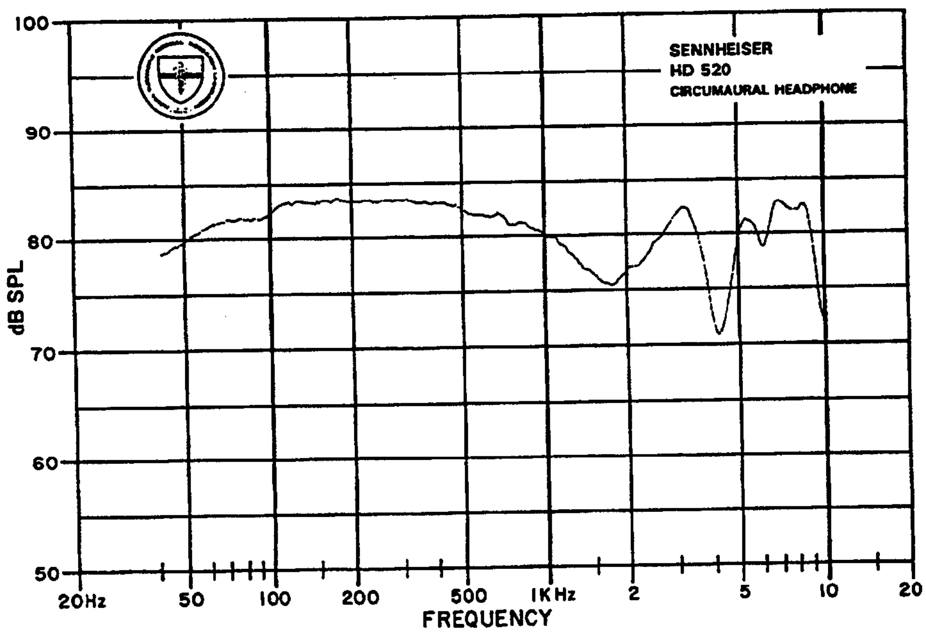
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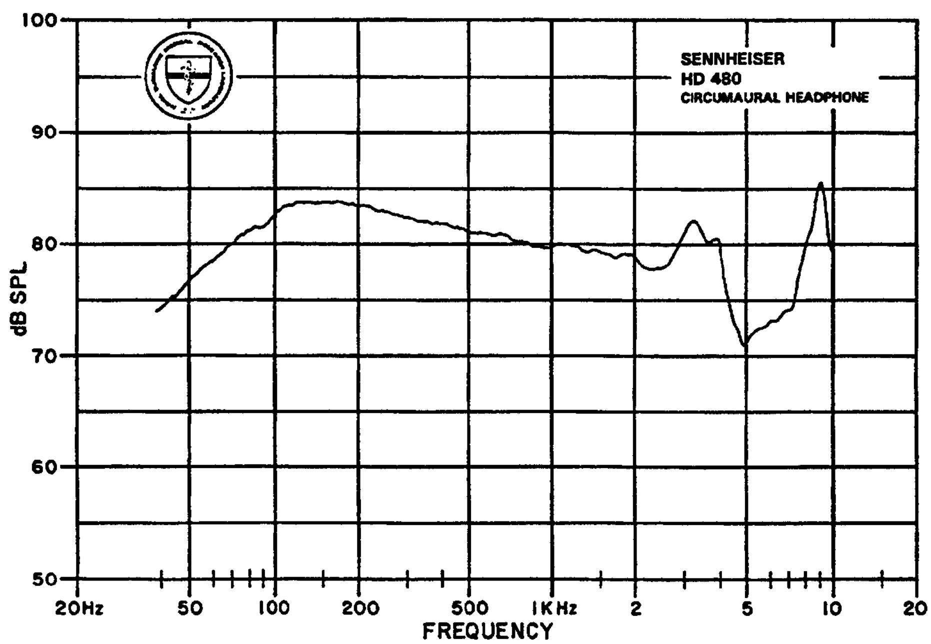
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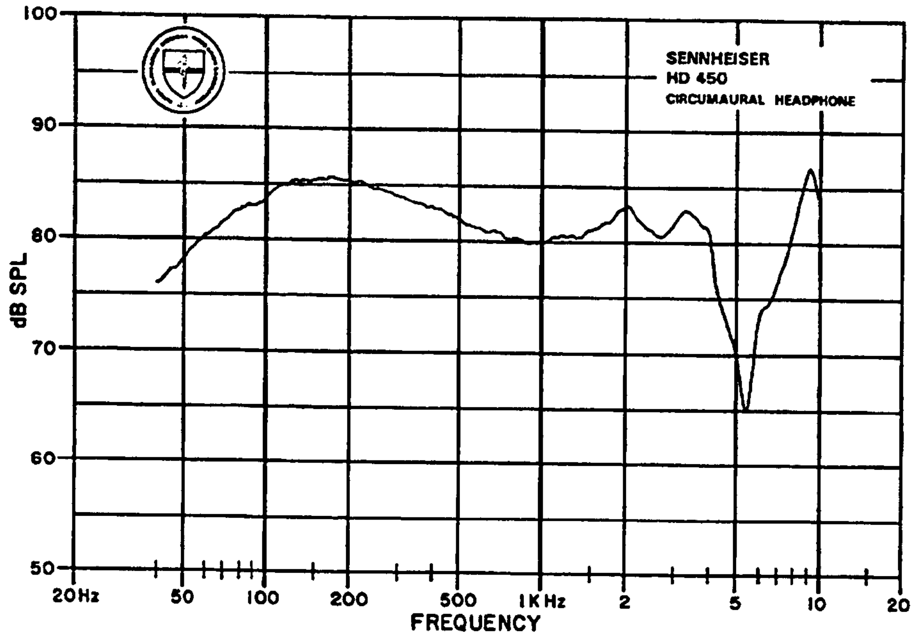
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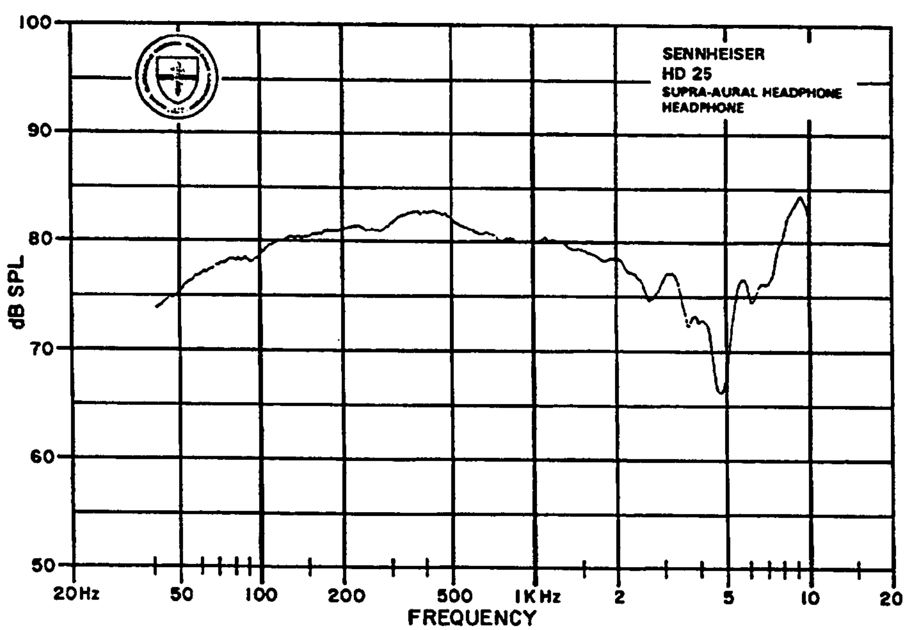
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Real-time auditory detection and aural analysis capability of passive broadband sonar systems needs improvement. A weak link in these systems is the use of communications-bandwidth low-fidelity headsets. Unfortunately, no procedure for headphone (earphone element inside headshell) frequency response measurement exists in military headset specifications. An accurate technique for headphone calibration was devised which provides the earphone element with an acoustic load similar to the one provided by a human wearer. Using this technique, headphone measurement data on commercially available headphones was collected and compared to the current sonar headsets. The advantages and disadvantages of open and sealed circumaural headsets and recent developments in noise canceling headsets are discussed, along with the possibility of reducing noise levels in sonar spaces to permit use of higher fidelity headphone designs.

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