

Naval Submarine Medical Research Laboratory

NSMRL Report #1222

23 October 2001



**SENSOR-OPERATED HEADSET SELECTION FOR
VIRGINIA CLASS SUBMARINE CONSOLES
[3CI]**

by

**Joseph S. Russotti
and
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**Released by:
M. D. Curley, CAPT, MSC, USN
Commanding Officer
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REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
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1. REPORT DATE (DD-MM-YYYY) 23-10-2001		2. REPORT TYPE technical		3. DATES COVERED (From - To) 01-01-2001 to 26-10-2001	
4. TITLE AND SUBTITLE Sensor-Operated Headset Selection for Virginia Class Submarine				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Russotti, Joseph S; Author Schwaller, Derek W; Author				5d. PROJECT NUMBER	
				5e. TASK NUMBER 64559.50006	
				5f. WORK UNIT NUMBER PMS450T2	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Submarine Medical Research Laboratory Naval Submarine Base New London Box 900 Groton, CT 06349-5900				8. PERFORMING ORGANIZATION REPORT NUMBER 1221	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Naval Submarine Medical Resea rch Laboratory Naval Submarine Base New Groton, CT 06349-5900				10. SPONSOR/MONITOR'S ACRONYM(S) NSMRL	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S) 1221	
12. DISTRIBUTION / AVAILABILITY STATEMENT A Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES This investigation was conducted for NAVSEA PMS 450T2 under Naval Sea Systems Command Task Statement 64559.50006.					
14. ABSTRACT The current research evaluated various headsets for use on C3I (Command, Control, Communication and Intelligence workstation) consoles installed in Virginia Class submarine. Of particular importance is their intended application in accurately presenting not only communications but also passive acoustic sonar data and other future advanced auditory displays that may use spatial coding. Of these applications accurate representation of broadband sonar data be-comes the most challenging <i>immediate</i> task. Headset evaluation of commercial off-the-shelf products confirmed our decision to press for development of high fidelity ANC sensor operator headsets. This study reports evaluation of a prototype ANC high fidelity headset developed to our specification for use in critical listening in a moderately noisy environment.					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Unclassified Unlimited	18. NUMBER OF PAGES 23	19a. NAME OF RESPONSIBLE PERSON Ronald Joe
a. REPORT UNCLASSIFIED	b. ABSTRACT UNCLASSIFIED	c. THIS PAGE UNCLASSIFIED			19b. TELEPHONE NUMBER (include area code) 860-694-5157

Sensor-operator headset selection for
Virginia Class Submarine Consoles
[C3I]

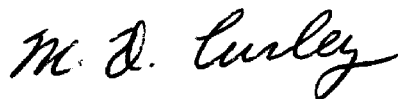
by

Joseph S. Russotti and Derek W. Schwaller

NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

Report No. 1222

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A handwritten signature in black ink, appearing to read "M. D. Curley". The signature is fluid and cursive, with the first letters of each word being capitalized and prominent.

M. D. CURLEY, CAPT, MSC, USN
Commanding Officer
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SUMMARY PAGE

Problem

With renewed interest in presenting relevant acoustic information to the 3CI (Command, Control Communication and Intelligence workstation console) sensor operator including the broadband-search sonar operator, headset selection continues to present a problem due to the degree of noise in the room and its spectral content.

Findings

Conventional noise-occluding (closed shell) headsets were designed for communication and are appropriately band-limited in frequency response to optimize speech intelligibility. Closed-shell earpieces confound accurate sound reproduction due to cavity resonance and interaction between frequency response and seal against the head. High-fidelity headsets, which extend frequency-response accuracy to well beyond the speech range, avoid using noise-occluding closed shell designs. As a result they provide little noise attenuation at necessary frequencies. Active noise cancellation (ANC) headsets *can* be designed to solve both the noise reduction and bandwidth response, but, since currently marketed for communication, have somewhat limited frequency response accuracy beyond the speech range. At-sea measurements of the airborne noise at the location of the operator's head reveal that its' low-frequency spectral content can severely interfere with operator detection performance. A high-fidelity ANC headset is the least expensive solution to the noise interference problem and is also an immediate one. The best solution would be to reduce the noise at its source. More efficient command and control designs, as found on Virginia Class, further exacerbate the noise problem as common control areas increase the concentration of hardware ventilation fans and console operators. Evaluation of commercial off-the-shelf closed-shell high fidelity and studio monitor headset products confirmed our decision to press for development of high fidelity ANC sensor operator headsets. This study reports evaluation of a prototype ANC high fidelity headset developed to our frequency-response specification for use in critical extended-bandwidth listening in a moderately noisy environment. The prototype headset was developed by Bose in interaction with the Naval Submarine Medical Research Laboratory. This extended-bandwidth prototype is based upon design modifications to the Bose Series X commercial aviation ANC headset. Based upon prior at-sea evaluations of similar earlier models, this advanced version is essential for use in console spaces.

Application

Design of sonar signal-processing equipment for optimal human auditory discrimination.

Administrative Information

This investigation was conducted for NAVSEA PMS 450T2 under Naval Sea Systems Command Task Statement 64559.50006. The views expressed in this report are those of the authors and do not reflect the official policy or position of the Department of the Navy, Department of Defense, or U.S. Government. This report was approved for publication on 23 October 2001, and designated at Naval Submarine Medical Research Laboratory Report No. 1222.

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OPERATIONAL ABSTRACT

In trying to select an accurate method of presenting acoustic information to submarine console-operators, and in particular the broadband-search operator, we are faced with a problem. The room is noisy. From *in-situ* tests of the acoustic output of headphones of all types, it is clear that any noise-occluding headset currently manufactured has a band-limited frequency response. Such band-limited headsets are *specifically* designed for communications. Because a noise-occluding headset requires a complete seal around the ear, headband pressures required for such a seal are extremely uncomfortable in extended wear. Once the headset has been specifically designed to work with a seal, the seal must be maintained or the low-frequency output inside the headshell is degraded. The inability to consistently maintain that seal with each repeated placement over the ears, creates a major critical loss of low frequency signal output. Since conventional passive noise attenuation used in headsets is less effective at low frequencies, that critical loss of low frequency information in the received signal, caused when proper seal is lost, is even more deleterious to detection. With reduced low-frequency output from the earphone, the airborne low-frequency components, which pass through the headshell, mask the relevant signal to be detected.

Commercial off the shelf (COTS) circumaural (around the ear) closed-shell headsets of excellent fidelity have been selected for the BSY-2 sonar system. But, high fidelity headsets have not been designed to attenuate noisy environments, therefore none attempt to tackle the formidable problem of maintaining a noise occluding complete seal against the head. Active noise cancellation (ANC) headsets circumvent the earcushion seal and headshell attenuation problem by acoustically monitoring the non-signal related noise inside the headshell and creating its inverse to actively cancel it. Also, because of their active electronics, ANC headsets can be equalized to reproduce accurately. ANC headsets solve this noise problem and dramatically improve detectability.

Evaluation of COTS closed shell headset products confirmed our decision to press for development of high fidelity ANC sensor operator headsets. This study reports evaluation of a prototype ANC high fidelity headset developed to our frequency-response specification for use in critical extended-bandwidth listening in a moderately noisy environment. This extended-bandwidth prototype is based upon design modifications to the Bose Series X commercial aviation ANC headset. The modified Series X provided the best combination of frequency response accuracy and sound attenuation of sonar shack noise. Based upon prior at-sea evaluations of similar earlier models, this advanced version is essential for use in console workstation spaces.

ABSTRACT

The current research evaluated various headsets for use on C3I (Command, Control, Communication and Intelligence workstation) consoles installed in Virginia Class submarine. Of particular importance is their intended application in accurately presenting not only communications but also passive acoustic sonar data and other future advanced auditory displays that may use spatial coding. Of these applications accurate representation of broadband sonar data becomes the most challenging *immediate* task.

With renewed interest in presenting relevant acoustic information to the broadband-search, and workload share operators as well as to the sonar supervisor, headset selection presents a problem. The listening environment is somewhat noisy, especially in lower listening frequencies. From *in-situ* tests of the acoustic output of headphones of all types, it is clear that any passive noise-occluding headsets are band-limited. Characteristically noise-occluding headsets are designed for use in communications where limited bandwidth (less than the full hearing range) is tolerable and cost effective. Noise-occluding headsets, which seal against the head to reduce noise, must maintain their seal or suffer a critical loss in low-frequency output. High fidelity headsets, on the other hand, are of open or vented design to avoid this seal problem, but as a result suffer from poor noise-attenuation. Active noise cancellation (ANC) headsets circumvent the headset-seal problem by electronically canceling unwanted noise and can also be internally equalized for accurate frequency response. These headsets are more expensive than conventional designs, but they achieve a dramatic improvement in at-sea detection performance.

Headset evaluation of commercial off-the-shelf products confirmed our decision to press for development of high fidelity ANC sensor operator headsets. This study reports evaluation of a prototype ANC high fidelity headset developed to our specification for use in critical listening in a moderately noisy environment.

INTRODUCTION

Accurate representation of an acoustical signal has been a long desired goal of both acoustic signal analysts and audio engineers engaged in sound reproduction. For the former group the task is simpler. An accurate transfer of acoustic to electrical energy is the requirement for signal storage and signal analysis. But, for sound reproduction, the process of signal storage must be followed by a far more difficult task. Namely, the recreation of the original acoustical signal into an acoustic space that is most likely substantially different from the one in which the original signal was generated. The simplest way to avoid the confounding of room acoustics with sound reproduction is through the use of headsets. In the case of passive acoustic information gathered from the ocean it is essential that all of the available energy, that can be received, be monitored so that any man made energy generated can be detected. Broadband monitoring is necessary, since this energy to be detected is of unknown frequency. Its radiated energy is not only speed related but is modified by many physical characteristics such as frequency dependent propagation loss, multiple paths from source to receiver caused by reflection, effects of salinity, temperature, depth and other factors. However well the acoustic signal is gathered and converted to an electrical signal, accurate reproduction of that received acoustic signal is equally critical.

For our particular application in accurately presenting acoustic information, especially sonar target information, in the confined and hardware-cluttered space of a military vessel, headsets are ideal. Although the task of accurate sound reproduction now becomes simpler, it is still a formidable one. The first major obstacle now becomes the evaluation of headset frequency response so that we can predict the sound pressure level for a given voltage at any specified frequency. Given the added requirement of listening in a noisy environment, an around-the-ear (circumaural) headshell is necessary. Shaw and Thiessen (1962), Shaw (1966), and others found that standard headphone coupler measurements did not represent sound pressure measurements taken inside headphone headshells using calibrated probe-tube microphones. Based on these findings, a report by the United States of America Standards Institute Writing Group S3-1-W-37 on the coupler calibration of earphones (Benson et al 1967) concluded it could not justifiably write a *standard* for the coupler calibration of circumaural headphones.

Russotti et al (1998) devised a technique which accurately measures headphone response when acoustically loaded by an ear-simulator and referenced to the diffuse free-field. The ideal headset reproduces the information without imparting any alteration in the original signal. Using this technique, measurements of both military and commercial off-the-shelf (COTS) high-fidelity headsets were taken and recommendations were made for headsets for application in passive aural sonar. In experience gained over 15 years of testing headsets using this measurement technique, open-air circumaural headsets and closed headsets having a controlled pressure-leak were found to produce the most consistent and most accurate frequency response. Headsets designed to completely seal around the listener's ear produce large variations in their low frequency response due to a less than perfect seal. Differences in head size, gaps between the mandible and neck, and presence of hair and eyeglass temple-pieces all can contribute to a less than perfect seal. As a consequence, passive noise-occluding headsets, which require a good seal for noise attenuation, are not a desirable design for accurate sound reproduction. Tests of military and commercial headsets have found that noise-occluding headsets are also characteristically band-limited (Russotti, 1995). Such headsets were originally designed for communica-

tions and are cost effectively band-limited to the speech range for that application. Despite the superior response accuracy of commercially available high-fidelity headsets, in selecting headsets for use in the noisy environment on all but the newest quieter sonar suites such as BSY-2 (Commanding Officer, Naval Submarine Medical Research Laboratory 1990) such high fidelity headsets could not be recommended. Because of their poor noise attenuation characteristics, ambient noise levels masked the signal in the headset. Instead, custom modified Active Noise Cancellation (ANC) headsets were designed to produce more accurate frequency response. These frequency-enhanced versions were recommended because of their demonstrated ability, during at-sea tests, to enhance detectability of contacts (Commanding Officer, Naval Submarine Medical Research Laboratory, 1993).

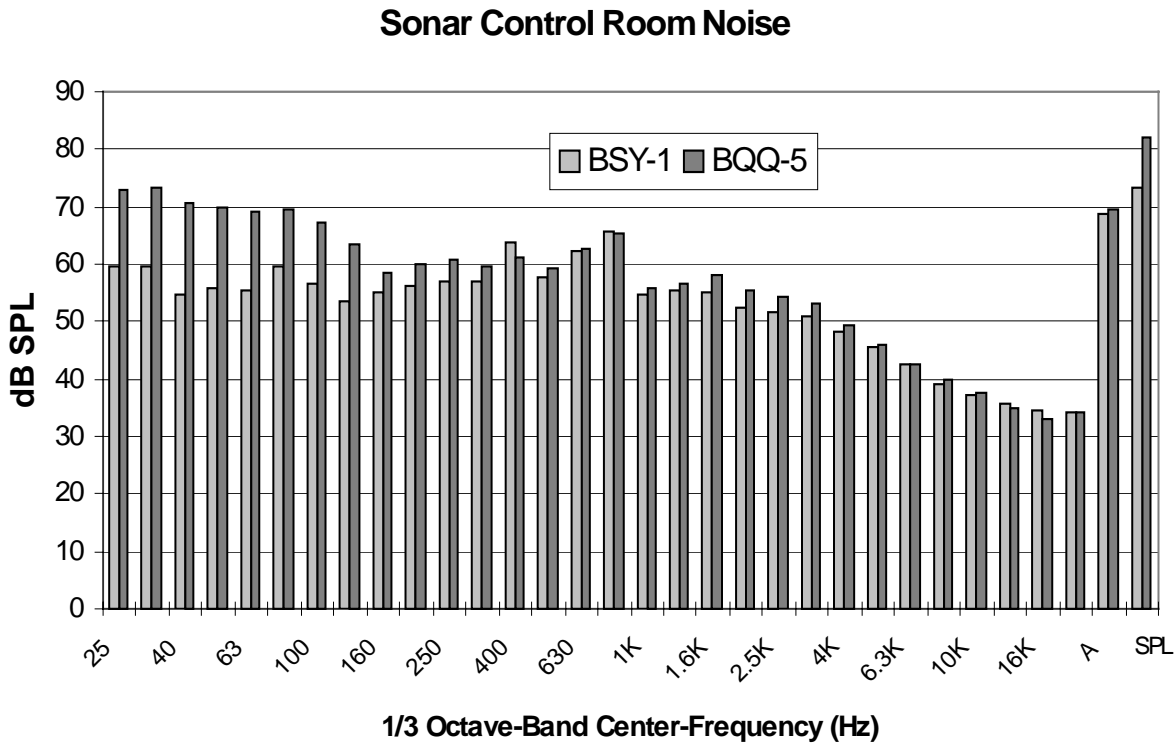


Figure 1. Spectral representation of sonar compartment on BQQ-5 and BSY-1 systems

Noise measurements (Russotti, 1998; Heller et al, 2000) clearly document the spectral content and intensity of airborne-noise in BQQ-5 and BSY-1 sonar spaces. The measurement system, used in place of a traditional sound level meter, complies with ANSI S1.4-1983 and S1.6-1984. Figure 1 presents a graphic comparison of differences between BQQ-5 and BSY-1 sonar control room noise. Root mean square (RMS) averages of the energy measured in 1/3-octave bands are depicted. Time-averaged sample-duration was approximately 30 seconds. All measurements are depicted re 20 μ Pascal. Comparisons are shown in 1/3-octave bands from 25 Hz to 20 kHz. At far right, dBA and overall dB SPL are represented as A and SPL respectively. The overall RMS, A-weighted, and 1/3-octave band data were averaged across data gathered at the operator's Command/Display Consoles (CDCs) and at the position of the sonar supervisor.

Although within safe noise levels for hearing conservation, BSY-1 and BQQ-5 systems have excessive noise in sonar operator work-areas where critical listening is required. There is significant low-frequency energy below 1 kHz. As seen in Figure 1, bands with center frequencies of

400, 630 and 800 Hz are above 60 dB SPL on both systems. For BQQ-5 there is especially unacceptable low-frequency noise in the region below 160 Hz. At those frequencies, and in fact at all frequencies below 500 Hz, attenuation *available* from conventional *passive* noise reducing headsets is greatly reduced and inadequate.

The presence of this high level of airborne low-frequency noise in the listener's ear, when wearing a *passive* noise reducing headset, means that there is inadequate dynamic range above the noise floor at normal listening levels. Since the overall level of the sea noise signal in the headset must be kept at a reasonably comfortable and safe level, these constraints result in airborne noise masking the low-frequency component of the target signal to be detected within the sea noise. This explains why previous reports (Russotti, 1993; Benedetto et al, 1995; Russotti, 1995) found improved sonar operator performance with ANC headsets. Should the target of interest have most of its radiated energy in these lower frequencies, the decrement in performance caused by the interference of this low-frequency airborne noise becomes even more detrimental.

ANC communications headsets use real-time techniques to remove unwanted acoustic signals that have passed through the headshell. A microphone inside each headshell provides a monitor signal, which is electrically compared against the headphone input-signal. The difference is inverted and added to the electrical input to cancel the unwanted energy inside the headshell. Inherent in such unique design is the potential to correct for diminished output due to a poor seal and the capability of enhanced frequency response through active equalization. Interactive work between Bose Corporation and NSMRL has produced a *modified* version of their ANC commercial aviation headset with enhanced frequency response for use in passive sonar. These headsets (Bose Series I commercial aviation headset-[*nsmrl prototype*]) have been tested at-sea with highly favorable results and commensurate acceptance by the sonar community (Russotti 1993, Russotti 1995, Benedetto, et. al. 1995, Commanding Officer USS San Juan 1993, Commanding Officer USS Albuquerque 1995). Subsequently the Bose Series II Aviation headset in standard form exhibited even more accurate response than our custom Series I model. As a result we recommended the Bose Series II COTS version. Unfortunately, the Series I and Series II models have been supplanted by the Series X Aviation headset, a superior design that is a more comfortable, more durable headset, but of lesser broadband fidelity. In COTS version this headset did not exhibit the necessary fidelity, exhibiting a 19 dB variation over the 40Hz to 10kHz frequency range. The earlier Bose Series II model exhibited a 9 dB variation in this range.

Since our needs for a replacement headset were immediate, we renewed our search for newer headsets, both ANC and conventional, and simultaneously began work with Bose to pursue modifying their ANC electronics to enhance broadband fidelity of the Series X model. Fidelity criterion was: lowest amplitude variation measured across the 40 Hz to 10 kHz frequency range.

The present research task was undertaken to identify ANC headsets of appropriate fidelity to effectively reduce low-frequency interfering noise, which cannot be reduced using conventional headsets. Given the concentration of console operators and hardware, noise reduction was essential for critical sonar listening. However, meeting hearing protection requirements was not of concern. Relative measures of low frequency headset attenuation would be adequate.

HEADSET RESPONSE

METHOD

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. Impedance measurements of human ears by Zwislocki (1957), Ithell (1963a, 1963b) and Delaney (1964) lead to development of several ear simulators. Zwislocki's (1970, 1971) easily replicated device successfully simulated the complex impedances found in average human ears. 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 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 2. Headphone under test on KEMAR manikin

Figure 2 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. Headset design should be free from coupler imposed constraints. For a real ear, and also for the simulator, the airborne acoustic signal that arrives at the eardrum has had its frequency response modified by the external ear structure, by resonance created by the pinna, and by the complex loading of the ear canal and eardrum with its ossicular chain. For practical use a conversion function is necessary to relate the received signal at the eardrum back to the airborne sound environment. This converted response should correctly reference the signal measured in the coupler back to the external sound field. If the original airborne signal had equal sound pressure across frequency then the properly converted transformation of the signal measured at the "eardrum" should produce this same flat response. If instead of airborne presentation a headset is used, then it too should re-create this flat response. By referencing the signal back to the airborne sound field we can evaluate how well the headset recreates the original airborne sound the ear would have heard. In practical terms if a constant voltage signal is supplied to the headset over the frequency range appropriate for the ear simulator, the transform-corrected response measured by the ear simulator should ideally be a straight line.

The required conversion function shown in Figure 3 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. Diffuse field measurement removes directionality created by the head and pinna from the transformation. Should directionality need to be coded into the presentation then head related transform functions (HRTFs) can be imposed onto the electrical signal presented to each ear. 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. The headphone is removed and repositioned for each of the 20 measurements. All of the x y 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

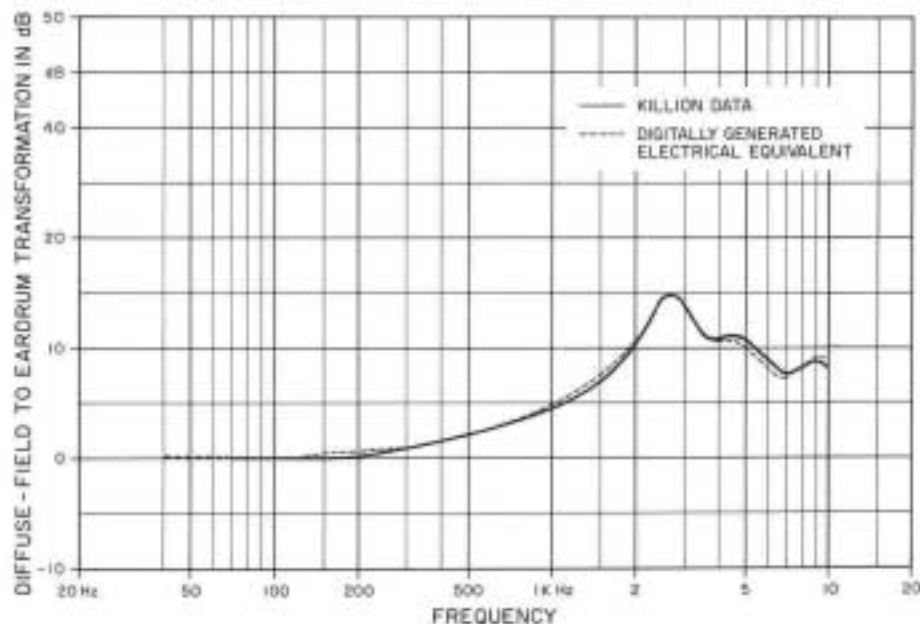


Figure 3. Conversion function necessary for diffuse-field transformation

As a comparison, the upper left curve in Figure 4 shows a prototype supra-aural (on the ear) earphone tailored to have flat response on a standard 6cc ANSI volumetric coupler. Below it is the averaged response of the same earphone element measured on the ear simulator. This lower curve is the diffuse-field corrected response of the earphone measured with appropriate acoustic impedance coupled to the earphone output. Note the huge difference in measured response with proper acoustic load placed on the headphone.

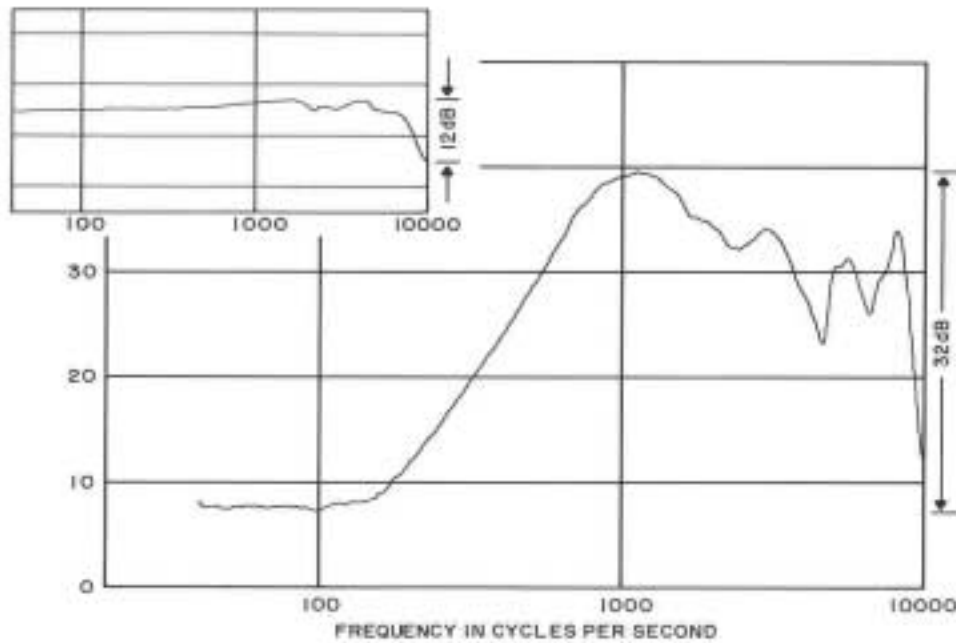


Figure 4. Earphone response on ANSI 6cc coupler and as measured loaded by an ear simulator.

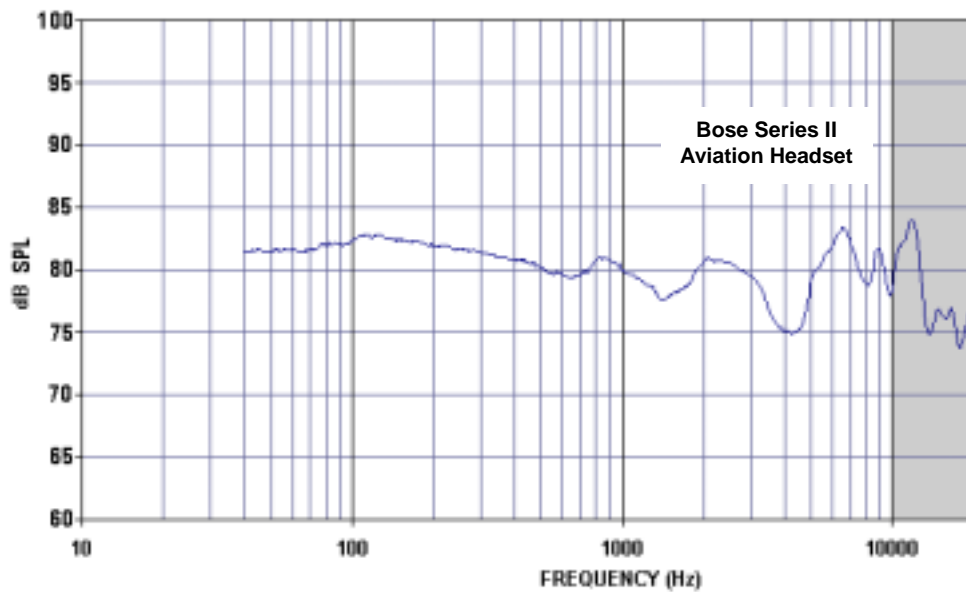


Figure 5. Averaged diffuse-field response of Bose Series II Aviation headset.

Figure 5 plots the diffuse field response for the Bose series II Aviation headset. These data were collected in previous research (Russotti, 1998; Heller et al, 2000). Frequency response measurements are relative to 80 dB SPL headphone output at 1kHz. Using the previously outlined measurement procedure, the specimen model had a total response variation of 9 dB over the 40 Hz to 10 kHz frequency range. In fact, in terms of frequency response variation in the 40 Hz to 10 kHz range, it is the most accurate headset of *any* type that we have ever tested.

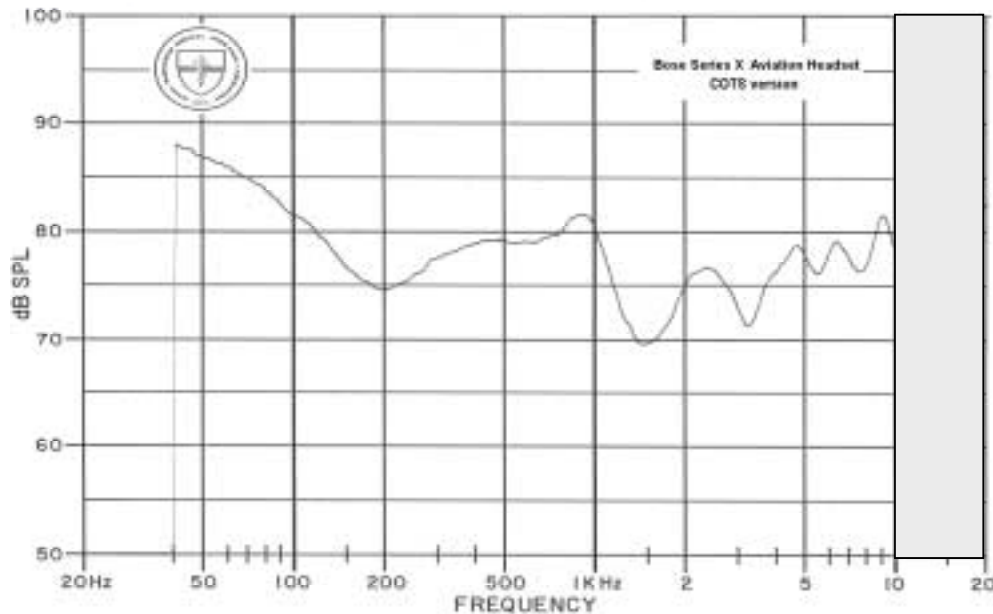


Figure 6. Averaged diffuse-field response of Bose Series X Aviation headset

Figure 6 plots the diffuse field response of the COTS Bose Series X headset which replaced the Series II model. Despite major improvements in headset and earcushion design to improve comfort durability and weight, the diffuse field response, while adequate for its intended application of communication, fell far short of its predecessor for our application. Following the standard procedure, the specimen model had a total response variation of 19 dB over the 40 Hz to 10 kHz frequency range.

Previous distortion measurements using ear simulators have shown that headsets of appropriate frequency response accuracy have extremely low distortion that is close to the limits of the necessary measurement hardware (Russotti et al 1985). In that study, at 95 dB SPL nine of the 11 top models had distortion levels of less than 0.1%. As a criterion for headset accuracy then, smallest variation in acoustic output in the 40 Hz to 10 kHz frequency range was the design goal, given the unknown and potentially changing spectral composition of the signal to be detected. Accurate reproduction of all energy in the 40 Hz to 10 kHz bandwidth would allow accurate representation of the signal to the ear. As a result of the unacceptably reduced frequency response accuracy found on the Series X replacement for the Series II ANC aviation headset, it was necessary to reassess COTS available models to determine if a substitute was available. Simultaneously Bose was contacted to determine feasibility of improving frequency response of the Series X replacement for the discontinued Series II.

FREQUENCY RESPONSE RESULTS

ANC and high fidelity closed headset models from various manufacturers were evaluated for their diffuse field response using the methodology described earlier. Only three previously untested closed-shell audio-quality models could be found.

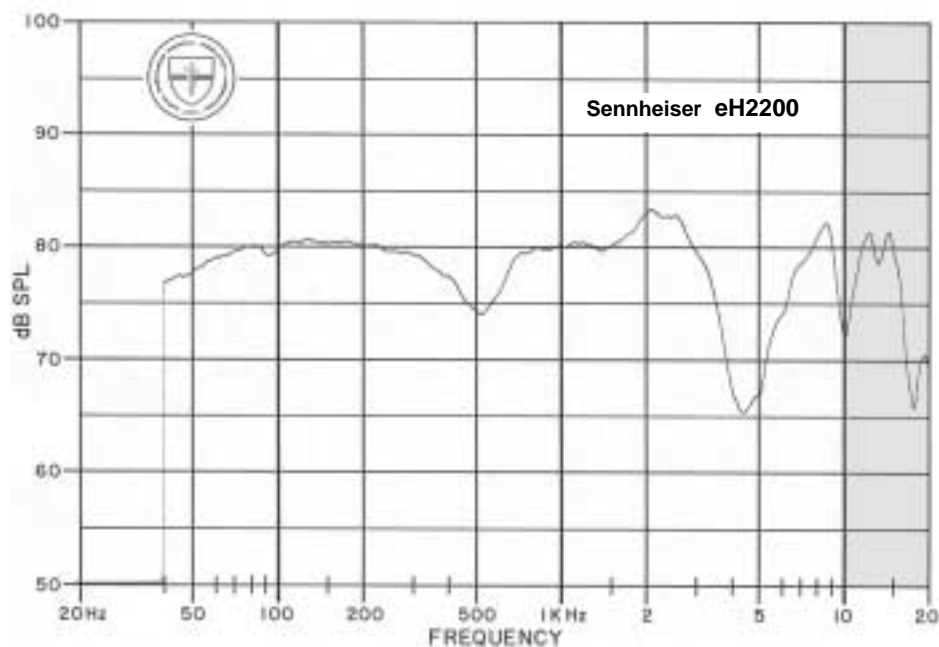


Figure 7. Averaged diffuse-field response of Sennheiser closed circumaural headset eH2200

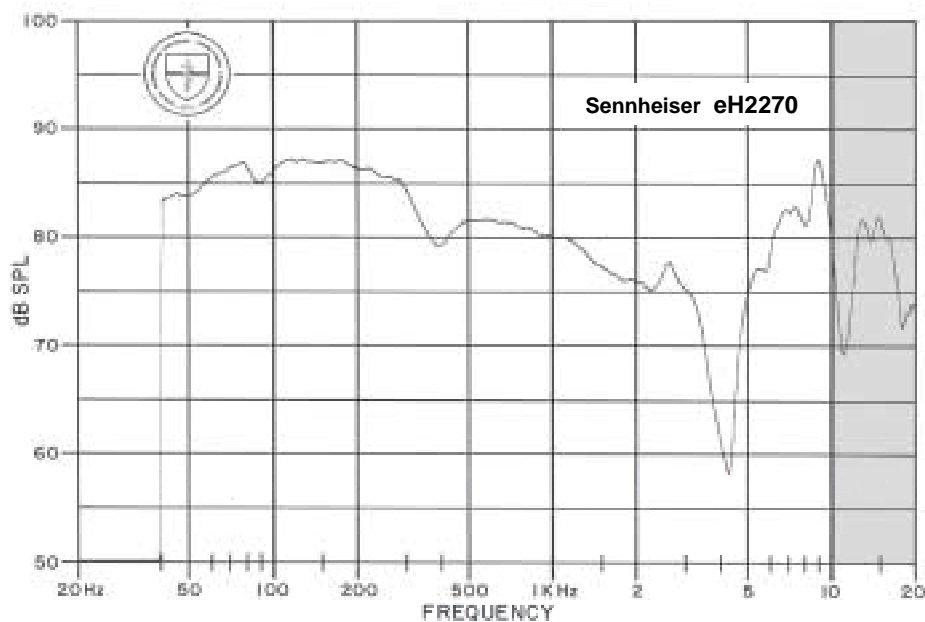


Figure 8. Averaged diffuse-field response of Sennheiser closed circumaural headset eH2270

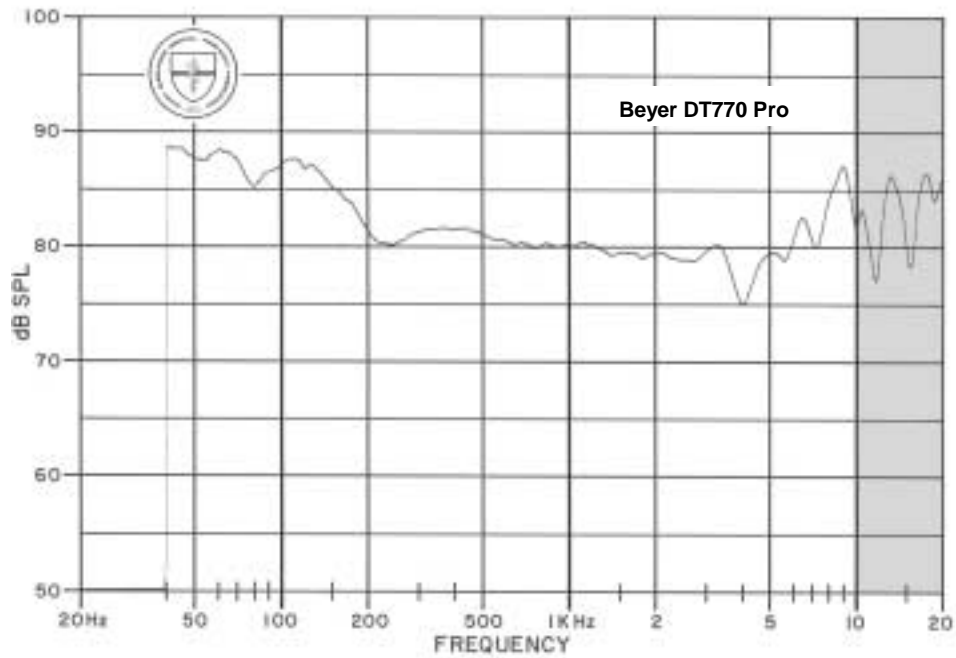


Figure 9. Averaged diffuse-field response of Beyer DT770 Headset

Figures 7, 8 and 9 represent the diffuse field response characteristics of 3 current closed-shell audio headsets that were evaluated for potential use in less critical listening applications or in quieter areas. Of the three, only the Beyer DT 770 exhibited an appropriate frequency response. Total response variation for this model was 14 dB from 40 Hz to 10 kHz. Noise attenuation measurements would determine potential suitability for passive sonar broadband listening applications.

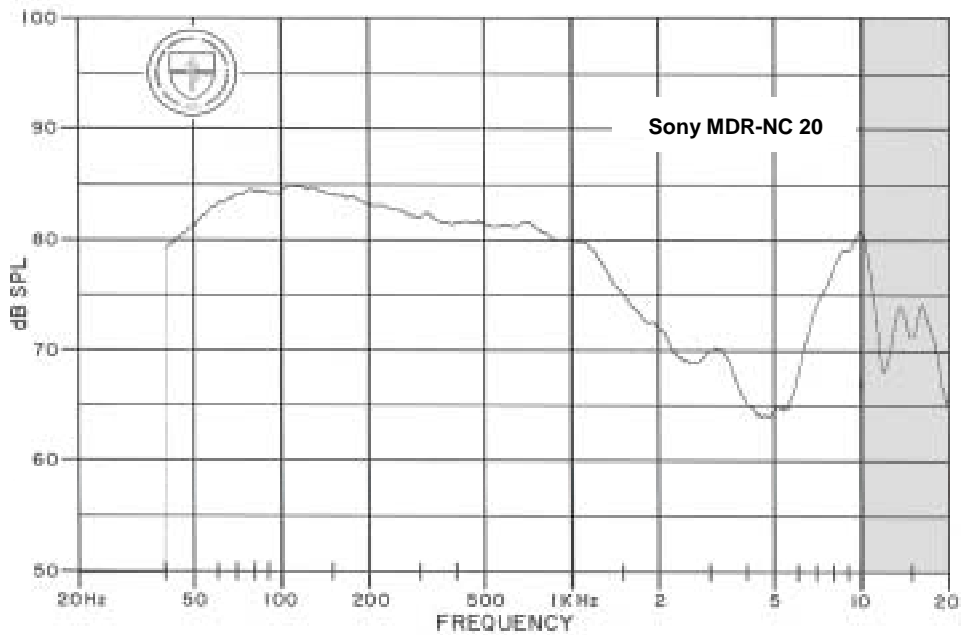


Figure 10. Averaged diffuse-field response of Sennheiser MDR NC-20 ANC headset

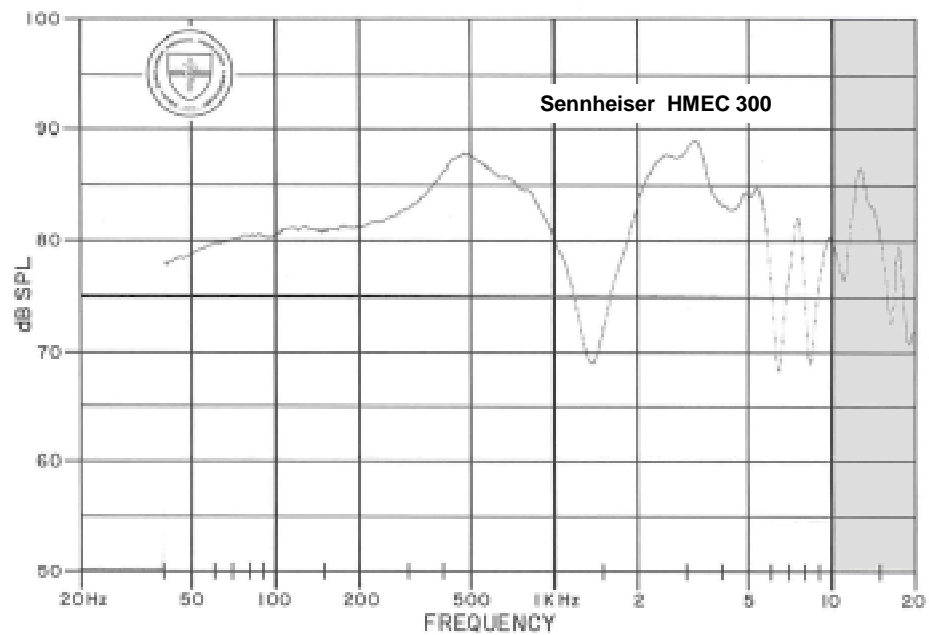


Figure 11. Averaged diffuse-field response of Sennheiser HMEC 300 ANC headset.

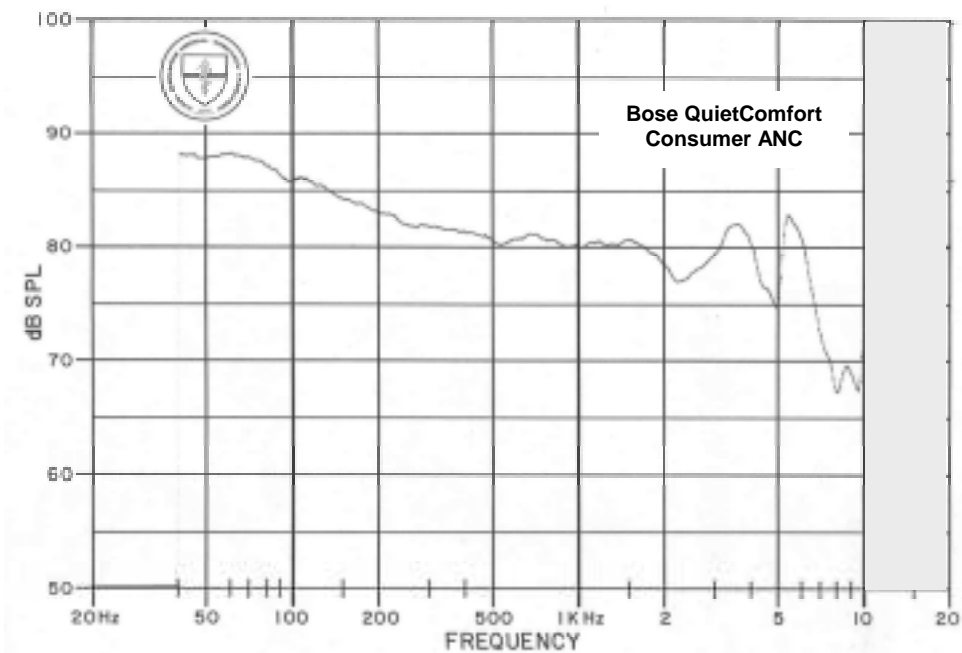


Figure 12. Averaged diffuse-field response of Bose *QuietComfort* Consumer ANC headset

Other than the Bose Series X, only three appropriate non-communications ANC headsets could be found. Figure 10 plots the diffuse-field response of an ANC headset, the Sony MDR NC-20. Response in the 1 to 10 kHz range is severely deficient and not appropriate for broadband signal reproduction. Figure 11 depicts the averaged diffuse field response of the Sennheiser HMEC 300 ANC headset. In the 500 Hz to 3 kHz region it varies by 21 dB.

Figure 12 graphs the averaged diffuse -field response of a new Bose consumer ANC headset. This model had a total variation of 21 dB in the 40 Hz to 10 kHz range. Physically, the COTS headset designed for consumer use would not withstand the rigors of 24 hour daily use in a shipboard environment.

None of these COTS ANC models, including the Bose Series X Aviation headset (Figure 6), exhibited a response that would allow recommendation as an appropriate headset for use on Virginia class C3I consoles. Of the available models, the Bose Series X headset was clearly a far more rugged model with decided improvements over its predecessors in weight and overall design. As a consequence, it alone had potential application, provided that internal equalization could produce an acceptable response. Previous Bose models had been required to use greater headband tension for noise reduction and depended upon gel filled earcushions to achieve sound isolation and comfort. These Series I and Series II headshells were heavily laden with electronic components, whose added weight reduced comfort in extended wear despite the superior fit and comfort of the ear cushions on the wearer. Further, the gel cushions required care to maintain their integrity and periodic replacement was necessary. The Series X had successfully eliminated all of these drawbacks. Once worn on the head, reverting back to older models was not a desirable option for the wearer. Following our measurements, Bose was contacted and in response to our request for a flatter frequency response, board level modifications were attempted. As an outcome of this interaction, a frequency-enhanced Series X prototype was developed and two samples were tested at NSMRL. Averaged results of diffuse-field response testing are presented in Figure 13.

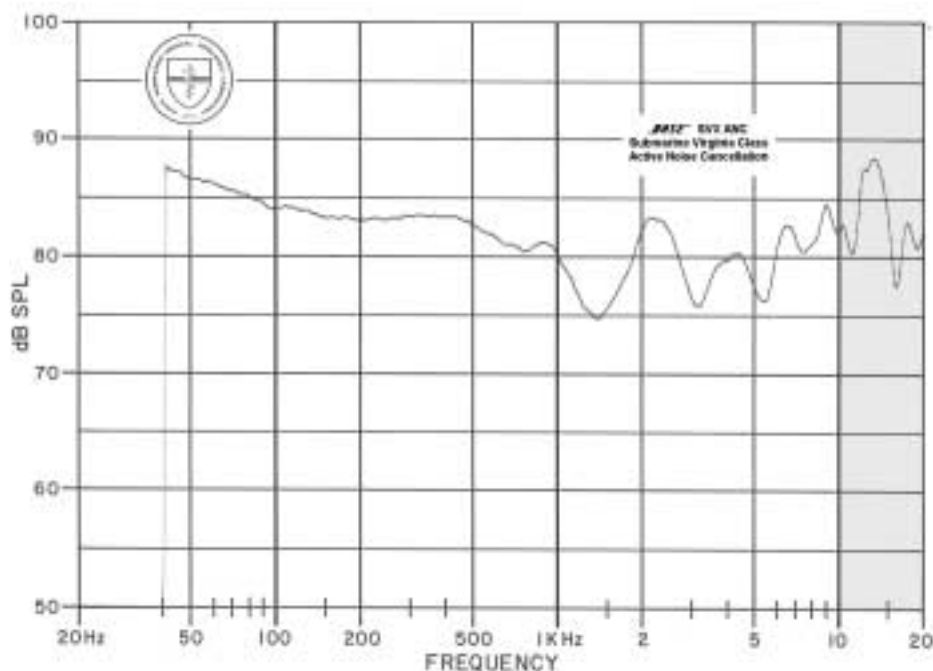


Figure 13. Averaged Diffuse-field response of Bose Series X *Submarine Virginia* [SVX] prototype.

As seen in the figure, the total variation of the Bose/NSMRL prototype is 13 dB from 40 Hz to 10 kHz, and 9.5 dB from 100 Hz to 10 kHz. This is a vast improvement from the COTS model.

HEADSET NOISE ATTENUATION

METHOD

Because anticipated noise levels in sonar spaces would be well below damage risk criteria, standards for hearing protectors (ANSI S12.6-1997) were not required. In addition ANSI measurements do not assess the attenuation characteristics below 125Hz. Objective 1/3 octave band measurements of the intrinsic ability of the noise-attenuating headsets to reduce noise were conducted using a specially modified KEMAR manikin. Pliant bags of lead shot placed within the manikin were used to block sound transmission to the calibrated microphone “eardrum” from pathways other than the ear canals. Electroacoustic test results confirmed the ability to attenuate such transmission at 40 dB or greater from 160 Hz to 500 Hz, 50 dB or better from 500 Hz to 2 kHz, and 60 dB or more from 2 to 15 kHz. Manikin measurements do not take into account the range of real-ear bone conduction pathways that reduce noise attenuation. However, they allow accurate evaluation of the relative attenuation characteristics available from a particular headset design over the entire 40Hz to 10 kHz measurement range afforded by the ear simulator.

A high-intensity sound system was instrumented to operate within a 30 x 16.5 x 11 foot high cement-block-walled reverberant room. The system consisted of four speaker arrays, each containing two 18 inch drivers, a 15 inch driver, and one 4 inch diameter titanium horn-driver. Each transducer was independently powered, by a configuration of Crown amplifiers capable of producing 1,310 watts RMS in each of 4 channels with Total Harmonic Distortion (THD) at less than .02% at rated power. Each channel of the system was fed by a separate channel of a Digidesign Pro Tools III digital hard disk recorder/editor. Four analog output channels of a Digidesign 888 interface were distributed to the amplifiers of each array through a pair of Rane AC-23 active crossovers. Just ahead of the AC-23 inputs, each of the channels was digitally controlled by a separate Wilsonics model PATT attenuator. Using the Digidesign system, each of four pink noise signals were fed through the separate speaker arrays to produce a homogeneous sound field of 94 dB SPL re 20 micro (μ) Pascal. Sound level measurements were taken without the manikin present at the location that would be occupied by the manikin head.

Ear simulator output was spectrally analyzed using a Data Physics ACE signal analyzer. Headset noise attenuation was calculated as the relative difference between *open* ear and ear *occluded* by the headset under test. Root mean square (RMS) averages of the energy measured in 1/3-octave bands were calculated. These represent the relative attenuation afforded by the headset device under test.

NOISE ATTENUATION RESULTS

Figure 14 represents the noise attenuation capabilities of the Bose Series X ANC headset compared to the Beyer DT770 headset. As seen in the figure, the passive attenuation available from the Beyer DT770 closed circumaural headset is insufficient for our application. In fact, in 1/3 octave bands below 500 Hz the headshell actually magnifies the external sound. In comparison, the Bose series X headset has far greater capability in reducing the transmission of external noise into the headshell. At 40 Hz center frequency, there is a reduction of external noise of 18

dB, and with the exception of the 1/3 octave band centered at 63 Hz, there is a 20 dB or greater attenuation at all other bands measured. From the 160 Hz to 10 kHz band, the noise attenuation afforded by the ANC is approximately 24 dB or better.

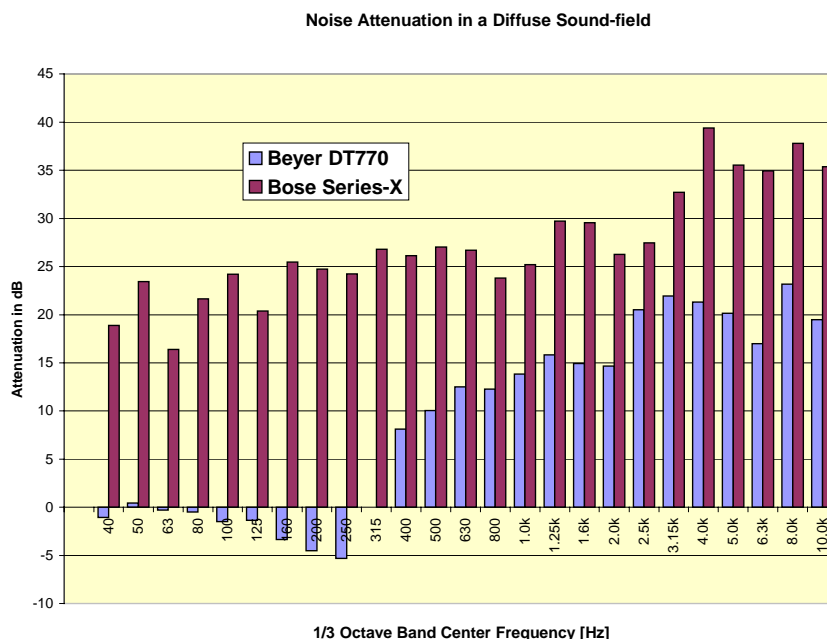


Figure 14. Headset noise attenuation of Bose Series X vs. Beyer DT 770.

For reference purposes similar measurements were made on the David Clark 12507G-20 federal stock headset used in passive sonar systems. Because they have become popular in the sonar community, results are also presented for the COTS Sony MDR-V600. Both closed-headset models use only passive noise reduction. Results of noise attenuation measurements of

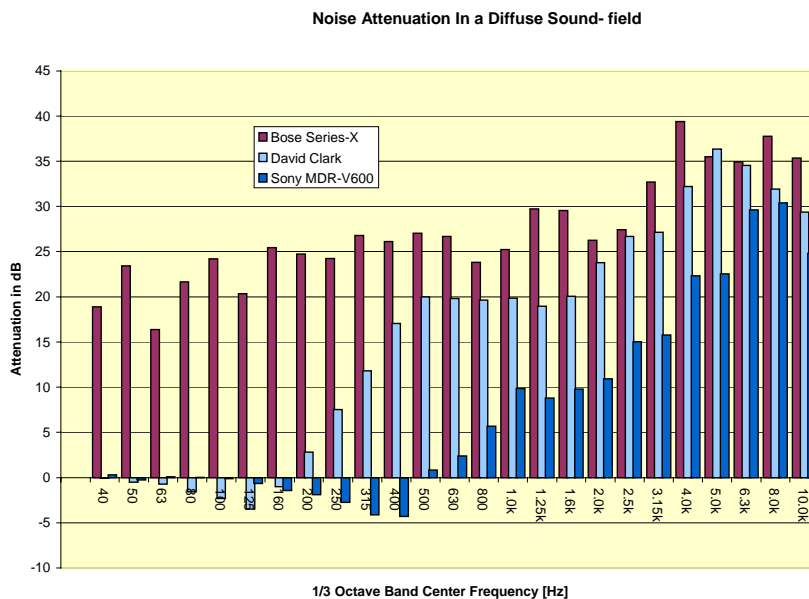


Figure 15. Noise attenuation of Bose Series X vs. David Clark 12507G-20 and Sony MDR V600 headset.

both of these headset models are presented in figure 15. Given the spectral content of the airborne noise in console spaces, these headsets clearly place the listener at a great disadvantage. The high levels of lower frequency airborne noise, which pass through the headshell, effectively mask the signal presented in the headset.

SUMMARY

Newer extended bandwidth afforded by modern A/D converters has enhanced the utility of broadband search and aural tracking operations. While headsets with appropriate bandwidth are essential they are of limited use unless they can effectively present the entire signal to the listener. Given the spectral content of airborne noise levels measured on current sonar suites, only ANC headsets can effectively mask the lower frequencies. The presence of such low-frequency energy interferes with critical listening rendering the best closed-headshell professional studio monitor headsets useless. While most ANC headsets have been cost-consciously designed for the limited bandwidth of communications, the active electronics available in ANC designs allows for electronic enhancement of frequency response characteristics. Part of NSMRL's research effort has been, in interaction with Bose, to provide an extended bandwidth or high-fidelity ANC headset for use in critical listening. Early Series I NSMRL prototype and Series II production models met that goal but were substantially heavier than conventional headsets. In addition specialized silicone gel filled ear cushions required periodic replacement. Tests of other ANC headsets conducted in the present study found none with appropriate frequency response. Current tests of passive attenuation headsets revealed adequate though not exceptional frequency response. Previously available COTS models had exhibited lower variability. However none of the current or previously manufactured passive attenuation models were effective in reducing the intrusion of low frequency noise into the headshell. The prototype Submarine Virginia Series X ANC headset, due to its noise attenuation and frequency response bandwidth meets the needs of critical listening in spaces containing low frequency equipment noise. Given the concentration of operators and console hardware anticipated on future systems, these headsets can also serve to reduce speech interference from adjacent operators. These specialized headsets are also essential for Advanced Rapid COTS Insertion (ARCI) and should be incorporated into the procurement system. Application of these headsets for surface naval operations is also strongly recommended.

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